Contextual Design in Industrial Settings: Experiences and Recommendations

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Keywords: Contextual Design, Contextual Inquiry, Requirements Analysis, User Involvement.

Abstract: The Contextual Design (CD) methodology offers a framework for planning and implementing a user-centered design process throughout all project phases. It is team-based and was designed especially for interdisciplinary teams. The application of CD is particularly profitable in projects confronted with implicit requirements and hidden factors of influence. In contrast to many other design and evaluation methods such as focus groups or usability tests, CD does not take users out of their everyday setting and more easily reveals important design issues and contextual influences like users' motivation, values, emotions or real-time interruptions. Despite these advantages, CD is often not used due to high costs in terms of time and effort. This paper provides a report on experiences with CD in two research projects in the industry domain. It is intended to help other researchers to plan and implement a CD process in industrial settings and benefit from our lessons learned.

1 INTRODUCTION

Requirements elicitation is a crucial task in every project that might have strong influence on the further procedure, methodical and implementation-related decisions and quality of the results. Gathering requirements is a non-trivial task, especially within projects of broader context and of scientific nature (where possible solutions are usually not known a-priori). Additionally, as e.g., discussed by (Holtzblatt et al., 2005; Holtzblatt and Beyer, 2017) the description of requirements is difficult for humans who often fail in uncovering so-called "hidden" factors, especially when being personally involved or affected. The reasons for this can e.g., be rooted in a certain operational blindness (when being directly or indirectly involved) or an (unintended) mental limitation of design freedom due to everyday experiences and habits. Humans often fail in describing what they do, and how and why they do it. They tend to perform certain tasks, especially routine ones, subconsciously and particularly fall short in the perception of contextual influences. Thus, requirement analysis might fail even if all important stakeholders are involved. The Contextual Design (CD) methodology described by (Holtzblatt and Jones, 1993; Beyer and Holtzblatt, 1999; Holtzblatt et al., 2005; Holtzblatt and Beyer, 2017) offers a framework for planning and implementing a User-Centered Design process with particular focus on uncovering hidden information and identification of actual user needs. It is an extensive step-by-step process for collecting field data and using it to design any sort of technical product (Beyer and Holtzblatt, 1997) and involves techniques to collect, analyze and present user data, drive ideation from these data, design product solutions and iterate them with customers (Holtzblatt and Beyer, 2014).

CD is intended to accompany a project from the first elicitation of requirements to a successful implementation. It thus comprises an interrelated sequence of methods that suit different project phases. (Holtzblatt and Beyer, 2014) describe CD as a team-based methodology designed to "take advantage of a cross-functional team including product management, marketing, product architects, user experience designers, developers, and service designers, each providing their unique skills and insights to help invent the right solutions for users". One of the main is-

Augstein, M., Neumayr, T., Pimminger, S., Ebner, C., Altmann, J. and Kurschl, W.
Contextual Design in Industrial Settings: Experiences and Recommendations.
DOI: 10.5220/0006674904290440
In *Proceedings of the 20th International Conference on Enterprise Information Systems (ICEIS 2018)*, pages 429-440
ISBN: 978-989-758-298-1

sues related to other design and evaluation methods such as usability tests, focus groups or questionnaires (or, in general, any technique with fixed questions and pre-defined tasks) is that they take users out of the context of their everyday settings. According to (Holtzblatt and Beyer, 2014), the missing context leads to such methods often not being able to reveal the most important design issues like users' motivation, values, emotions, strategies, work-arounds, real-time interruptions and interactions with others. Thus, it is a main aim of CD to understand users in their own context and to be able to apply these understandings to design problems.

Although the application of CD involves a wide range of advantages, it is often not used, especially in time-critical projects (which already gave rise to a compacted variant called rapid CD in 2005). The main disadvantage which is often decisive, is that applying CD is costly in terms of time and effort. It requires not only project personnel but also the cooperating clients to contribute intensively. This is certainly also the case during the requirements elicitation phase of projects not using CD (especially those that follow agile approaches), however the intensity increases with using CD. Further, for some domains there are only few reported examples that provide lessons learned and practical recommendations.

This paper describes the application of a CD approach in industrial settings using the example of two different research projects (RP1 and RP2) that are conducted by research organizations in cooperation with industrial partners. It explains the different phases in the CD process and provides a practical set of implications and recommendations related to application of CD in industry. The following paragraphs provide a concise overview of the two projects which have in common that they aim at creating novel, innovative solutions beyond the current state of the art.

RP1 researches novel interaction methods for manual industrial welding machines. It comprises conceptualization as well as prototypic implementation and evaluation in the field and aims at improving the welding process in terms of time and quality. Currently, the welding process often has to be interrupted in case a parameter (such as current) needs to be changed on the fly because every little movement of the welder's hands negatively affects the high-precision welding task and its output. RP1 aims at the introduction of alternative interaction methods that fit the welders' needs and comply with industrial standards. RP1 is a two-year project. The main reasons for employing CD methods in RP1 were that researchers did not have domain knowledge, the specific (micro) interactions with the welding machine cannot be simulated easily outside the usage context, and is not comparable to working with other interactive systems in regard to time pressure and precision.

RP2 aims at the conceptualization and prototypic construction of a human-centered industrial workplace. It focuses on two types of industrial work: i) manufacturing/assembly (at the example of industrial welding machines and industrial computers) and ii) commissioning. The experiences described in this paper are related to the first use case (machine manufacturing) only. RP2 researches work context analysis and personalized means of assistance via a contextual feedback system. It is a four-year project and aims at optimizing the industrial work place in terms of ergonomics, efficiency and worker satisfaction. We have experienced that (for the reasons mentioned earlier) just asking workers about their needs for assistance will not lead to success ultimately. Also, hidden knowledge, which is not documented and passed on only informally, is often necessary when assembling products. We employ CD methods to i) better understand the users and ii) identify activities and work steps that can be supported by technical assistance systems. Our goal is to minimize the training phase and maximize the quality of daily work.

2 RELATED WORK

This section explains in further detail the background behind CD and summarizes selected CD use cases in concrete industrial and other domains.

2.1 Contextual Design

According to (Holtzblatt and Beyer, 2014), CD was first invented back in 1988. In 1990, CD was first published and presented as an "emergent method for building effective systems" at CHI (Wixon et al., 1990). One of the objectives back then was to challenge traditional, predictive research techniques which "have fallen short of delivering timely and relevant design information". The process explained by Wixon et al. already involved the core characteristics of today's CD. For instance, they list the following guidelines for the conduction of a contextual interview (which has its roots e.g., in the work of (Winograd and Flores, 1988; Ehn, 1988)): i) interview users about their work in the real work environment, ii) be concrete and talk about what the user is doing, just did or talk in the context of a work product, iii) let the user lead the conversation in order to co-interpret and co-design, iv) expand and challenge the background of assumptions one brings to each interview, probe all surprises and assumptions, v) summarize your understanding at the end of each session to determine what to focus on next, vi) build an understanding of user work and of the environment being designed, vii) understand, design and build a first cut at a user environment, and viii) iterate the prototype with real users doing real work. These guidelines are still valid today, mainly for Contextual Inquiry (CI), i.e., the CD method recommended for early project phases.

In 1993, (Holtzblatt and Jones, 1993) described CI in further detail, affirming the challenges addressed by Wixon et al., e.g., that "people speak about their work in abstractions" and pointing out the "difference between summary information and ongoing experience". According to Holtzblatt and Jones, when asked about a computer system, people provide a summary or their general opinion which is often a strongly abstracted statement derived from everyday experience. This might lead also to people not reporting positive aspects because they are frequently not aware of what they like about a system as it works well and does not call attention to itself. We can affirm these problems as we experienced similar behaviours when talking to stakeholders. (Beyer and Holtzblatt, 1997) published the first book describing CD in-depth and involving an extensive guide to the preparation and implementation of a CD process. They explain all CD phases and provide practical examples of roles, artifacts, analysis methods and results. (Holtzblatt et al., 2005) introduced Rapid Contextual Design (RCD) which was our primary guide, accounting for the immense effort involved with CD. RCD provides a more dense guide for practitioners and focuses on the core CD techniques that most easily drive customer data into the corporate design process. Starting in 2013, CD was overhauled in order to account for changes in technology and its influence on humans' lives, e.g., through "always-on, always-connected, and always-carried devices" (Holtzblatt and Beyer, 2017).

2.2 Application Use Cases

(Gellatly et al., 2010) describe the first of several CD projects undertaken by the General Motors UX design team. The project called "Journey" focused on gaining a deeper understanding of how drivers interact with today's entertainment, communication, navigation, and information systems in their vehicles. It followed the CD process as described by (Beyer and Holtzblatt, 1997; Holtzblatt et al., 2005) and specifically aimed at i) documenting user intents for entertainment, communication, navigation and information system usage, ii) studying the balance between in-car systems and carried-in devices usage, iii) determining how users' outside lives should be supported in-car, iv) capturing how in-car tasks interact with the driving task, v) determining effects of individual differences in tolerance to sensory overload, mental models of navigation and age, and vi) uncovering the values that customers have around brand, design and aesthetics. The process comprised CI, interpretation sessions, affinity diagram, work models and visioning and is thus similar to ours regarding methodology. However, while Gellatly et al. focus on the description of their findings, our paper emphasizes more strongly the experiences with CD and related lessons learned.

(Coble et al., 1995) describe a CI process conducted to gather physicians' requirements for a clinical information system. Their CI sessions comprised orientation, interview and wrap-up. Following the CI session, data were analyzed and used to derive a sequence, a flow and a context model, and detailed observations and a user profile. The sequence model documented the sequences of activities the physician performed. The flow model documented the information and items flowing between physician and other people or places. The context model documented external influences which affected how the physician cared for patients. The observations contained the details of what the physician did and were the primary source for requirements. The process followed in our research projects differed in that our main data consolidation and analysis tool was the affinity diagram as suggested by (Holtzblatt et al., 2005). Coble et al. describe their CI efforts as extensive and time-consuming which complies with our experiences. E.g., they report 80 physician hours, 130 staff hours in direct participation, 90 staff hours in post-session documentation and additional 1300 staff hours in data analysis sessions over three months.

(Fouskas et al., 2002) applied CI for gathering users' requirements in the context of mobile exhibition services. They describe their process with a focus on the method itself, aiming at providing a guide for further investigations and experiments in using the CD methodology (with emphasis on CI). Their paper is thus of similar nature compared to ours, however, we believe that i) the application domain does actually influence "best practices" for the conduction of CD/CI and ii) the characteristics of interactive solutions have changed since 2002, which is also affirmed by (Holtzblatt and Beyer, 2014). Other major differences can be found in the project phase discussed; Fouskas et al. do not describe the analysis of the data gathered via CI, which is one of the main contributions of our paper. Further, they suggest the derivation of a unified requirements specification report from CI data in combination with external business-strategic and technological requirements. Our work uses CI data as the exclusive source of user requirements.

(Viitanen, 2011) describes the application of CI for user-centered clinical IT system design. She briefly outlines the structure and themes of her inquiries and lists advantages and challenges related to the CI method. Her findings are largely rather general (such as "might be time-consuming") or closely related to the domain (such as "makes it possible to analyse clinicians' actions with interactive systems in environments in which numerous systems are used simultanously"). Some of the findings affirm the issues named by Holtzblatt et al. while others might not be transferable to industrial settings. Here, we thus aim at i) an in-depth description of the CD/CI process and ii) a clear focus on lessons learned related to industry.

3 CONTEXTUAL DESIGN IN INDUSTRIAL SETTINGS

This section describes our settings, procedure and experiences with the CD methodology. Lessons learned (specific to CD) and practical considerations (general tips) can be found at the end of the sections, a more exhaustive reflection is provided in Section 4. We focus on the phase of CI but describe other CD methods as well. CI is especially beneficial if, as in our case, the project personnel is not familiar with the project domain. Our CD process comprises all steps from CI to first functional prototypes in RP1 and all steps from CI to a consolidated affinity diagram in RP2.

In RP1, eight CIs were conducted at two companies. Data were then used to construct an affinity diagram which organizes data in groupings based on their natural relationships. The affinity diagram was revised and consolidated in several steps before being used to create personas and derive requirements. In a subsequent visioning process, comprehensive visions were created that later served as a basis for the conceptualization, design and implementation of functional prototypes. These phases took about a year in total (10 weeks for CI). The companies involved were a welding process specialist and a producer of agricultural machinery. All CI participants were professional welders. Not more than one CI was conducted per day. The core team that did the CIs and instructed the further phases consisted of two researchers (both involved in all CIs). During the following phases, four additional researchers were engaged.

In RP2, four CIs and four additional interviews were conducted at two companies in the area of automation technology and welding machine production. Data gathered there was used to construct and consolidate an affinity diagram which will serve as a basis for i) the deduction of requirements and ii) the derivation of design ideas. The CD process so far took about nine months (four weeks for CI and standalone interviews). The CI participants were production employees, the four standalone interview partners were a production line scheduler, a shift supervisor, a team leader and a manager. The CI research team was led by three core researchers but involved seven people in total. Several CIs had to be conducted in parallel (on three dates) due to the tight schedule at the industrial partners. Later, nine researchers were involved. Our CD process is sketched in Figure 1 and described in further detail in the following sections.

3.1 Contextual Inquiry Preparation

Before the actual CIs were planned, researchers of RP1 including the core inquiry team (all unfamiliar with the welding process and professional welding equipment) participated in a one-day, hands-on welding workshop. The two persons responsible for the CIs in RP1[1] then underwent a half-day interview training. Because they had no prior experience with CD, they both researched and practiced the most important parts of CI interviews which proofed very useful. The preparation of the CIs themselves started with the authoring of a "project focus" (Holtzblatt et al., 2005) that contains the objectives of the research project (e.g., novel interaction approaches in the field of industrial welding, or design of efficient and ergonomic work place settings), the affected stakeholders (e.g., professional welders), typical activities, tasks and procedures, relevant situations and locations. Moreover, numerous equipment was employed during the CIs. To record the interview portions, the dictation machine functionality of a smartphone was used. The audio quality was sufficient in quiet environments; another advantage was that a smartphone lying on the table is perceived as less invasive than other recording mechanisms might be. Video recording was done with two different conventional cameras from two different perspectives and one camera with a wide-angle lens capturing the whole setting. Finally, a professional digital camera was used to photograph important situations and artifacts (e.g., interaction methods, control elements or equipment). Both interviewers took paper-based notes during the CI. It was also important to bring pen and paper for the participants as many of them created sketches to explain their statements. Important organizatio-

[1]The CI phase of RP1 was before RP2 so the general preparation was re-used for RP2.

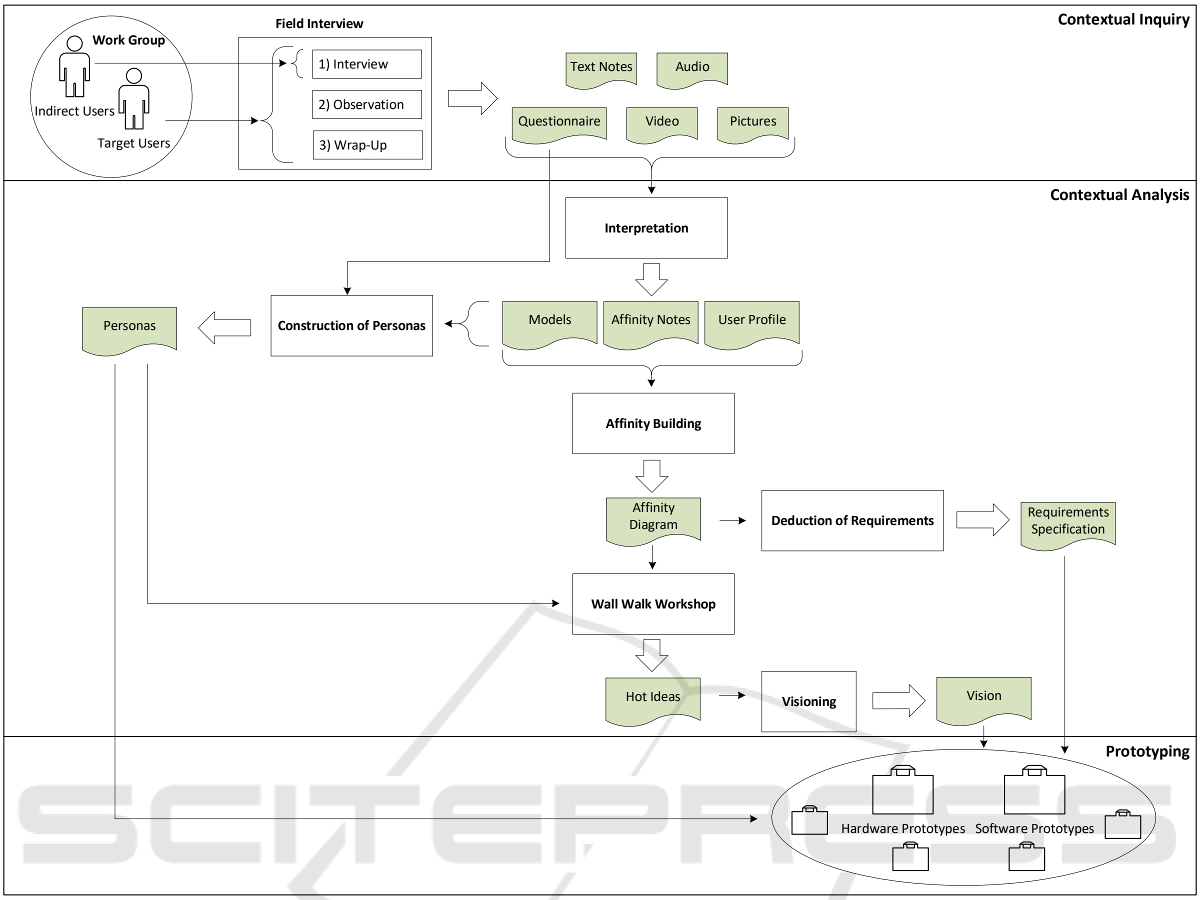

Figure 1: Overall CD process. The small arrows indicate documents and artifacts used as input for the respective step. The documents and artifacts resulting from each step are shown in green.

nal questions that should be clarified with the partner companies before the CIs dealt with adequate forms of consent, secrecy, the time period that employees cannot do their usual work, and a short briefing each company should do with their participating employees in advance. The briefing can have a major influence on the participants' attitudes and should be carefully formulated. It is recommended to highlight improvements of peoples' working conditions and emphasize that humans are not intended to be replaced by the technology to be introduced. The personality of the ideal participant in a CI is curious and open to new ideas. A good mixture of established employees and newcomers is advantageous. Participants should provide honest and constructive answers and be enabled to work on their daily tasks at their own work place rather than in a lab environment. Before carrying out the first CI, the researchers internalized the suggestion of (Holtzblatt et al., 2005) that interviewers should act as curious apprentices. They stated this explicitly during the CIs and it had a positive impact on the conversations. E.g., they explained that they did not know much about the circumstances in this profession and the participants could help them understand how they work, which problems typically arise, or what aspects make the activities enjoyable.

Differences in the Preparation. As all CIs of RP1 took place before the ones of RP2, experiences from RP1 could be utilized for RP2. Some differences in the preparation and process that arose are described as follows. In RP1, the company that provided most participants for the CIs was part of the project consortium. In planning meetings and discussions, the responsible people there already had basic knowledge about what will happen during the CD process. Therefore, time schedules and recruiting of suitable participants according to criteria that were defined together could be arranged with little effort. Yet, it was necessary to clarify what should be part of the participant briefing and which details should rather not be mentioned. RP2 worked solely with external partner companies. Therefore, more effort was necessary to brief them and a detailed guideline for the CIs and further process was created that included a description of the CD methodology, aims, interview and observation guidelines, and a check list for the CIs. It also identified the different roles of the requested participants which included i) employees (assembly workers) and ii) supervisors (e.g., production line scheduler).

Lesson: *If you design for an unknown usage context, it is tempting to familiarize yourself before the CIs take place. However, there is a chance that you are not unbiased anymore after such a familiarization. Researchers could make assumptions about processes and working methods that might not be in accordance to (industrial) reality. On the other hand, a familiarization might facilitate the observation of certain factors that might otherwise be hard to detect, e.g., physical effort resulting from body posture.* ***Note and discuss any assumptions or interpretations you have with your interview partners during the CIs.***

3.2 Pretest

Before the actual CIs, a pretest was conducted as a trial run for the later inquiries. It is important that a pretest and the following CIs are carried out under the same conditions (e.g., using the same CI interview guide and questionnaire, audio and video recording). A pretest can help to control i) the logical sequence, ii) timing and schedule, and iii) technical equipment. It can show that interview topics and their order are not harmonious and thus have to be changed. In addition, the asked questions might prove too extensive and have to be revised due to time constraints. It is also important to check the technical equipment. It must be ensured that recording over the entire period of the interview and observation is interruption-free.

Lesson: *It is favorable to perform the pretest approximately 1-2 weeks before the first interview. This leaves enough time to apply changes to documents and processes. Depending on the quality and outcome of the pretest, it is justifiable and helpful to interpret and use the materials of the pretest in later analysis.*

3.3 Contextual Inquiry

This section describes the phases of the CI sessions as conducted in RP1 and RP2. ***Part 1 (about 60 minutes)*** comprised the following items in the order listed here (the items marked *italic* were audio-recorded): welcome, introduction of interviewer, project context, agenda, *introduction of participant, questionnaire (RP1), interview according to guide, questionnaire (RP2)*. ***Part 2 (about 90 minutes)*** comprised an observation of work activities (video-recorded). ***Part 3 (about 10 minutes)*** comprised a *wrap-up* and *thank you* (including a small gift), both audio-recorded.

After careful consideration, we planned the CIs with two interviewers (and not one) both due to the inexperience in the methodology of the persons involved and the need for an exhaustive observation, although according to (Holtzblatt et al., 2005) this yields a number of drawbacks: "To establish an intimate relationship you want the user to focus on relating to one person. When one person drives the conversation he follows his focus and the conversation has a coherent thread that the user can engage with. But if two people talk, then the necessary jumping back and forth makes the conversation more disconnected, creates less intimacy, and produces competing threads of conversation." Holtzblatt et al. consequently suggest that if it is necessary to inquire with two persons, the roles "interviewer" and "note taker" should be clearly defined and many switches should be avoided. Thus, we positioned one researcher as the main interviewer while the other one acted as a note taker but could bring up questions on their own. For the latter it was easier to observe the interview process, create sketches and keep an eye on the big picture (e.g., whether all desired topics had been addressed). A description of the individual CI phases is provided in the following subsections. We processed about 12 hours of audio, 16 hours of video recordings, 370 photographs and 35 pages of written notes to create 419 affinity notes after CI in RP1. The total effort for the researchers was about 500 man-hours. In RP2, we processed about 13 hours of audio, 10 hours of video recordings, about 150 photographs and 35 pages of written notes to create 682 affinity notes (effort: about 430 man-hours). The effort for the industrial partners was 45 to 50 hours in RP1 and RP2.

Lesson: *In our experience it can be useful to inquire with two persons if they are either not acquainted with CD methodology or a thorough observation of details of the context is important.* ***Two heads may be better than one, but avoid switching back and forth between the roles of an interviewer and note taker.***

Lesson: ***We see building trust and rapport a key issue in a successful inquiry.*** *Only then will your users share sensitive information with you.*

3.3.1 Introduction

The first step was to welcome the participants and introduce the researchers before participants gave informed consent. After a short explanation of the project context, the researchers provided an overview of the goals and inquiry approach and explained the inquiry agenda. At this point, audio recording was started and participants were asked to introduce themselves. This included career progression and a brief description of their current position in the company.

3.3.2 Interview

In preparation of the interview, an initial pool of questions was scripted. In total, we prepared 17 questions (e.g., about daily routine or working instructions) in RP1 and 26 in RP2. We found it helpful to first ask for typical day-to-day routines on a specific day (e.g., last Tuesday). This provides an easy starting point for the participants and helps the researchers to expand the different areas of interest from that on. We see the prepared questions as an aid and not as a checklist that has to be worked through. Thus, new questions can arise through conversation and observation.

Lesson:* *Prepare your initial interview questions well and start with a specific question about day-to-day routine. *This helps to ask for a specific day. The information provides a good overview of daily activities and then can be transferred into a user profile.*

Lesson: *To ensure the quality of the findings the user should be open and talkative. In our experience this can be achieved by* ***transition from a question-answer situation into a smooth conversation.***

***Lesson:* *Actively motivate participants to question and reconsider aspects of their daily work*.**

3.3.3 Questionnaire

A written questionnaire was used to gather information about the participants' general situation. It was divided into three parts: i) general information (e.g., socio-demographic data), ii) educational background, occupation and work experience, and iii) experience with new technologies. In RP1, the questionnaire included additional, project-specific data about welding experience (e.g., welding hours per day, preferred equipment). However, the questionnaire was kept short (one page) to be answered quickly. The main intention was not to be forced to collect this data during the interview. The questionnaire was filled in before the interview in RP1. However, after considering that the questionnaire might interfere with the establishment of a trust base, it was handed out at the end of CI's first part in RP2. However, no differences in quality of gathered data could be identified.

Lesson: *Even if a questionnaire does not seem to be the most important part of a CI, the answers will help you to get a* ***more complete picture of your participants****. Also, personas are easier to author with basic demographic data and additional information.*

3.3.4 Observation

The observations should, if possible, take place at the participant's workplace and users should do their daily tasks in an undisturbed way. While this was possible for RP2, not all participants in RP1 worked with manual welding on a daily basis. For this and other reasons, most of them could not be observed in their usual workplace but on a recreated one. All observations were recorded with three different cameras. In RP1, the work steps included various weld joints with different materials and material strengths. Parts and components for a serial production were also processed. The observations lasted about 45 minutes on average. In RP2, the observed work tasks involved the assembly of a complete product. The observation was done in a production line with several stations (but by a single employee). One observation took place in the context of a training where the user had not manufactured the product before and got step by step instructions from an experienced employee. The observations lasted about 75 minutes on average.

***Practical Consideration:* *Use a wide-angle camera*.** *Even seemingly stationary activities might suddenly spread. People could pass by or participants might fetch tools from outside their workplace.*

Practical Consideration:* *Plan enough time for equipment setup *(it took 15 to 30 minutes per CI).*

Practical Consideration: *It is important to* ***provide all devices with sufficient power supplies****. As observations could become lengthier than expected, you can use power banks in between but should try to* ***connect as many devices to the mains as possible for permanent charging. Bring your own outlet power sockets if unsure about local equipment.***

3.3.5 Wrap-Up

The final step of our CIs was to engage the participants in a short talk about what had just been observed. The researchers explained how they understood the different activities and interactions they observed and asked if these interpretations were correct. Thus, any unclear points or backlogs of questions from previous inquiries might then be clarified. Finally, participants were asked to provide a vision about future work practices (e.g., interaction methods or work place designs) and express own ideas.

Lesson: ***Keep and update a list of open questions*** *that can be clarified during later CI's wrap-ups. In our projects, this list was integrated into the interview guidelines. As CI is a qualitative method, we freely adapted our guidelines as we saw fit in order to gather as many insights as possible in each session.*

3.4 Generation of Affinity Notes

Affinity notes are the basic building blocks of the CD methodology. They result directly from observation and questioning in the actual work context and are a description of meaningful events, problems or issues. The material reviewed for this process included the notes taken during interview and observation (typically two to four pages), voice recordings of the interviews and audiovisual material of three cameras during the observation. We started by creating a short user profile containing the respective participant's name, picture, background, main activities, and daily routines before we created the affinity notes. Example notes in RP1 are "Participant used a component he randomly stumbled across to brace against the working surface" or that a participant expressed their wish that the welding torch was as light as a pen. In RP1, generation of affinity notes was done directly after the CI. Thus we could construct the most interesting topics, issues and interactions and create the notes from fresh memory. This was not possible in RP2, due to its tight schedule with multiple interviews per day. For later reference, the notes were given a unique ID in the form P_iN (participant id, consecutive number). We created 40 to 70 affinity notes per session.

Lesson: *As recommended by (Holtzblatt et al., 2005), it helped keep the memory fresh to* ***not talk to anyone about the interview and observation between CI and interpretation*** *which is based on the notion that the human brain prioritizes those memories lower that have already been externalized.*

Practical Consideration: *If there is a* ***longer period of time*** *between inquiry and interpretation, you will have to* ***rely on the audio recordings*** *of the interview, which increases time and effort (but generally works).*

3.5 Generation of Affinity Diagram

The aim of transforming the affinity notes into an affinity diagram is to systematically organize the gathered pieces of information. In both projects, the generation of the diagram took place in several team workshops (see Figure 2) with in-depth discussions about the observed phenomena. Each workshop was directed to a systematic grouping of the affinity notes resulting in hierarchical arrangement. In RP1, the first workshop took place after all but one CIs, in RP2 after all CIs. We used a large room decorated with flip charts and prepared 20 stacks of randomly assembled affinity notes. A core team of three researchers then started to group the affinity notes on the wall. This was done by thinking about what each affinity note really implies. E.g., when a participant used a random component to brace against the working surface, this might mean that they needed stabilization. Regarding a participant's wish for his torch to be as light as a pen, the participant's underlying assumptions were probably that the welding torch should be *i)* as small as possible (but well graspable), *ii)* as light as possible, *iii)* as easily movable and flexible as possible (e.g., without the obstructive cable-hose assembly). According to these aspects, the affinity notes were grouped on the wall. In RP1, up to 6 people worked on the diagram simultaneously (up to 9 people in RP2).

On the first full day event, we could group most of the several hundred affinity notes on the wall and add blue labels (as suggested by Holtzblatt et al.) to most of the emerging groups. In several subsequent workshops, the remaining affinity notes and those gathered from the last CI were integrated. Pink and green labels were added to further aggregate the groups and identify top-level categories. For an alternative to a paper-based approach see (Judge et al., 2008) who describe multiple display environments for diagramming. In total, the effort during the affinity building and visioning phase was about 650 man-hours for the researchers in RP1 and 340 hours so far in RP2. The effort for the industrial partners was about 100 manhours in RP1 (in RP2 the affinity diagram has not yet been consolidated with the partners).

Lesson: *It is important to* ***abstain from a keyword-based grouping*** *in order to enable development of natural, semantic groupings.*

Lesson: ***The support of additional researchers that join the affinity building process was not always helpful*** *(people who think in solutions right from the beginning might even hinder the process at this stage).*

3.6 Review of Affinity Diagram

After completing the affinity building, the diagram was reviewed together with domain experts of the industrial partners. The main objective of the review was to examine whether CI data were correctly un-

Figure 2: Three researchers building an affinity diagram.

derstood and interpreted. Furthermore, some of the questions and data holes that came up during the affinity building workshops could easily be fixed while reviewing the diagram. Since the affinity diagram was constructed with notes printed out and arranged on a flip chart, a digital version was created for RP1. The digital version is much cleaner and easier to read, additionally it conveys a more professional impression with stakeholders (e.g., industry partners) as printed out with a plotter. A drawback might be that the diagram cannot be edited on the fly when discussed (which is possible otherwise through simple rearrangement of sticky notes). We used Microsoft Visio for digitalization which is particularly suitable in case the affinity notes already exist in digital form (e.g., in Microsoft Excel). It is then easy to import them in Visio and visualize the data based on shape templates. This makes it also easier to generate different versions of the diagram. For example, we created a version that includes the notes' IDs for internal use and an anonymous version that could be given to the industrial partner. In RP2, we did not create a digital version of the affinity diagram for time reasons. See the plot of the RP1 affinity diagram in Figure 3.

Lesson: *For industrial partners (especially on the executive level) that are often used to follow formal processes, there is the danger that a CD approach might appear too informal. Coming there with a myriad of flipchart pages and sticky notes might seemingly confirm this impression for them. Therefore, a* ***suitable visual preparation of the diagram*** *(e.g., printed or plotted) can help to* ***translate between business language and CD****. The diagram was valued highly by all external partners in our case.*

Practical Consideration: *If plotting the affinity diagram,* ***use a font of sufficient size*** *and allow for* ***enough white space*** *to later place sticky notes.*

3.7 Construction of Personas

The construction of personas that are grounded in contextual data was mainly useful for two reasons. Firstly, they made it easier having real target group users in mind when designing technological solutions. Secondly, they were very supportive for introducing new stakeholders (e.g., designers, developers) into the project later on. In order to ensure that the personas are composed with a real foundation in the contextual data we gathered, we carried out the following steps: i) *determine which participants are suitable as a basis for the persona*, ii) *assign a realistic name to the persona*, iii) *extend user profiles* (by using notes from the interview, audio recordings and affinity notes), iv) *author the persona as a synthesis of the material*, v) *refine personas* by listing roles, tasks, and goals, and vi) *add a portrait picture* that matches the persona.

3.8 Deduction of Requirements

In many organizations it is an established procedure to formalize and create a catalog of requirements. As a final result of a requirements engineering process, stakeholders and executives are typically longing for this piece of documentation. However, in CD-driven projects, a formal requirements catalog is not the main focus. The requirements are embedded in their specific context directly within the affinity diagram that is the basis for the next steps. By reflecting on the diagram, design solutions can be devised that are grounded directly in the contextual data instances. It is important to keep in mind and communicate that the affinity diagram does not represent designs or even requirements, but rather an "accurate and complete picture of the users' work domain, including their concerns and descriptions of their current usage" (Hartson and Pyla, 2012). Yet, it can be useful for a quick overview or for strategic reasons to obtain a list of requirements. Hence, (Hartson and Pyla, 2012) describe how it can be extracted from an affinity diagram. According to our aims, we extracted interaction requirements (IR) and corresponding system requirements (SR) directly form the pink label (i.e., mid-level) groups. For example, a pink label we introduced read "Feedback during the welding process is important to me.". This was further translated to the IR "Feedback about the welding process must be available for welders." and the SR "The system must show welders currently relevant feedback.".

Lesson: *Communicate early that **requirements** will **not** necessarily be **available** in the way they would in a more formal requirements engineering process and explain why this is **not necessary**.*

3.9 Wall Walk Workshop

The main purpose of the Wall Walk workshop was to introduce persons from outside of the core inquiry team to the data gathered so far and spark feasible and practical ideas from the different professions and experiences among all participants (about 20, including industrial partners, in RP1). In preparation, a large room was decorated with the plotted affinity diagram. Firstly, all participants silently inspected the whole diagram (see Figure 3), read the data instances (i.e., affinity notes and labels) from the top downwards, inserted sticky notes of emerging ideas or issues and placed them at those positions in the diagram where they emerged. For about two hours, participants remained almost completely silent and focused solely on the data. This process was followed by a break of about one hour that was used by the core team to gather and digitalize all ideas and issues. When the participants returned from their break, the ideas were discussed in their particular context. The participants' different backgrounds were invaluable to evaluate ideas based on their feasibility, practicability, and corporate philosophy. Finally, a list of "Hot Ideas" (high-potential ideas for technological solutions for the interaction with welding machines) was prepared.

3.10 Visioning

Based on the list of Hot Ideas that was discussed and compiled during the Wall Walk workshop, a Visioning session was conducted. Six team members gathered in a large room that was prepared with the Affinity Diagram and personas. First, the participants (re)familiarized themselves with the Affinity Diagram during a personal and silent wall walk (of ca. 60 minutes). Afterwards, the list of Hot Ideas was reviewed. To come up with starting points for the visions, each participant could freely distribute six votes. The highest-ranked Hot Ideas were then integrated into the visions as initial solutions. Over about two hours, a brainstorming and group storytelling process unfolded. One team member acted as "pen", responsible for sketching the ideas of the stories told by other members, and one as a "poker", keeping an eye on the big picture and pointing to Hot Ideas that should also be considered. Three visions (i.e., sketches of the envisioned work practices including new technology to help welders) were created accordingly. Next, the visions were evaluated and a list of positive and negative points was compiled for each vision. On a separate date, two team members integrated all ideas that were evaluated positively and fit together well into a consolidated vision. This final vision was created on a large interactive touchscreen (Microsoft Surface Hub 84") with sketching functionality which proofed useful (e.g., zooming, copy and paste, and electronic distribution were very valuable).

Figure 3: Participants engaged in the Wall Walk workshop.

3.11 Prototyping and Current Status

In RP1 functional hardware and software prototypes are currently created. The features and properties of these prototypes are strongly informed by the contextual data we gathered. Although a thorough evaluation is yet to come, we can a priori say that many subtle constraints would have stayed hidden without the CIs (e.g., a strong focus on weight reduction of the equipment). Apart from constraints, visioning helped us to come up with prototypic solutions we are confident will help target group users. In RP2, the next steps are the Wall Walks with industrial partners.

4 DISCUSSION

In this section we discuss our experiences with the CD methodology in industry-related projects and derive recommendations for researchers and practitioners.

4.1 General Remarks

To ensure a smooth CD process, initially clarify all framing conditions (e.g., participants, declarations of consent) with industrial partners and create a shared understanding of the methodology with all involved parties. We recommend to rely strongly on the companies regarding the selection of participants (but give them criteria). Inform the company that you need the employees for at least three hours but they can get some work done in the meantime. Some companies might want to provide you with personnel that is easily dispensable. For the CIs themselves, plan enough time. Some participants might need time to gain trust, open up and then converse more extensively.

4.2 Contextual Inquiries

The CIs do take a lot of effort from you, industrial partner companies, and the participants themselves. It is difficult for companies to remove workers form their activities for a long time, since they cannot work as productively as usual during this period. This should also be communicated early. Time is a critical factor and companies try to keep interruptions for employees as low as possible. Thus, in RP2 several CIs were conducted by several teams on one day.

In RP2, we planned the CI with different target groups with potentially different interests (e.g. production line planners and workers). We found that the collected data complemented each other well. This could also be observed when creating the affinity where the data of two companies was combined. It is also important to carefully select and inform the employees that should participate in the inquiry. Participants are not expected to deliver the "best possible performance". In RP2, a selected employee had to be replaced on short notice. She had been informed that she would be taking part in an observation and then memorized the work instructions over the weekend.

Due to a tight schedule, resource bottlenecks can also occur in the inquiry team. Since several surveys had to be carried out on one day in RP2, researchers without CD experience were involved. These were i) briefed in advance, ii) present during the pretest or iii) in a team with experienced researchers when possible. Yet, differences in the quality of the collected data could be observed, e.g., inexperienced researchers paid less attention to the answers in the questionnaire. Although the data could be completed from audio recordings, this information should have been acquired together with the user. This led to a lot avoidable effort. We managed to develop a sound basis of trust with all participants, and in our experience, most participants were open-minded and willing to give constructive and honest answers to the questions we asked. They knew that they were experts and their respective fields – while the researchers were the "apprentices" – and they were pleased to be involved.

To prevent loss of contextual data, we recommend bringing at least two audio recording devices (in RP2's pretest the recording failed so we had to interpret data from notes and memory). When observing participants in productions halls, the noise level was high which made audio recording more difficult. It is thus advisable to deal with certain questions again in the wrap-up. Video recordings from different perspectives were also essential. Countless times, we discovered important details in the interaction with machinery or the handling of equipment only after careful analysis of all different perspectives. To facilitate this, we synchronized all different image tracks to one video. Finally, it is important to plan sufficient time and resources for data interpretation. According to (Holtzblatt et al., 2005), this phase should take place within 48 hours. This was not possible in RP2 and the preparation of the affinity notes took almost one month. This caused considerable additional effort as researchers had to repeatedly view the video recordings where memory was not instant.

Hidden Requirements. In both projects, we could uncover numerous requirements and constraints that would most probably have stayed hidden without CI. E.g., we observed that a participant took a look at a faraway central display A, although they were holding a display B presenting the needed information right in their hand. When asked why they looked for the information on display A, they replied that they were just standing nearby. Yet, after video analysis, we saw a deliberate movement to the display A only for the purpose of receiving the information. The reasons could be that it was not legible in display B or the participant trusted display A more. Findings like these had strong implications for the later design stages and can help us to develop usable and reliable solutions.

4.3 Affinity Building

In both projects, the building of the affinity diagram started with a workshop. First, the building was done together, after a certain time in pairs and later individually. In RP2, the transition to work independently was done too quickly. This led to a too hasty integration of the affinity notes into the diagram. There was a strong thinking in the given categories (labels) which we should have divided at an early stage. Furthermore, we advise you to start with the pink labels only after the blue labels are ready. Another problem was "pattern matching". For some researchers, it was difficult to correctly interpret the key message of affinity notes. Similar words on similar notes do not necessarily indicate a similar message. We also saw difficulties in finding the right form of abstraction and some researchers were often unsure whether an information was relevant or not. In our experience, poorly instructed team members slow down the affinity building process or cause a lot of extra work. We recommend working with a small team (3-4 people) permanently involved in the building process. If people are only available temporarily, assign them self-contained tasks (e.g., subdivision of a blue label group).

5 CONCLUSIONS

In this paper, we presented and discussed experiences and lessons learned with the CD methodology. They are rooted in the industry domain as both CD processes we described here were conducted in industrial research projects. In summary we would like to strongly encourage other researchers in using CD in spite of well-known challenges such as the time and effort involved for all participating parties. In our experience, CD did not only help to reveal hidden factors of influence, requirements and design ideas for RP1 and RP2 but also other information not of direct relevance for the projects but generally of interest for the industrial partners. All partners concordantly confirmed that the additional effort paid off for them. This paper provides a guideline intended to help researchers to i) circumvent avoidable risks and mistakes and ii) more realistically assess the effort involved with each of the CD phases in beforehand. We do not suggest deviation from the CD methodology described by Holtzblatt et al. but highlight it from an industry-related perspective. Future work could study more in-depth how the time- and effort-related cost of the (R)CD methodology could be further reduced.

ACKNOWLEDGEMENTS

Our work has been conducted within the scope of the projects *Welding Interaction in Future Industry* and *Human-Centered Workplace 4 Industry*, funded through the BRIDGE and COIN programs, managed by the Austrian Research Promotion Agency (FFG).

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