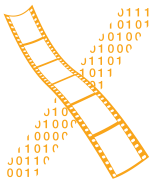

Chair for Computer Science 10 (Media Computing and Human-Computer Interaction)

RWTH AACHEN UNIVERSITY

Investigating Documentation Processes of Digital Fabrication Projects in the Maker Community

Master's Thesis
submitted to the
Media Computing Group
Prof. Dr. Jan Borchers
Computer Science Department
RWTH Aachen University

by
Tanja Golinski

Thesis advisor:
Prof. Dr. Jan Borchers

Second examiner:
Prof. Dr. Ulrik Schroeder

Registration date: 11.06.2019
Submission date: 11.09.2019

Eidesstattliche Versicherung

_____ _____

Name, Vorname Matrikelnummer

Ich versichere hiermit an Eides Statt, dass ich die vorliegende Arbeit/Bachelorarbeit/ Masterarbeit* mit dem Titel

_____

_____

_____

selbständig und ohne unzulässige fremde Hilfe erbracht habe. Ich habe keine anderen als die angegebenen Quellen und Hilfsmittel benutzt. Für den Fall, dass die Arbeit zusätzlich auf einem Datenträger eingereicht wird, erkläre ich, dass die schriftliche und die elektronische Form vollständig übereinstimmen. Die Arbeit hat in gleicher oder ähnlicher Form noch keiner Prüfungsbehörde vorgelegen.

_____ _____

Ort, Datum Unterschrift

*Nichtzutreffendes bitte streichen

Belehrung:

§ 156 StGB: Falsche Versicherung an Eides Statt

Wer vor einer zur Abnahme einer Versicherung an Eides Statt zuständigen Behörde eine solche Versicherung falsch abgibt oder unter Berufung auf eine solche Versicherung falsch aussagt, wird mit Freiheitsstrafe bis zu drei Jahren oder mit Geldstrafe bestraft.

§ 161 StGB: Fahrlässiger Falscheid; fahrlässige falsche Versicherung an Eides Statt

(1) Wenn eine der in den §§ 154 bis 156 bezeichneten Handlungen aus Fahrlässigkeit begangen worden ist, so tritt Freiheitsstrafe bis zu einem Jahr oder Geldstrafe ein.

(2) Straflosigkeit tritt ein, wenn der Täter die falsche Angabe rechtzeitig berichtigt. Die Vorschriften des § 158 Abs. 2 und 3 gelten entsprechend.

Die vorstehende Belehrung habe ich zur Kenntnis genommen:

_____ _____

Ort, Datum Unterschrift

Contents

List of Figures

Abstract

The maker community is a community of people who practice some form of tinkering. Documentation is necessary to enable a global exchange of knowledge and ideas in the maker community. In this thesis, we investigate documentation processes of digital fabrication projects in the maker community. The improvement of documentation processes could enhance the exchange in the maker community. In our approach documentation processes are investigated from the view of users who create documentation voluntarily as well as makers who are required to create documentation or do not want to create documentation at all.

Our research question is where and how documentation processes in the maker community could be improved. To answer this question we conducted two studies. In the first study, we investigated online documentation to get an overview of the current state of documentation published online. Moreover, we used the information we gained as input for questions for a user interview study. During semi-structured interviews, we questioned 12 makers about their documentation habits, motivations, and problems with documentation processes.

Using coding methods for qualitative research we analyzed the user interviews regarding users' documentation habits, motivations, and problems related to documentation processes. Our results show that for some makers the benefits of creating documentation do not outweigh the effort required to create documentation. Besides, we discovered that it can be difficult for makers to identify when creating documentation is worth the required effort.

Our findings helped us to identify three research opportunities. Those are the development and improvement of tools for the creation and publication of documentation, the search for possibilities to help maker identify when the creating of documentation is beneficial for them or others, and the automation of documentation processes.

Überblick

Die Maker Community ist eine Gemeinschaft aus Menschen, die sich mit einer Form von Bastelei oder dem Herstellen von Dingen beschäftigt. Der globale Austausch von Ideen und Wissen in dieser Gemeinschaft erfordert Dokumentation. In dieser Masterarbeit untersuchen wir Dokumentationsprozesse von digitalen Fabrikationsprojekten in der Maker Community. Die Verbesserung von Dokumentationsprozessen könnte den Austausch in der Maker Community verbessern. Dokumentationsprozesse werden sowohl aus der Sicht von Makern, die Dokumentation im Rahmen ihres Hobbys veröffentlichen, als auch Makern, die Dokumentation erstellen müssen oder gänzlich unmotiviert sind Dokumentation zu stellen, betrachtet.

Im Rahmen dieser Masterarbeit wird die Forschungsfrage beantwortet wo und wie Dokumentationsprozesse in der Maker Community verbessert werden kann. Hierzu werden zwei Untersuchungen durchgeführt. Zunächst wird eine Untersuchung von online verfügbarer Dokumentation durchgeführt, um Informationen über derzeitig veröffentlichte Dokumentation zu gewinnen. Die daraus gewonnenen Informationen dienen zudem als Grundlage für Nutzerinterviews im Rahmen einer weiteren Untersuchung. In halbstandardisierten Interviews werden Maker über ihre Dokumentationsgewohnheiten, Motivationen und Probleme während des Dokumentationsprozesses befragt.

Mithilfe von Coding-Methoden aus der qualitativen Forschung werden die Interviews in Bezug auf den Dokumentationsprozess, Motivationen von Nutzern und Probleme während des Dokumentationsprozesses analysiert. Die aus diesen Interviews resultierenden Ergebnisse zeigen, dass für einige Maker der Nutzen von Dokumentation nicht den für die Herstellung von Dokumentation erforderlichen Aufwand rechtfertigt. Außerdem kann es für Maker schwierig sein zu erkennen in welchen Situationen das Herstellen von Dokumentation nützlich ist.

Aus unseren Ergebnissen werden drei übergreifende Forschungsfragen abgeleitet. Diese adressieren die Entwicklung und Verbesserung von Tools für das

Erstellen und Veröffentlichen von Dokumentation, die Suche nach Unterstützungsmöglichkeiten für Makern zur Identifikation von Situationen, in welchen Dokumentation nützlich für sie selbst oder andere sein kann, sowie die Automatisierung von Dokumentationsprozessen.

Acknowledgements

To begin with, I would like to thank my thesis Advisor M.Sc. Marcel Lahaye for his constant support throughout my master thesis. Thank you for giving me feedback, ideas and advice.

Moreover, I would like to thank Prof. Dr. Jan Borchers for the opportunity to write my master thesis at the i10 chair and for examining my thesis. I also want to thank my second examiner, Prof. Schroeder.

Furthermore, I want to thank the 12 participants of my user study. Thank you for spending your time with this study and for making my research possible.

Finally, I want to thank my family and my boyfriend for supporting me during my master thesis but also during all of my studies leading up to this master thesis.

Conventions

Throughout this thesis we use the following conventions.

Text conventions

Definitions of technical terms or short excursus are set off in coloured boxes.

EXCURSUS:
Excursus are detailed discussions of a particular point in a book, usually in an appendix, or digressions in a written text.

Definition:
Excursus

Source code and implementation symbols are written in typewriter-style text.

```
myClass
```

The whole thesis is written in Canadian English.

Download links are set off in coloured boxes.

File: myFile[a]

[a] http://hci.rwth-aachen.de/public/folder/file_number.file

Chapter 1

Introduction

In this work, we want to investigate documentation processes of digital fabrication projects in the maker community.

To create a common understanding of the terminology used in this thesis, we present the following definitions of terms that are commonly used in literature:

We use the following definitions of some common terms.

DIGITAL FABRICATION:
Digital fabrication is the term for creating objects with a machine controlled by a computer, e.g. a laser cutter or a 3D-printer. Personal fabrication is digital fabrication performed at home (Mota [2011]).

Definition:
Digital Fabrication

MAKER COMMUNITY:
Makers are people who practice tinkering in some form, e.g. by gardening, knitting or creating digital fabrication projects. The maker community is the community formed by all makers (Dougherty [2012]).

Definition:
Maker Community

DOCUMENTATION:
Documentation is every material, which provides specifications or instructions to recreate a process.

Definition:
Documentation

The maker community needs better documentation processes to exchange ideas and knowledge.

Makers can use documentation to exchange with other makers. This exchange can help to share knowledge and ideas. We wanted to investigate documentation processes further because related work shows that some makers have problems with documentation processes. For example, authors of posts on Instructables (Ins) have problems when creating documentation (Tseng and Resnick [2014]). The work of Tseng et alia indicates that documentation processes are unoptimized and lack tool-support. This poses the question of how documentation processes can be improved.

We want to find design input and research opportunities related to documentation processes.

In this work, we want to look at the maker community as a whole to further investigate their needs concerning documentation. We want to improve documentation processes by identifying their problems and by finding corresponding research opportunities.Our approach to this is to first investigate online documentation to get an overview of the current state of documentation. Moreover, we want to use our findings to generate questions that we will use in user interviews. We will conduct these user interviews to get qualitative data about documentation processes. Interviewed users will be users who create documentation for personal reasons as well as users who are required to create documentation for their job or education. This will help us to gain insights into documentation processes from a wider range of perspectives.

We will first discuss related work, our methodology, results from our studies, their evaluation and a summary with consequences for future work.

In the course of this work we will first discuss related work in chapter 2. Subsequently, we describe our methodology and the resulting limitations in chapter 3. We present and discuss the results of our work in chapter 4. The results include results from research on current documentation online and results from the 12 user interviews on documentation processes with members of the maker community. Moreover, we will include the evaluation of each topic after presenting the results about the respective topic in chapter 4. Finally, we will summarize the work of this thesis and discuss conclusions regarding possible further research related to the topic of documentation processes in chapter 5.

Chapter 2

Related work

In 2012, Dale Dougherty published an article (Dougherty [2012]) about the maker movement, in which he characterizes makers and talks about the importance of the maker community. We use his work to define the *Maker Community* (see chapter 1). Kuznetsov et alia further discuss DIY (Do it yourself) culture and practices in Kuznetsov and Paulos [2010]. This work underlines that research in the field of maker communities is relevant.

Research regarding the maker community is relevant.

De Roeck et alia proposed a ”manifesto for diy internet of things creation” (De Roeck et al. [2012], p. 1). This manifesto includes 13 design principles for DIY internet of things creation systems. As the aim of this thesis includes finding design input for documentation-related systems, the work of De Roeck et alia could inspire further design input. Torrey et alia wrote about the search for craft knowledge on the internet, how this knowledge is sought and found and how search can be improved (Torrey et al. [2009]). This topic is relevant in the context of *Reach* (see chapter 4.2.4). Wakkary et alia discuss the importance of tutorial authorship and the quality of DIY tutorials in Wakkary et al. [2015]. This work is linked to our work in the context of *Publishing Documentation* (see section 4.2.2). There are also systems to support makers in crafting, e.g. a ”Smart Makerspace” (Knibbe et al. [2015]) was developed by Knibbe et alia in order to guide users through a DIY task with ”detailed contextually-relevant assistance,

We Research that provides further information related to our research

domain knowledge, tool location, usage cues, and safety advice" (Knibbe et al. [2015], p. 1). This shows how documentations or tutorials can have other *Formats* (see section 4.2.4) than text.

Previous work on documentation processes in the maker community

Papers with a focus on documentation processes include a survey from 2015 in which Peppler et alia examined the importance of documentation and portfolio practices in makerspaces (Peppler et al. [2015]). The majority of the 51 makerspaces they surveyed stated, that documentation practices were important. However, they had problems integrating documentation in the daily routine of a makerspace. These findings are related to our results about *Workflow Interruption* (see section 4.2.4). Moreover, they show that makers have problems to regularly create documentation in general. Tseng et alia conducted interviews and a survey about documentation processes (Tseng and Resnick [2014]), where they interviewed authors and readers of Instructables, which are online tutorials on the website Instructables (Ins). Their work is relevant to research about documentation because Instruactables are a form of documentation. We want to expand on their work by looking at a wider group of users.

Existing systems aiming to improve documentation processes in the maker community

The goal of this thesis is to find design input for possible systems and tools that improve documentation processes. Thus, looking at existing systems can help to identify important design principles or problems of possible systems. An example of such a system is that of Määttä et alia, who wrote about the development of open and distributed tools for FabLab project documentation (Määttä and Troxler [2011]). Another system was created by Tiffany Tseng who developed a photography turntable system called *Spin*, that aids makers in creating documentation (Tseng [2015]).

Chapter 3

Methodology

In this thesis we deal with the investigation of documentation processes of digital fabrication projects in the maker community. The goal of this thesis is to identify problems of documentation processes. We also want to find opportunities for improvement of documentation processes and design input for possible tools and systems for documentation. As the first step of our research, we want to formulate our research questions.

The goal of this thesis is to identify problems of documentation processes.

The general research question we want to answer is where problems of documentation processes exist. To be able to answer this question we want to understand documentation processes first because understanding these processes could help to identify their problems. Moreover, we want to find out why makers create documentation. By understanding the motivations and goals of makers we can find opportunities to fulfill user needs better and help users reach their goals.

We want to understand how and why makers document to identify opportunities for improvement.

As describes in chapter 2, the work of (Peppler et al. [2015]) indicates that there is a lack of documentation in makerspaces. We want to find out why some makers do not document sufficiently. For this purpose, we have to identify the problems of documentation processes. Thus, we want to find out where there are problems with documentation processes and whether there is a need for improvement of documentation processes.

We want to find out why some makers do not document sufficiently.

We want to look at external and internal problems of documentation processes.

When investigating problems of documentation processes we want to look at external as well as internal problems of documentation processes. Investigating external problems of documentation processes means investigating external problems that occur due to the nature of documentation processes. Examples for such problems are tools, time or the process of writing text. Internal problems of documentation processes are problems that result from the internal thought processes of makers. These include that makers perceive a lack of interest in their projects or feel like their projects are not complex enough.

We want to look at documentation from the perspective of makers who create documentation as a hobby and makers who are not interested in creating documentation.

In order to see whether any of our research questions have already been answered previously we conducted a literature review in chapter 2. Tseng et alia investigated documentation from the perspective of readers and writers of Instructables (Tseng and Resnick [2014]). We decided to search for further opportunities for improvement of documentation processes of digital fabrication projects in the maker community by considering makers who create documentation as a hobby, makers who are required to create documentation and makers who are not interested in creating documentation. Qualitative research is suitable to answer our research questions because we want to identify problems, find design input and look for research opportunities.

We want to answer our research questions with the help of an investigation of online documentation and with user interviews.

We decided that we wanted to conduct user interviews because user interviews help to view a topic from the perspectives of different users. We hoped that user interviews could help us to think of problems and approaches we did not think of previously. Besides, user interviews enable us to differentiate between points that have been mentioned often or less often. More details of our approach to conducting user interviews can be found in section 3.2. To find interview questions that are more specific than our research questions we decided to investigate online documentation first. We described our approach of investigation online documentation in further detail in section 3.1.

3.1 Investigating Online Documentation

28 online documentations were compared regarding format, level of detail and general peculiarities.

To get first impressions about documentation in the maker community, we conducted an investigation of online documentation. As there is no catalog of all existing documentations, we could not choose online documentation representatively. Therefore, we considered a total of 28 documentations from different sources, namely the documentation-sharing website Instructables (Ins), personal blogs, forums and websites found via an internet search. Documentation in the maker community can cover a broad range of topics and to gain useful insights we choose documentations with a common task. With a common task, it is easier to quantify findings. We choose documentation with the common task of drilling a hole because the task of drilling a hole is rather simple and occurs often in digital fabrication projects. Concerning the task of drilling a hole, we compared documentations by looking at the formats that were used to display information, the details provided for the task, and general peculiarities. More precisely, we calculated the count of documentations that included the formats text, photos, diagrams, material lists, and videos. These formats were chosen because there were no other formats used in the documentations at hand. We will explain each format in more detail in the result section of the investigation of online documentation (see 4.1). Moreover, we calculated the count of documentations providing each detail, e.g. the hole depth for the drilling task. The results of these calculations can be found in section 4.

3.2 User Interviews

We conducted semi-structured interviews with a length of approximately 25 minutes.

The focus of this work lies in user interviews about documentation processes of digital fabrication projects. With these user interviews, we aim to answer the questions presented in chapter 3. We chose the format of semi-structured interviews because it allows being responsive to user input. This is of importance because further investigating topics based on user responses can help to understand documentation processes in the maker community better.

We conducted a pilot interview to improve the catalog of questions for the interview.

A pilot interview was conducted to estimate the length of the interview and test the clarity and productiveness of the questions. The pilot interview helped to modify the interview questions. Moreover, the interview length could be estimated at 20 to 30 minutes. This length is acceptable for an interview in one sitting without breaks.

3.2.1 Interview Questions

We asked users 21 questions about their experience in digital fabrication, documentation habits, motivations and struggles.

Before conducting the interviews we asked participants to fill out demographic information on their age, gender and occupation to be able to assess the external validity of our study. The interview for this user study consists of 21 questions. As the interview is semi-structured, we asked questions in a different order depending on the course of the interview and used different wording for the questions. As I conducted the interviews, interviews were conducted by someone who is an outsider to the maker community. Moreover, we asked additional questions arising from the course of the interview. We also asked users about their reasoning for most questions. In this section, we will present the 21 questions we chose for our user interview and explain why we included them.

We included interview questions to assess interviewees' experience in fabrication and documentation.

The first few questions aim at assessing the experience and expertise of the user. This could reveal relations between documentation behavior and experience. If users inquired, they were provided with a definition of digital fabrication and documentation. Users were not expected to give an exact number for questions 2 and 3, but an assessment of their experience.

1. What kind of things do you create?
2. How often have you completed a digital fabrication project previously?
3. How often have you documented a digital fabrication project previously?

In order to relax the interview and encourage participants to talk freely, we asked questions in resemblance to contextual inquiry interviews (see Holtzblatt et al. [2004]).

We included questions in resemblance to contextual inquiry interviews.

4. What was the last digital fabrication project you documented?
5. Tell me something about the documentation process for this project.

Then, we posed questions about documentation habits of participants. Question 11 aims at learning whether participants consider publishing their documentation and question 12 aims at learning how participants interact with existing documentation.

We included questions about publishing and interacting with documentation.

6. When you are not required to, how often do you document your digital fabrication projects? Any form of documentation counts.
7. Which digital fabrication projects do you document, and which do you not document?
8. In what formats do you document your digital fabrication projects?
9. Which tools do you use for documenting your digital fabrication projects?
10. How do mistakes you make during fabrication influence your documentation?
11. What do you do with your finished documentation?
12. Did you ever consider adding to a documentation or improving a documentation that you have read or watched?

The next block of questions aims at gaining further insight into what motivates the participants to create documentation for their digital fabrication projects and what could prevent them from wanting to create documentation. Questions 15 and 16 are included, because the results from

We included questions about interviewees' motivations to create documentation.

section 3.1 indicate that feedback and expressing personality might be a motivation. Questions 17 and 18 are included because a user might consider a task tedious but not difficult.

13. What is your goal when documenting crafting processes?
14. Which benefits for yourself and others do you see in creating documentation?
15. To what extent is feedback on your digital fabrication projects important to you?
16. Do you want to express your personality when creating documentations?
17. Which parts of documenting digital fabrication projects are difficult for you?
18. Which parts of documenting digital fabrication projects are tedious for you?
19. If writing documentations was less tedious or difficult, would you create more or different documentation for digital fabrication projects?
20. What do you like about documenting digital fabrication projects?
21. What would motivate you to document your digital fabrication projects more?

We encouraged interviewees to add their thoughts.

At the end of the interview, users are encouraged to add any thoughts and ideas that they could not mention previously.

3.2.2 Recruiting Users

We recruited 12 users who visited the FabLab, the Aachen Maker Meetup or

We asked different makers to participate in our study. First, we recruited some makers who enrolled in the Fab Academy, a "fast paced, hands-on learning experience where students learn rapid-prototyping by planning and

executing a new project each week, resulting in a personal portfolio of technical accomplishments" (Fab). Moreover, we recruited makers who visited the FabLab at RWTH Aachen University, which is a makerspace "equipped with the tools for every aspect of the technology development process: design, fabrication, testing and debugging, monitoring and analysis, and documentation" (Mikhak et al. [2002], p. 2). Finally, we recruited makers who visited a local maker meetup in Aachen (Mak). A total of 12 users were recruited for this study and all of them were male. They ranged in age from 20 to 61 years. 10 of the participants were students from different fields, one participant was working in a field related to digital fabrication projects and another one was working in a different field.

participated in the Fab Academy for our user interview study.

3.2.3 Evaluating User Interviews

To analyze the user interviews, we transcribed the audio files recorded during the interview to text after the interviews. The text format allows for better possibilities to analyze the interviews. We then analyzed the interviews using coding methods from *The Coding Manual for Qualitative Researchers* (Saldaña [2015]). For this, passages of text were annotated with so-called codes, which can e.g. describe the topic of a passage. Moreover, we organized and structured the codes.

User interviews were recorded, transcribed and evaluated with coding methods.

Overall coding was subdivided into first cycle and second cycle coding methods, though the codes were iterated on continuously. First cycle coding methods "are those processes that happen during the initial coding of data" (Saldaña [2015], p. 58) and we chose to use *Descriptive Coding* and *Structural Coding* as described in the next paragraphs. *Code Mapping* was used in between first and second cycle coding methods and during second cycle coding. We chose *Pattern Coding* as a second cycle coding method. Finally, *Code Landscaping* was applied to each category of final codes.

We used *Descriptive Coding*, *Structural Coding*, *Code Mapping*, *Pattern Coding* and *Code Landscaping*.

Descriptive Coding: A phrase describes to the topic of a passage.

Descriptive Coding Descriptive coding is used to summarize "in a word or short phrase - most often as a noun - the basic topic of a passage of qualitative data" (Saldaña [2015], p. 88). However, these words or phrases should not describe the content of a message, but it's topic. In the context of this thesis a code named *Feedback as Motivation* could describe the topic of a passage in the interview, but the code makes no statement on whether the interviewee considers feedback to be a motivation for writing documentation or whether he does not care about feedback as a motivation. Descriptive coding is a suitable tool to analyze the interview conducted because it can be applied to "virtually all qualitative studies, but particularly [...] studies with a wide variety of data forms (e.g. interview transcripts, [...])" (Saldaña [2015], p. 70). The advantage of descriptive coding is, that it helps to reflect on what the study is about and works as a basis for further coding methods.

Structural Coding: A phrase represents the frame of a passage.

Structural Coding Structural coding applies "a content-based or conceptual phrase representing a topic of inquiry to a segment of data that relates to a specific research question used to frame the interview" (Saldaña [2015], p. 84). An example of such a code could be "Documentation Formats". Structural codes can help to access information relevant to a topic quickly because they act as a labeling device for segments of interviews. This makes structural codes especially applicable for interviews with multiple participants or semi-structured interviews (Saldaña [2015]) and thereby for the interviews in this study.

Code Mapping: Codes are organized in a list with different categories.

Code Mapping Code mapping can be used to improve organization when moving from first cycle to second cycle coding. The full set of codes is reorganized into a list of categories containing the codes to disclose the central themes of the study (Saldaña [2015]). The categories we found in this study are presented in section 4.2.1. Code Mapping helps to transition from codes to categories to concepts. Thus, it makes it easier to find the most important concepts in the study.

Pattern Coding After first cycle coding, second cycle coding methods like pattern coding are used to reorganize and re-analyze data. Patter coding is used to develop major themes from data, find rules, causes and explanations and to form theoretical constructs (Saldaña [2015]). For example passages of interviews could be coded with different codes or even different sorts of codes. However, sometimes pattern code like *Lack of Project Complexity* can be used as a final code for a subset of similar other codes like *My project is not special* and *Project Importance*. That is, they can replace codes created in first cycle coding. In summary, pattern codes help to find rules and relationships between codes.

Pattern Coding: Finding patterns in codes and summarizing codes to one pattern code.

Code Landscaping Code landscaping can be used to further analyze codes. It is the technique of creating a word map, where words that occur frequently are displayed bigger than words that do not occur often. The technique offers the advantage to "see both the forest and the trees" (Saldaña [2015], p. 199). There are some limitations to code landscaping because the format of a semi-structured interview with reoccurring questions leads to reoccurring codes. Moreover, descriptive codes, that describe a topic and not the content of a segment, are used. Thus, it is important to not jump to premature conclusions. If, for example, the word feedback appears big in the word map it does not necessarily mean, that it is important to makers, because feedback was simply included in one of the interview questions. Despite these limitations, code landscaping can still be used to recognize important topics of our user study. We present and evaluate our code landscapes in section 4.2.1.

Code Landscaping: Creating a landscape of codes through a word map.

3.3 Limitations

In this section, we discuss the limitations of our methodology.

We conducted qualitative research to identify problems of documentation processes and find research opportunities related to documentation processes. In this section, we discuss the limitations of our research.

Our results are limited through sample selection.

Sample Selection As described in section 3.2.2 we recruited users who created documentation as a hobby as well as users who were required to create documentation or did not want to create documentation at all. 11 out of 12 participants ranged in age from 20 to 32 years. One participant was 61 years old. All of our interviewees were male. 10 of our interviewees were students. Moreover, all of our participants were currently living in Germany.

Chapter 4

Results and Evaluation

In this section we will discuss the results of the two studies described in chapter 3. First, the results of the investigation of online documentation will be presented and evaluated. The findings of both studies are linked. Therefore, the evaluation of each paragraph may include findings from both studies. Then, the results of the user interviews will be presented and evaluated.

In this section, we present the results of the two user studies carried out in this work and evaluate them.

4.1 Investigating Online Documentation - Results and Evaluation

Formats - Results As seen in figure 4.1 the 28 documentations at hand conveyed information through *Text*, *Photos*, *Material Lists*, *Videos* and *Diagrams*. More precisely, all documentations included text. 23 of the 28 documentations included photos of the created object or the documentation process. 5 out of 28 documentations included diagrams. Diagrams include sketches, photos with sketches, graphs, charts and all other images that conceptualize parts of the fabrication process. We differentiate between photos and diagrams because the process of creating diagrams and taking photos is different. 9 out of 28 documentations included material lists. We differentiate between text and material lists but, because material lists do not share all properties of

The 28 documentations at hand used five different formats. Text was used in all documentations.

text. For example, a user interview participant mentioned that he had problems to produce documentation in a foreign language because of grammatical issues. Grammatical issues affect continuous text more than material lists. Finally, 5 out of 28 documentation included a video.

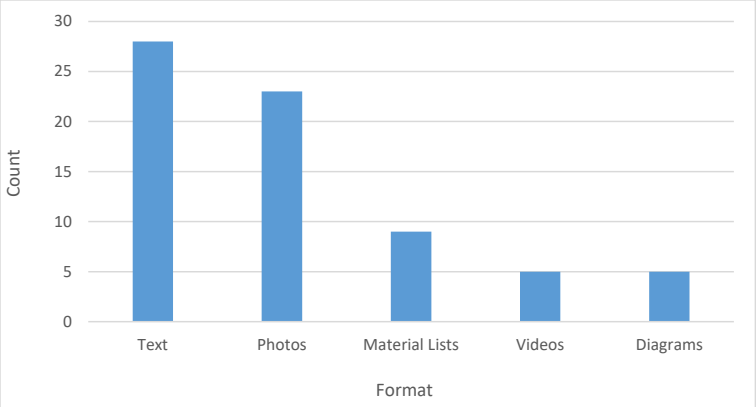

Figure 4.1: This figure shows which formats were used in 28 different online documentations. The x-axis shows which formats occurred and the y-axis shows the count of each format.

The documentations included the formats *Text*, *Photos*, *Material Lists*, *Videos* and *Diagrams*.

Formats - Evaluation In section 4.1 we describe what formats were used in documentations from different online sources. All documentations included *Text* and the second most popular format was *Photos*. As described in section 3.1, we sampled documentations from the website Instructables, personal blogs, forums and websites found via internet search. Sampling documentation from different platforms could have lead to different results. For example, choosing documentations from the platform YouTube would have resulted in more documentation in video format. Nevertheless, the results related to *Formats* from the user interview study (section 4.2.2) also show a prevalence of the formats *Text* and *Photos*.

Six interviewees had problems producing *Text* in the user interview study. A user suggested a

In the paragraph *Format Text* in section 4.2.4 we described that half of the interviewees had troubles to produce text. Interviewees especially considered long texts, text coherence, and a lack of experience in writing documentation to be problematic. This indicates, that participants strug-

gled to establish a framework for their text. A tool that can provide a predefined structure without being too restricting could ease the task of producing text for users. A user suggested such a tool in a different context. When talking about *Reach* (see section 4.2.4) the user suggested that a website, that showed usual steps of a project to users and let users chose a version which they would like to read, would improve on the ability to reach readers when publishing documentation online. Such a website that enabled authors to subdivide their documentation into different steps could aid users in establishing a structure for their documentation by using the information on structure provided by other users.

solution that would help to structure *Text*.

Although *Text* was the most used format in documentations, the authors in this study also used four other formats. Just like *Text* these formats have advantages and disadvantages. For example, in section 4.2.4 some interviewees mentioned problems related to the *Video* format. These included a lengthy process of recording videos and concerns about video quality. In our studies, authors did not use different formats than the five formats from figure 4.1. However, other formats can be used. For example, Schoop et al. describe how augmented reality can be used as an aid for a drilling task in (Schoop et al. [2016]). All formats have advantages and disadvantages and each user might prefer a different format. Thus, tools for creating or publishing documentation should allow for a great variety of formats to cater to the preferences of each user.

Tools for creating and publishing documentation should enable users to use a variety of formats.

Details - Results As described in section 3 we looked at documentations that included the task of drilling a hole. This enabled us to have a look at details related to this task. These details include information on the tools used for the task, preconditions, postconditions, and properties like *Location* or *Hole Size*. Figure 4.2 shows which details exactly were mentioned in the documentations at hand and how often they occurred. Not all details were stated explicitly. For example, the purpose was often conveyed via the context or the location was visible in pictures.

Different documentations provided different details for a similar task.

The *Purpose* was the detail mentioned most in the 28 documentations at hand.

18 out of 28 documentations made the purpose of the hole clear before the drilling task was elaborated on further. That means that the purpose of the hole suggested other information about the drilling task. An example of this is a documentation in which the author states that a hole is drilled to attach a certain element later. The circumstance that a certain element has to be attached later results in restrictions on properties like the *Hole Size* or the *Location*.

Except for *Purpose* and *Location* all details were provided in less than 10 out of 28 documentations.

Other information than the purpose was provided less frequently. 11 out of 28 documentations mentioned the *Location* of the hole, which was the second most mentioned detail. All other details were mentioned in less than 10 out of 28 documentations. The least mentioned details were *Preconditions* like safety precautions and the *Angle* in which the hole should be drilled. These details were mentioned in one documentation each.

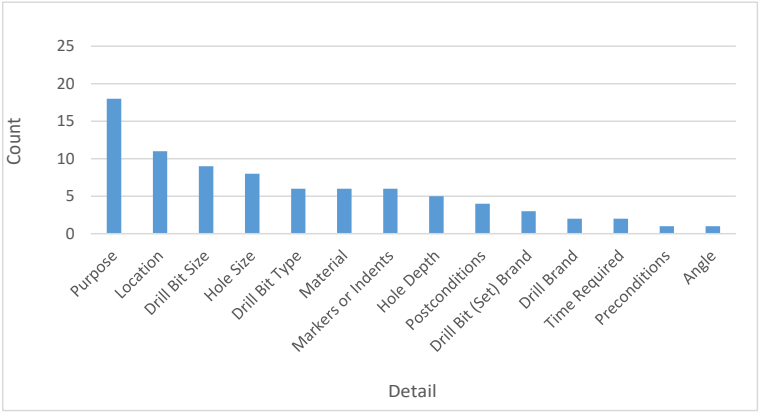

Figure 4.2: This figure shows which details about a drilling task were mentioned how often in 28 different online documentations. The x-axis displays the details that were mentioned and the y-axis shows how often each detail was metnioned.

Some makers are uncertain what they should include in their documentation. Reducing this uncertainty could

Details - Evaluation The results about details show that there is a variety in the details provided for a similar task in different documentations. This indicates that makers are uncertain which details they should include in their documentation or that makers have different opinions on what details are important. In section 4.2.4 a participant men-

tioned that his lack of experience in writing documentation makes the process of writing documentation difficult for him. A different user talked about the problems arising due to readers of different skill levels. These statements underline that uncertainty when creating documentation exists. Thus, the search for possibilities to reduce this uncertainty offers a research opportunity to facilitate the creation of documentation in the maker community.

facilitate documentation processes.

Peculiarities - Results There were some peculiarities of documentations that could not be quantified because they were subjective. For example, some documentations read like field reports. That means the authors outlined how they created something but do provide few details that are useful for reconstructing their project. These documentations often contained humorous passages or include non-essential pictures. For example, one documentation contained a picture of a child playing with the finished project.

Documentations varied in style. Some included humor or other personal touches.

Some documentation included information on which mistakes the author made and how they can be avoided or general information about possible mistakes and errors. However, we can not tell whether an author of documentation did not make any errors or whether he or she did not describe them in the documentation. Thus, this aspect can also not be quantified reliably.

Some documentation included information on possible mistakes and errors.

Finally, most platforms for publishing documentations provided some way for users to interact with the documentations of others. For example, some platforms provided a comment section where users could give feedback or provide information for the author or others reading the documentation.

Platforms for sharing documentation provide ways to interact with documentation.

Peculiarities - Evaluation The humorous passages and non-essential pictures found in some documentation indicate that some makers use documentation as a way of self-expression. Therefore, we decided to ask makers during user interviews whether they use documentation as a form of self-expression. As we found that some makers included errors they made during the fabrication process

We used the peculiarities found in online documentation to formulate questions for user interviews to gain further information.

in their documentation, we asked interviewees about their error documenting habits. Moreover, we noticed that platforms usually provided a way to interact with documentations of others. Thus, we asked users whether they consider these options to interact with documentations of others and whether they are content with them. In addition, we asked users whether they value feedback on their projects because the interaction mechanisms on platforms enable others to provide feedback. With these questions we hoped to gain more information on the topics of self-expression, documenting errors, complementing documentations of others and feedback mechanisms. The respective results to the questions will be presented and discussed in section 4.2.

4.2 User Interviews - Results and Evaluation

In this user study, 12 user interviews were conducted, transcribed and annotated with codes as described in section 3.2. Section 3.2.2 also contains information about the user demographic, their background and how users were recruited. In the following section, section 4.2.1, we will first describe the codes found using the coding methods described in section 3.2.3. With the use of coding methods, we subdivide the information extracted from user interviews into four categories. We will present and discuss the results of the user interviews in a subsection for each category. In section 4.2.1 we provide further information on the categories. Moreover, we will use *Code Landscaping* as described in section 3.2.3 to visualize the four categories.

We conducted 12 user interviews. Their results will be described and evaluated in the following sections.

4.2.1 Codes

Using the coding methods described in section 3.2.3 a total of 104 different codes were used to annotate the user interviews. Code mapping was used to find four superordinate categories for all codes. These categories are:

We found 104 different codes with four superordinate categories.

- *Documentation Processes*
- *Motivations*
- *External Problems of Documentation Processes*
- *Internal Problems of Documentation Processes*

Their content will be discussed in sections 4.2.2, 4.2.3, 4.2.4 and 4.2.5 respectively. In the following paragraphs, we will describe which codes and information each category contains.

The first category is the category of *Documentation Processes*. It contains codes related to the process of creating and publishing documentation.

Documentation Processes The category *Documentation Processes* includes codes that deal with aspects of documentation processes. That includes the process of creating documentation as well as the process of publishing documentation. The category also contains codes for information about how users interact with documentations of others. Examples for codes in the *Documentation Processes* category are *Formats* and *Publishing Documentation*. The category *Documentation Processes* does not include information about the motivations of interviewees or a lack thereof. That information and information about problems arising through documentation processes are discussed in the context of other categories.

The category *Motivations* described what motivates makers to create documentation.

Motivations The *Motivations* category contains all codes that have to do with what motivates users to create documentation. Examples for such codes are *Sharing Knowledge with Others* and *Encountering the Same Problem Again*. The category also contains codes related to the motivations feedback and self-expression, which were prompted through the findings from section 4.1.

The category *External Problems of Documentation Processes* describes problems of the process of creating documentation.

External Problems of Documentation Processes The two final categories are related because both deal with reasons why makers do not document their digital fabrication projects. The category *External Problems of Documentation Processes* contains codes that describe what hinders documentation processes for makers. That means it contains codes for external problems like *Format Text* and *Tools*.

The category *Internal Problems of Documentation Processes* describes problems related to internal thought processes of makers.

Internal Problems of Documentation Processes The category *Internal Problems of Documentation Processes* contains codes that describe why makers have a lack of motivation to create documentation. That means the category contains codes for problems caused by makers' internal thought processes. Examples for such problems are a *Lack of Project Complexity* and *Laziness*.

Code Landscaping Results As described in section 3.2.3 we decided to use *Code Landscaping* to get an overview of the four categories we found. Including all codes in one code landscape would have been too confusing because of the large number of codes. The code landscapes resulting from the codes in the categories *Documentation Processes*, *Motivations*, *External Problems of Documentation Processes*, and *Internal Problems of Documentation Processes* can be seen in figure 4.3, 4.4, 4.5, and 4.6 respectively. When evaluating code landscapes it is important to keep in mind that some topics and codes came up repeatedly because questions were covering these topics. The questions we used in user interviews can be found in section 3.2.1. Moreover, one participant could mention a topic multiple times. Thus, a code displayed bigger than others does not necessarily mean that the topic of the code was mentioned by many participants.

We used code landscaping to get an overview of codes used, but code landscaping has limitations.

In general, the results from code landscaping indicate the importance of topics. The details of what interviewees said about each topic and the implications of these results can be found in section 4.2. Code Landscapes were generated using a online tool for generating wordclouds (Wor).

More detailed information about each topic is presented in section 4.2.

Figure 4.3: Code Landscape - Documentation Processes

The code landscape about the *Documentation Processes* (figure 4.3) shows that the codes *Formats*, *Tools*, *Complementing Documentation of Others* and *Documentation of Errors* were used often. This can be explained by the fact that our interview included questions about these topics. Thus, interviewees discussed these topics. Moreover, the code *Necessary Files as Form of Documentation* often appeared although we did not ask about necessary files as a form of documenta-

Necessary files as form of documentation seem to be especially relevant to interviewees.

tion specifically. This indicates that the topic of files as a form of documentation was relevant to interviewees.

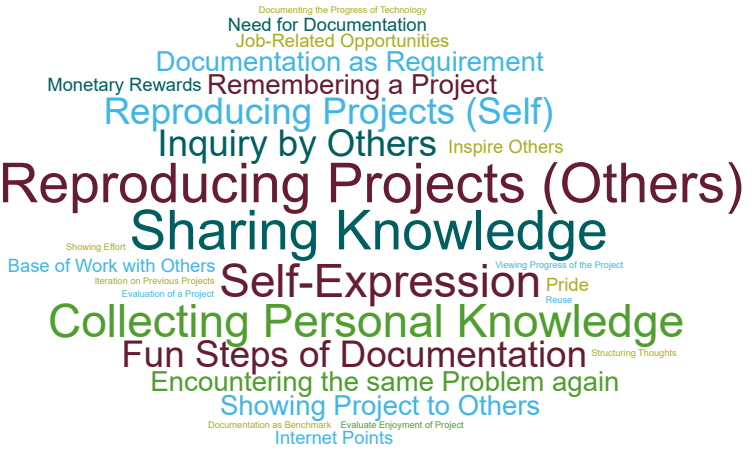

Figure 4.4: Code Landscape - Motivations

The motivations of *Reproducing Projects*, *Sharing Knowledge*, *Inquiry by Others* and *Collecting Personal Knowledge* could be especially important to makers.

The code landscape about the *Motivations* of interviewees shows that the motivations of *Reproducing Projects (Others)* (this code means enabling others reproduce projects), *Reproducing Projects (Self)* (this code means that the maker enables him- or herself to reproduce projects), *Sharing Knowledge*, *Inquiry by Others* (this means that someone asks for documentation of a project) and *Collecting Personal Knowledge* were mentioned by interviewees more often than other motivations. The motivations of *Self-Expression* and *Fun Steps of Documentation* appear big in the word cloud because they were covered by interview questions. These results indicate that personal motivations to create documentation like *Collecting Personal Knowledge* as well as altruistic motivations like *Sharing Knowledge* are relevant to makers.

The external problems *Time*, *Reach*, *Publishing*, *Workflow Interruption* and *Format Text* could be especially important to makers.

The code landscape about the *External Problems of Documentation Processes* (figure 4.5) shows that the problems *Workflow Interruption*, *Time*, *Publishing*, *Format Text* and *Reach* were mentioned most often. As our interview questions included a question about publishing documentation the frequency of this code could be influenced by this. The codes that appear bigger in this code landscape could be more relevant external problems of documentation processes.

Figure 4.5: Code Landscape - External Problems of Documentation Processes

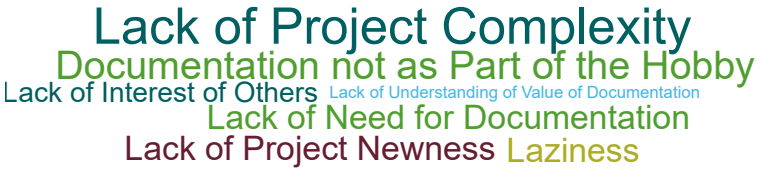

Figure 4.6: Code Landscape - Internal Problems of Documentation Processes

Interviewees seemed to perceive their projects as problematic in some way.

The code landscape about the *Internal Problems of Documentation Processes* (figure 4.6) shows that there are multiple internal problems of documentation processes that were mentioned by interviewees. These problems included multiple problems where interviewees perceived their project as problematic in some way. For example, they perceived a lack of project complexity, newness or interest by others. In section 4.2.5 we discuss the implications of these perceived problems of projects. Moreover, multiple makers mentioned that documentation was not part of the hobby digital fabrication or that they were to lazy to create documentation. We discuss the implications of these problems in section 4.2.5.

4.2.2 Documentation Processes

11 out of 12 interviewees documented a digital fabrication project previously.

11 out of 12 users documented a digital fabrication project previously and the last user was planning on doing so soon. One user mentioned that he wished he would document more. The following paragraphs describe further details of documentation processes of digital fabrication projects.

When makers are not required to create documentation they often decide whether it is worth it to create documentation based on project complexity and newness.

Decision to Document a Project - Results Except for one user, who had only created one digital fabrication project previously, no user documented all of his previous projects. The purpose and context of a project is a deciding factor on whether interviewees document projects. 8 out of 12 users were required to create documentation for their job, a university course or a competition they participated in. When users create private digital fabrication projects, they mainly decided which projects they document based on project complexity. They felt that it is not worth creating documentation when a project is not complex enough. One interviewee said that his project was one of many similar projects and if he uploaded the project somewhere, nobody would be interested in it and his effort would be in vain. Five interviewees stated that they document their projects if someone interested in the project asks them to do so.

User needs might vary depending on whether makers want to or have to create documentation.

Decision to Document a Project - Evaluation Except for one interviewee, no participant documented all of his projects. Some interviewees were required to create documentation for their job or education. This means a situation may arise where a maker would not create documentation if he had the choice, but is required to do so. Therefore, the same maker can be motivated to create documentation sometimes and only required to do so other times. This means any tools or systems for documentation should cater to both needs, the needs of a maker who is motivated to create documentation and the needs of a maker who has to create documentation without being motivated to do so. The exact needs of both groups will be discussed further in the context of section 4.2.

Reasons to document a specific project correlate with *Internal Problems of Documentation Processes* and will be discussed in further detail in the respective paragraphs of section 4.2.5. These reasons include project complexity, interest of others and the perceived need for documentation. Different *Motivations* (see section 4.2.3) also influence the decision to documentation a specific project.

The desicion to documentat a project is influenced by different motivations and considerations like project complexity.

Formats - Results We asked users in what format they create their documentation, i.e. text, videos or other formats. 11 of 12 interviewees reported having used text or intending to use text as a format to create documentation. 10 out of 12 interviewees reported having used pictures or intending to use pictures as a format to create documentation. One user also recorded videos as a means of documentation in addition to text and pictures. Some other users recorded videos of their finished products but did not consider them to be part of the documentation, because these videos do not show the process of creating their project. Another user complemented text and pictures with a time-lapse recording but reported that the use of time-lapse videos is situational because they can not be applied in most situations. Time-lapse videos were more suited in situations where a machine carried out a homogeneous task than in situations where a lot of different tasks were executed. A further user created a mind map in which embedded all of his documentations.

Almost all participants used text or pictures as a format for documentation. Only one user considered a video to be part of his documentation.

10 out of 12 users also document by archiving or sharing code and files that they produce for their project as part of their documentation. This includes code for microcontrollers, communication protocols, CAD files for 3D printing, SVG files for laser-cutting or circuit diagrams. One user said that those files are sufficient as documentation for most projects and no textual instruction is necessary. However, this user exclusively shared documentation with friends and acquaintances who asked him to do so. Most interviewees used files and code in combination with other formats.

Participants used files like code, CAD files or SVG files as means of documentation.

Platforms and tools should support different formats including files to cater to user needs.

Formats - Evaluation Some implications of the use of different formats, e.g. the need to cater to users with different preferences, were discussed in section 4.1. In contrast to the results from the investigation of online documentation, interviewees also used code and files which they produced for their projects as a form of documentation. This poses the questions whether popular platforms where documentation is published do not allow to include such formats sufficiently and if so, how platforms can improve on such functionality. We discuss other problems related to formats in further detail in section 4.2.4.

The most used tools of the participants were text editors and smartphone cameras.

Tools - Results We asked users whether they use any kind of tool for documentation purposes. Users who used text as a format for documentation reported using text editors on their computers or laptops to write text. The user who created and documented a single project previously used a physical notebook instead. This user did not publish his documentation. Interviewees used smartphones or photo cameras to take pictures and record videos and one user edited photos with Adobe Photoshop. Two users created diagrams with a pen and paper. The user who used a mind map as a format used a special tool for creating mind maps, but could not remember the name of the software. He also embedded a wiki into his mind map, used a personal server and used a tool for photo management. He said, that he could not find a single tool, that fits all of his needs and that he uses a combination of tools for this reason.

Interviewees used additional tools for publishing documentation.

Interviewees who published or shared their documentation used additional tools. One user reported publishing his findings on a blog, which was based on the version control software *Git*. Two other interviewees also used *Git* to share documentation. Platforms that are used for publishing documentation could also be considered tools, but they are further discussed in the paragraph about *Publishing and Storing Documentation* in section 4.2.2.

Tools - Evaluation One user mentioned that he could not find a tool that fits all of his needs for documentation. No user mentioned using tools tailored for documentation. This shows that makers are either unaware of tools tailored for the creation of documentation, or that there are no such tools that fit user needs sufficiently. In section 4.2.4 we describe which external problems of documentation processes users reported, including problems related to tools. This indicates that developing suitable tools tailored for documentation offers a research opportunity because users seem to be unable to overcome all external problems of documentation processes with suitable tools. Moreover, users use different tools for creating and publishing documentation. This poses the question of whether a tool that embeds both tasks could be useful for users.

Developing tools better suited for creating documentation offers a research opportunity.

Publishing and Storing Documentation - Results 8 out of 12 participants have published documentation previously. Six participants were required to publish documentation on websites for projects they participated in. Three participants also published documentation on Instructables, Thingiverse or YouTube. One participant shared documentation on his blog and Instagram. Another participant published documentation on his website. Documentation on a project of a different participant was published in a magazine, but he did not write the documentation himself.

8 out of 12 participants published documentation previously.

10 out of 12 interviewees participants did not mention storing their documentation somewhere else, except the platform they publish their documentation on. A single interviewee mentioned that he saved a folder with documentation of his projects on his computer. One participant stored his documentation in a physical notebook.

Most participants do not physically store documentation.

Publishing and Storing Documentation - Evaluation 8 out of 12 participants have published documentation previously. Thus, someone who develops a tool or system for documentation purposes should also consider that a share of users will want to publish their documentation. Interviewees published their documentation on different websites and apps. As there does not seem to be a platform consid-

Devloping platforms better suited for publishing documentation offers a research opportunity.

ered to be superior to other platforms, platforms can likely be improved or a new platform combining the advantages of other platforms could be built. For example, in section 4.2.4 we describe how a user liked to publish his documentation piecewise on his blog. However, he feared that he could not reach enough readers on his blog. In contrast, he could reach more readers on Instructables, because the website had more regular visitors. Though, Instructables does not allow to publish documentation piece by piece. A platform that combined both benefits would improve on the process of publishing documentation for this user.

Platforms for publishing documentation should also offer functionalities for personal use.

Most participants did not store their documentation somewhere else than the platform they published it on. This indicates that those interviewees put more emphasize on sharing documentation than on using documentation for personal use or that they do both by publishing documentation. Again, this shows the importance of the process of publishing documentation in the context of creating documentation. In section 4.2.3 users also mentioned personal benefits of documentation, e.g. *Enabling Self to Reproduce a Project* or *Collecting Personal Knowledge*. In combination with the fact that few users store their documentation except for the platform they publish their documentation on, this indicates that users also want to realize these personal benefits through the use of platforms for publishing documentation. Thus, these platforms should offer according functionalities.

Seven participants interacted with documentation of someone else in some way.

Complementing Documentation of Others - Results As describes in section 4.1 most platforms for sharing documentation offered a way to interact with documentations of others. For example, they provided a comment section. Participants were asked whether they consider the option to complement the documentation of others in some way. A total of seven participants improved on documentation of others in some way or used the information from these documentations for their documentation. Three of those participants used information from other documentations but decided to publish their related work separately. Reasons why participants opted for republishing documentation, included that the information might be irrelevant to

the initial project. A participant gave a reason for this with the fact, that he only uses small chunks of information from others. He gave the example of using the suspension of a car for a soapbox. Two of the participants who republished documentation mentioned that they referenced the original, e.g. with a link. One participant reported that he did not refer to the original documentation, because there was no convenient way to reference the original.

The four participants who complemented documentations of others without republishing it used different ways to improve on existing documentation. They respectively chose to update a *Git* repository, engage in forum discussions, send a message with suggestions for improvement to the initial author of the documentation and function as a proofreader for a book. One of the users who had not previously considered complementing documentation of others stated that he liked the idea.

Interaction methods include using version control software, forum discussions, private messages and proofreading.

Complementing Documentation of Others - Evaluation
The fact that 3 out of 12 users used documentation of others and chose to publish their related documentation separately indicates that these interviewees were not aware of a convenient way of complementing documentation. Four participants tried to complement on documentations of others without publishing a new documentation. All of those four participants used different methods to complement on documentation of others. This indicates that there is no consensus on how to interact with documentations of others. Moreover, one participant did not come up with the idea of interacting with documentations of others but liked the idea after being asked whether he considered it previously. This leads to the conclusion, that the ways of interacting with documentations of others are unoptimized and people are not aware of existing possibilities to interact with documentation. Thus, improving on possibilities to interact with documentation and embedding better ways of interactions in existing platforms for publishing documentation offers a research opportunity.

The ways of interacting with documentation of others are unoptimized.

All users who created documentation previously stated that they described errors they made during the fabrication process.

Documentation of Errors - Results The results from 4.1 showed, that some documentations included information on mistakes and errors that the authors made during fabrication or considered likely. Thus, we asked interviewees how making an error during the fabrication process would influence their documentation. All users who have created documentation previously stated, that they describe errors to help others prevent those. One user said that it was difficult to document errors because he would fix them before he started to write documentation. One user mentioned, that not all errors are relevant and have to be documented. He user gave the example of a malfunctioning laser cutter. He said he could not find out why the laser cuter malfunctioned and that mentioning such problems would rather confuse readers than help them.

Including errors in documentation offers an opportunity for self-expression.

Documentation of Errors - Evaluation One user mentioned that he forgot to document errors because he fixed them before starting to create documentation. This problem is related to *Workflow Interruption* (see section 4.2.4). In general, users were motivated by the prospect of helping others to avoid errors as described in section 4.2.3. Moreover, some users reported that they handle errors in their documentation humorously. This offers an opportunity of self-expression which is a motivating factor for some interviewees as described in section 4.2.3.

Making errors during fabrication could conflict with the wish of being proud of a project.

However, as described in section 4.2.3, some interviewees were motivated by being proud of their project. In some situations making an error during the fabrication process can not be undone and the project has a defect as a consequence. Although no interviewee reported on this phenomenon, it is thinkable that an error resulting in a defect of the project can discourage users from making documentation.

A participant purposefully directed his documentation at advanced learners with previous

Adjusting the Level of Detail - Results One of the participants talked about the style he chooses for his documentation in detail. The first choice in his style was to not include too basic information for complex projects because these projects were not suitable for beginners and it took

too much time to include all information. He mentioned using a molding cutter as an example for a simple task which he would not describe in detail. Moreover, this basic information distracted from more important aspects. Therefore, he required basic knowledge for the documentation he creates for more complex projects. The existence of his previous documentation influenced how he wrote documentation. An example of this is how he wrote that he soldered something in his usual manner in one of his documentations. He said he hoped that his readers would figure out what that means.

knowledge.

Adjusting the Level of Detail - Evaluation A participant adjusted the level of detail for his documentation depending on the skill level that he assumed possible readers have. He stated that he hoped that readers knew his previous documentations. This indicates that he is uncertain about the level of detail he should include. This problem could be solved, if he knew exactly which skill level readers of his documentation have. This could either be realized by finding ways to enable users to address a group of readers that have a certain skill level or by finding a feedback mechanism that helps users to see what skill level readers of their documentations have. Such methods could also be helpful for other authors of documentation than this user because the results from section 4.1 indicated that authors were unsure which details they should include.

Finding possibilities to address readers of a certain skill level or getting information on readers skill level could improve documentation processes.

Iteration of Documentation - Results Four users mentioned that they do not create their documentation in one piece. Instead, they stated that they iterate on their documentation. Three users considered the version-control software *Git* to be a suitable tool to make iteration on documentation possible. One of them published his documentation on a blog and Instagram. He stated that posting on a blog and Instagram had the advantages that he did not have to write the documentation of a big project in one sitting. Moreover, he said that it was important to post a lot of small updates to entertain readers for an extended duration of time. A further interviewee talked about iterations of files he produced for his project. As he used these files

Four users iterated on their documentation.

as a form of documentation, he iterated on his documentation by iterating on the files. He saved different variations of these files. Finally, one user said that he feels like his project is never finished.

Version control is a relevant feature for tools for creating documentation.

Iteration of Documentation - Evaluation 4 out of 12 users mentioned that they do not finish their documentation in one sitting, but iterate on their documentation. Users who iterated on their documentation used *Git* or saved multiple versions of files. This indicates, that these users value the possibility to be able to go back to older versions of their documentations. Hence, systems and tools for documentation should integrate adequate version control. This would also help users who feel like there project is never finished to create documentation, because they could start creating documentation while their project is incomplete.

4.2.3 Motivations

In this section, we describe why the interviewed makers decided to create documentations. In the following paragraphs, we present the results related to motivation and evaluate them.

In this section, we describe and evaluate motivations for documentation.

Sharing Knowledge with Others - Results 10 out of 12 participants stated that they think their documentation can be used as a means to share knowledge with others and that others could profit from their documentation. This included gaining information that helps to fabricate something as well as information that helps to avoid errors. One of those participants acknowledged that he did not publish any of his documentations, although he could see the advantages for others.

10 out of 12 participants thought that they can share knowledge with others through their documentation.

How much of a motivation sharing knowledge with others was varied from participant to participant. One interviewee gave a class in the past and said the biggest motivation for him was the knowledge that the attendees who visited this class needed the documentation to make something. In contrast, a different interviewee stated that reading his documentation might help someone to avoid doing the same errors, but he doubted that anyone would find his documentation.

How much of a motivation sharing knowledge was varied between interviewees.

Four participants mentioned that they are more motivated to create documentation when they are asked to do so by someone. Two participants mentioned that they also want to inspire others with their documentation.

Inquiry by someone else can be a motivation.

Sharing Knowledge with Others - Evaluation 10 out of 12 participants thought that sharing knowledge with others through their documentation is possible. The participant who put the biggest emphasis on the motivated gained by sharing knowledge with others was the participant who gave a class where participants used his documentation. Participants who were unsure whether someone would read their documentation seemed to be motivated less by

Researching opportunities to assess the interest in documentation of a project could motivate makers to create relevant documentation.

the thought of sharing knowledge with others through documentation. Four participants said that they would create documentation for a project if someone inquired them to do so. Thus, it is likely that makers who know that someone will read and profit from reading their documentation are more likely to create and publish documentation. In section 4.2.5 we describe how makers feel that there is a lack of interest and a lack of need for their documentation. If makers could gain information on whether someone is interested in their project and the documentation of their project, they could make an informed decision on whether they want to create and publish documentation. The results from section 4.2.5 indicate that few makers currently use feedback mechanisms to estimate the interest in their projects. Only two makers mentioned that they assessed interest in their project by showing their projects to friends. However, participants can hardly assess broader interest in their project if they do not showcase their project online. A single participant mentioned that he showcased some of his projects in YouTube videos. Other participants did not mention showcasing their documentation in another way than through documentation. Thus, researching possibilities to assess the interest of a broader audience in projects could help to motivate makers to create more and more relevant documentation. Creating more relevant documentation through the use of a feedback mechanism could lead to a positive feedback loop because makers could be more likely to be pleased with publishing their documentation if their motivations like sharing knowledge or enabling others to reproduce their project become a reality. Thus, they are more likely to create documentation for interested readers again.

Interviewees were motivated by the ability to enable others to reproduce their projects.

Enabling Others to Reproduce a Project - Results Seven participants stated that their documentation could help others to reproduce their projects. Most participants mentioned enabling others to reproduce their project in connection with sharing knowledge. However, two participants mentioned sharing knowledge as a motivation, but not enabling others to reproduce a project. On the other hand, there was an interviewee who wanted to enable others to reproduce his projects by providing the necessary files, but

he did not mention that he wanted to share knowledge with them.

Enabling Others to Reproduce a Project - Results The motivation of enabling others to reproduce a project acts similarly as the motivation of sharing knowledge with others. These motivations are stronger if there is interest in the project and the resulting documentation. Thus, the results of this paragraph support the conclusion from the paragraph about the motivation of sharing knowledge with others in section 4.2.3.

The results support the conclusion from the paragraph about *Sharing Knowledge*.

Collecting Personal Knowledge - Results Five participants mentioned collecting their personal knowledge as a motivational factor. That means each of them wanted to use documentation as a collection of his own knowledge. Three participants stated that having documentation helps them when they want to do a similar project again. For example, a participant had to do intense research to solve a problem. He recorded the information he found to avoid looking for them again in the future. Two participants stated that writing documentation helps them to learn.

Five participants wanted to create documentation to collect their personal knowledge.

Collecting Personal Knowledge - Evaluation Five participants were motivated by the idea of collecting their personal knowledge, but as described in section 4.2.2 only two participants mentioned storing their documentation anywhere but on the website where they published the documentation. This indicates that interviewees used platforms for publishing documentation as a way to store documentations as their personal collection of knowledge. This can be explained by the fact that it is likely easier and less time-consuming to use platforms for publishing documentation for personal use, too. Thus, it could be useful for makers if platforms for publishing documentation supported and integrated other features for personal use to bundle functionality. Moreover, if such features attracted makers who would otherwise not publish their documentation, but store it for personal use only, possible readers gain the benefit of more available documentation.

Platforms for publishing documentation could attract makers who were not interested in publishing documentation previously through features for personal use.

Five participants said that documentation could be useful for reproducing or changing a project in the future.

Enable Self to Reproduce a Project - Results Five participants stated that they find documentation helpful for reproducing a project. One of them said that documentation is also helpful if he wants to change something in an existing project. Besides, two participants mentioned that documentation helps them to reuse parts of previous projects for new projects.

Features that help makers to reproduce projects could be a motivation.

Enable Self to Reproduce a Project - Evaluation The ability to reproduce a project or parts of a project based on documentation was considered helpful by interviewees. Tools and systems for creating or publishing documentation should offer features related to this need.

Encountering the same problem again inspired participants to create more documentation.

Encountering the same problem again - Results The anticipation of encountering the same problem again motivated participants to collect their knowledge as described in the paragraph above. Two participants also encountered a problem twice. This inspired them to create more documentation in the future. Another participant stated that if he did not face the problem he was not motivated to find a solution to the problem. He said that encountering a problem for a second time motivated him to create documentation. A different participant said that documentation might be useful for him when dealing with electrical engineering in the context of digital fabrication. However, he emphasized that this problem rather occurs because of his lack of understanding of electrical engineering than because of a lack of documentation.

Makers could be motivated to create documentation by finding ways to identify problems that will likely occur again.

Encountering the same problem again - Evaluation Interviewees stated that they would likely create more documentation if they encountered a problem that they had solved before again. This indicates that they would also create more documentation if they could identify problems that are likely to occur again. Thus, researching ways to identify problems that are likely to occur again could help makers to identify situations where documentation could be useful. A participant attributed encountering the same

problem again to the lack of expertise in a concrete field of knowledge. This indicates that researching methods to enable makers to solve reoccurring problems caused by a lack of expertise in a field of knowledge in a more efficient way could facilitate the fabrication process for makers.

Reviewing a Project - Results Five participants said that they like to review their projects through documentation. The first participant who was in the process of fabricating a guitar said that he wanted to have some kind of history of how he created that project. The second participant mentioned that he liked to look back at projects after a few years to see how the way makers fabricate changed. He gave the example of using a code library instead of programming from scratch. The third participant said that he likes to retrace the fabrication process, but he also looks for things he would do differently in the future. The fourth participant said that he enjoys seeing the progress of a project. He gave the example of seeing how a block of wood turns into a finished project. The fifth participant said that he uses documentation to evaluate his enjoyment of projects to decide what he wants to work on in the future.

Five participants were motivated by the possibility to review their project through documentation in the future.

Reviewing a Project - Evaluation Interviewees saw different benefits in reviewing documentation of their projects. As described in the paragraph about collecting personal knowledge in section 4.2.3, it could be useful for makers if platforms for publishing documentation offered functionalities offer personal benefits to the authors of documentation. This could include features that make reviewing a project better in some way.

Platform that included features to review projects would benefit some makers.

Showing a project to Others - Results Five participants mentioned that they like to use documentation as a means to show their projects to someone else and as a means to talk about their projects. Three of them emphasized that they especially like to do that when they are proud of their project. One of them said that he wants others to be able to recreate his projects so that they can understand what

Five participants were motivated by the thought of showing their project to others through documentation.

enthuses him about his projects. A further interviewee said that he likes to use documentation as a means of showing how much effort goes into a project.

Makers could be more motivated to create documentation if they could reach many readers efficiently.

Showing a project to Others - Evaluation Participants were motivated by the thought of showing their projects to others through documentation. Thus, enhancing opportunities to display documentation to as many interested readers as possible will likely increase the motivation of makers to create documentation.

Three interviewees wanted to express their personality through documentation.

Self-Expression - Results The results from section 4.1 indicate that some makers use documentation as a means of self-expression. One interviewee said that he actively uses documentation as a means of self-expression. He embeds emoticons and jokes in his documentation. Moreover, he provides information unrelated to the project itself in his documentation. Another user said that he does not aim to use documentation as a form of self-expression, but he still shows his personality in his documentation. For instance, he tries to make his documentation entertaining. He and one other interviewee used a humorous style to describe errors and mistakes. The remaining nine interviewees were not interested in expressing their personality through documentation.

Platforms for publishing documentation should implement social features to cater to the motivation of self-expression.

Self-Expression - Evaluation Some interviewees used documentation as a means of self-expression. Self-expression is a form of social interaction and because of that platforms for publishing documentation should encourage social interaction to cater to the need for self-expression. Thus, platforms should allow users to interact, give feedback and engage in discussions. Popular features used in social media, for example likes and subscriptions to a content creator, could be adjusted for the use on platforms for publishing documentation. This could improve on user activity and makers who want to express their personality through documentation could be motivated to create more documentation. Moreover, social features could also encourage interaction with documentations of others.

Documentation as a Requirement - Results Although only one of the interviewees was occupied in a field related to digital fabrication, eighth interviewees were required to create documentation in some way. Five interviewees participated in the FabAcademy, a course on "How to make almost anything" (Fab), and had to create documentation for this course. One of them also had to write and publish documentation on the websites Instructables and Hackaday for a side job he had. Two participants were occupied with a final thesis related to digital fabrication and had to produce documentation to write their respective thesis. A further interviewee had to write documentation for a practical course that was required for enrolment in his field of study. He also participated in a contest called "Jugend forscht" where he had to create documentation.

Eight interviewees were required to create documentation.

Documentation as a Requirement - Evaluation In the paragraph about the decision to document a specific project in section 4.2.2 we already discussed some of the implications that having to document a project as a requirement for business or education has. Some makers might not want to create documentation but have to. Thus, they could have other priorities than users who create documentation with a different aim. In section 4.2.4 we discuss internal and external problems of documentation processes. Some of these problems apply to a greater extent to makers who are required to create documentation. For example, makers who were required to create documentation mentioned problems related to the themes *Laziness*, *Workflow Interruption*, and *Documentation is not Part of the Hobby*. Hence, solving the problems that makers who have to create documentation are more likely to have could improve the efficiency of documentation processes in business or teaching institutions. In section 4.2.4 we discuss the implications of each problem in further detail.

Makers who are required to create documentation might have different needs than other users.

Being Proud - Results Three participants stated that they are motivated to create documentation when they are proud of the project they created. Two participants stated that they liked the feeling of being proud of their documentation and of being able to help others with their documen-

Five participants were motivated by pride of their project or documentation.

tation.

Fostering pride could motivate more makers to create documentation.

Being Proud - Evaluation The results about being proud show that the interviewees were more motivated to create documentation if they were proud of their project or documentation. Thus, the question of what helps makers to be proud of their projects and documentations arises because proud makers could more likely to create documentation.

Three participants enjoyed steps of documentation processes.

Fun Parts of Documentation - Results Participants were asked whether they liked anything about the process of creating documentation. Two participants stated that they like to take pictures of their projects. One of them emphasized that he enjoys using pictures as a format. A further participant said that he enjoys making technical drawings because he also uses them during his studies at university.

Documentation can be part of a hobby. Automating all aspects of documentation could lead to frustration of makers who see documentation as their hobby.

Fun Parts of Documentation - Results Some parts of documentation processes can be fun for makers, and they might see it as part of their hobby. Thus, it could negatively affect the experience of creating documentation for makers if a system or tool removed the respective fun aspects of documentation. Which aspects of documentation are considered fun will depend on the personal preferences of each maker. Adaptability to those individual preferences should be a design principle when designing tools or systems for creating documentation.

A need for documentation can be a motivation.

Need for Documentation - Results One participant said that he likes to create documentation for projects that he would look for himself or that he would enjoy.

The results support the conclusion from the paragraph about *Sharing Knowledge*.

Need for Documentation - Evaluation The motivation of wanting to fulfill the need for documentation acts similarly as the motivation of sharing knowledge with others. These motivations are stronger if there is interest in the project and the resulting documentation. Thus, the results

of this paragraph support the conclusion from the paragraph about the motivation of sharing knowledge with others in section 4.2.3.

Two participants used documentation as a base for work with others.

Base of Work with Others - Results Two participants mentioned that documentation is important as a base of work with others. One of them was in the process of starting a start-up and wanted everyone involved in the process of creating the product to have a common base. The other participant used documentation as a base for a project where multiple people were involved. He also said that he liked to help others by documenting their projects. Moreover, he worked on a different project which he left before it was finished. He said that documentation helps those who finish the project now to proceed.

Looking into creation an publication of documentation of a group could be a research opportunity.

Base of Work with Others - Evaluation The results about documentation as a base of work with others show that some makers want to use or create documentation together with others. Because of that tools and systems for creating documentation should allow working on documentations together. Moreover, collective authorship of documentations could be important to makers who want to publish documentations that they created as a group.

Four participants would be motivated to create more documentation by a monetary reward.

Money and Job-Related Opportunities - Results Four participants said that a monetary reward would motivate them to create documentation. One of them said that a further possible motivation to create more documentation was being allowed more slots in the makerspace he visited because renting time at machines somewhere else was expensive. This participant also mentioned that he knows people who try to gain attention from possible employers by publishing documentation. However, he stated that he was not interested in attracting employers, because he already had an occupation. This participant also mentioned that some kind of virtual points could function as a motivation to create documentation, but he would not be motivated by such points. A further participant mentioned that he would enjoy the possibility of a job where he would teach with the

help of his documentation, but his primary goal was learning. A further participant gave courses related to digital fabrication and used his documentation as a reference for his knowledge.

The integration of features that support the use of documentation as reference for employers could be relevant to some makers.

Money and Job-Related Opportunities - Evaluation The results about money and job-related opportunities show that some makers would be motivated to create more documentation by monetary rewards. The results also show that non-monetary rewards can be a motivation. However, which rewards motivate each individual maker will vary. The results of this paragraph also show that documentation can be used as a reference for possible future jobs. Thus, offering possibilities to organize documentation in a way that it is presentable as a reference could be appealing to makers. Moreover, linking platforms for job-search with platforms for creating documentation could offer a benefit for makers who are interested in job-related opportunities.

Two participants saw documentation as an opportunity for improvement.

Opportunity for Improvement - Results One participant stated that creating documentation helps him to organize his thoughts. He said that documentation fosters a structured procedure. A further participant said that he uses documentation as a benchmark for his future projects.

Features related to documentation as opportunity for improvement could be relevant to some makers.

Opportunity for Improvement - Evaluation The results about documentation as an opportunity for improvement show that some makers use documentation as an aid for their projects by organizing their thoughts or by using documentation of previous projects as a benchmark. Supporting these tasks could be beneficial for makers who use documentation in this way.

Feedback - Results The results from section 4.1 showed that multiple platforms allow giving feedback, e.g. in the form of comments. Participants were asked whether they are motivated by the perspective to get feedback. Nine participants stated that feedback on their projects is important to them. Three participants said that feedback based on their published documentation is relevant to them.

Three participants were motivated by the chance of receiving feedback based on their documentation.

Feedback - Evaluation 3 out of 9 participants who said that feedback was important to them also said that feedback based on their published documentation was relevant to them. These results suggest that a part of makers who are interested in feedback about their project might not see feedback based on published documentation as a relevant source of feedback. As described in section 4.2.4 makers stated that they feel like nobody would read their comments to documentation. This indicates that the ways how others can interact and give feedback are unsatisfactory. This could include problems related to *Reach* as described in section 4.2.4.

Improving feedback mechanisms for online documentation could offer a research opportunity to make feedback more relevant.

4.2.4 External Problems of Documentation Processes

In this section we describe external problems of documentation processes.

In this section, we describe external problems of documentation processes. That means we describe problems related to outside influences like tools or the publication process, but that are not related to internal thought processes of makers. In the following paragraphs, we elaborate on the different external problems of documentation processes.

Half of the participants had problems using text as a format.

Format Text - Results Six participants reported that they had problems when writing text for documentations. Four participants said that they dislike or struggle to express themselves via text. Two participants stated that they dislike writing long texts. One participant said that it was difficult for him to write a coherent text when working on the documentation of a project for a long time. A further participant stated that his lack of experience in writing documentation was a problem.

We also discuss format text during the investigation of online documentation.

Format Text - Evaluation The results about formats in section 4.2.2 show that a large share of interviewees chose to use text as a format. In section 4.1 we discussed implications of the results about formats from the investigation of online documentation in combination with some findings of the user interview study.

Improving the process of creating text could improve documentation processes.

The results about the format text, in particular, showed that 6 out of 12 interviewees reported problems related to producing text. This poses the question of why makers chose the format text although they have problems related to the format. The first possibility is that makers think that text is the best format for writing documentation. In that case, researching solutions for the problems related to the format text mentioned in the paragraph above could improve documentation processes for makers. In section 4.1 we discuss a possible solution suggested by a participant.

Support of more formats could

A different answer to why makers chose text as a format could be that they think that other formats are not sup-

ported well. In section 4.1 we found that the 28 documentation we looked at all used text as format. This could indicate that platforms put a focus on supporting documentation in text format. Offering more or better features related to other formats could enable makers to use other formats. A third answer to why makers use text as a format could be that they are unaware that other formats can be suitable for documentation or could fit their needs better. This poses the question of how makers can be made aware of other possibilities better. Again, better support of other formats on platforms for publishing documentation could be one of the solutions for this problem.

improve documentation processes.

Format Pictures - Results As described in the paragraph *Workflow Interruption* in section 4.2.4 taking photos can interrupt the workflow of a fabrication project. Two participants also mentioned that the production of graphs, drawings and schemas can be difficult. One of those participants said that capturing the idea in his mind visually was difficult.

Producing graphs, drawings, and schemas was difficult for some participants.

Format Pictures - Evaluation The conclusions of the evaluation of *Format Text* in section 4.2.4 partially also apply to the format pictures. That means improving tools that support the format pictures, but also offering functionalities to work with other formats, could improve documentation processes for makers. The implications of the workflow interruption through taking photos are discussed in the paragraph *Workflow Interruption* in section 4.2.4.

Improving the process of creating pictures could improve documentation processes.

Time - Results Two participants stated that creating documentation takes too much time. One of them said that he would create more documentation if he had enough time. Two other participants stated that documentation in video format is too time-consuming and they chose other formats because of that.

Four participants said that documentation or documentation in a certain format was too time-consuming.

Creating documentation should be less time-consuming or more beneficial to be more appealing.

Time - Evaluation Because each individual has a restricted amount of time they try to spend this time most efficiently. When participants say that documentation is too time-consuming then they mean that the benefit they or others gain by creating documentation is too small compared to the amount of time required. There are two solutions to this problem. The first solution is to reduce the amount of time required for creating documentation to make the task more worthwhile. This can be realized in several ways. An example to reduce the time required is automation. The other solution is to increase the benefit of creating documentation to make it more worthwhile to spend time creating documentation. In section 4.2.3 we discuss benefits of creating documentation. This gives an idea of how the benefits of documentation can be increased. In section 4.2.5 we discuss some perceived problems of the benefits of documentation. This also leads to possible opportunities for improvement of documentation processes and its benefits.

Seven participants had problems related to publishing documentation.

Publishing - Results Seven participants reported some problems related to publishing documentation online. The first participant stated that it was difficult to reach an interested reader-base currently, and he was unaware of a suitable platform that facilitates reaching interested readers. In the paragraph *Reach* in section 4.2.4 we discuss this problem in further detail. This participant and another participant stated that they were turned away from platforms because they did not want to put in the effort of registering there. The same participant said that he was feeling uneasy when publishing documentation based on documentation from someone else because there was no easy way to credit the original creator. He said that he wished for options to credit someone on a platform for publishing documentation. A further participant said that he did not want to deal with copyright issues when using work from someone else in his documentation. This user and a further user stated that it requires additional effort to edit documentation in such a way that they felt comfortable publishing it online. One of them said that he could understand his documentation with fewer details than someone else, and he considered it to be difficult to find the right words to convey

his ideas. Moreover, he stated that one has to consider different skill levels when publishing documentation, and he considered it to be difficult to edit documentation in a way that is was understandable for beginners. The fifth participant said that he felt like his project was never finished. He and another participant also feared that their documentation would not be of sufficient quality to be published somewhere. A further participant feared that documentation in video format would not be of sufficient quality. A further participant said that his projects often exist in a narrow context. He stated that if he published his documentation somewhere, someone might try to adopt it in a different context. He said that this would likely lead to irritation of the reader because applying the documentation would result in a problem in a different situation than his own.

Publishing - Evaluation The results about publishing show that it requires additional effort to create documentation in a way that makers feel confident about publishing it online. First of all, makers feel like they have to put additional effort into ensuring the quality of their documentation. Interviewees emphasized the problem of adjusting a documentation they can understand to a documentation all readers can understand and use in the right context. Moreover, they have to deal with issues related to the process of publishing documentation. This includes the barrier of registering on a platform and dealing with possible copyright issues. Finding solutions to these problems offers a research opportunity that could facilitate the process of publishing documentation and thus motivating more makers to publish documentation.

Publishing documentation in addition to creating documentation requires additional effort and should be facilitated so that more makers are willing to publish documentation.

Reach - Results Two participants stated that they had problems publishing their documentation in a way that they could reach readers. One of them elaborated on possibilities to publish documentation further. He said that he published his documentation on a personal blog because he liked to publish documentation piecewise. However, he felt like his blog was cut from the outside world and there were no readers. Moreover, he said that it was difficult to identify whether it was worth posting on a forum because most

Two participants had problems with the reach of their published documentation.

forums seemed to be rather inactive. He also said that he liked to look for inspiration on Pinterest, but the platform was not suited well for publishing documentation. Furthermore, he mentioned that he updated his Instagram profile with the progress of his project, but he was afraid of annoying his followers. Moreover, he said that YouTube was probably suited well to publish documentation, but only in video format.

Researching and solving problems related to reach could motivate more makers to create documentation.

Reach - Evaluation The results about reach show that interviewees had problems to reach readers with their documentation. It seems to be difficult to find a platform that is active, supports the format the user wants to publish documentation in, supports all features relevant to the user and reaches an audience of interested readers. Further research could help to identify why makers can not reach interested readers and how this problem could be solved.

Keyword search in the context of digital fabrication is problematic.

The work of Torrey et al. (Torrey et al. [2009]) looks at this problems from the perspective of readers who search for knowledge. They found that users have problems to find content through keyword search "because the names of tools, materials, and techniques are flexible and are not known by novices". They found that some makers browsed specific online sources regularly. Thus, keyword search has to be improved or other methods to reach readers than keyword search should be applied to achieve better reach.

Three participants had problems with tools they used for documentation.

Tools - Results Three participants reported having some problems when using tools for documentation. The first participant stated that he wished he had a better camera to take better pictures. A further participant stated that problems occurred when working with wikis. It was difficult to update wiki entries because it was not possible via pull and push requests, but instead, he had to open an issue manually. The third participant reported that he had problems when working with software to create a necessary file for a laser cutting task. He said that it was difficult to position fine details.

Tools - Evaluation In section 4.2.2 we discuss what kind of tools makers used. The existence of external problems of documentation processes indicates that better tools could solve some problems of documentation processes because these problems are caused by outside influences. The fact that makers used a lot of different tools also poses the question of whether a tool that combines functionalities of other tools could improve documentation processes. Although no interviewee mentioned this, it is possible that makers chose tools that are less powerful than others because of the availability of tools. For example, some tools could not be available in all languages or could be too expensive.

Functionality and availability of tools could be improved to facilitate documentation processes.

Language Barrier - Results Three participants stated that creating documentation was difficult because of a language barrier. Two of them learned German as a foreign language but wanted to write documentation in German. The third participant wanted to write his documentation in English. Those participants stated that they had problems with vocabulary, grammar and the fact that they had to review their documentation for errors.

Three participants had problems because they chose to write documentation in a foreign language.

Language Barrier - Results The language a makers wants to write his documentation in can hinder documentation processes. Thus, further development of tools that aid users in creating content in a foreign language could improve the ability of makers to create documentation in a different language. The availability of such tools can also be an issue for makers as described in the paragraph about *Tools* in section 4.2.4. Moreover, problems related to *Reach* as described in section 4.2.4 can magnify the effects of problems with language barriers. If makers feel like they can not reach enough readers with documentation in their first language they might choose to create documentation in a different language because of that.

Researching methods to overcome language barriers of documentation processes could improve documentation processes.

Workflow Interruption - Results Five participants stated that documentation interrupts the workflow of creating a project. All of them mentioned the problem of taking photos during the actual fabrication process. They stated that

Five participants were troubled by interrupting their workflow for

documentation.

photos of the finished project did not capture the crafting process well. Two participants said that they often forgot to take enough photos. Furthermore, one of them added that is was distracting to think about what he had to write down and include in the documentation during the fabrication process.

Researching methods to integrate documentation processes in the fabrication process suitably could improve documentation processes.

Workflow Interruption - Evaluation Participants stated that creating documentation interrupts the workflow of creating a project. This poses the question of how creating documentation can be integrated into the fabrication process better or how documentation can be created after the fabrication process suitably. The participants who talked about the interruption of their workflow emphasized the problem of taking photos during the fabrication process. This poses the question of whether taking photos could be automated in some way or whether there is a way to take suitable photos after the fabrication process. Tseng et. al. developed a "photography turntable system for creating animated documentation" (Tseng [2015]) that aims to solve the problem of workflow interruption through taking photos.

Two participants said that comment sections were not well suited for interacting with documentation.

Complementing Documentation of Others - Results We asked interviewees whether they ever considered complementing documentation from someone else. Two interviewees stated that the way platforms offer comment functions as a way to interact with the documentation of others is unsatisfactory. Both felt like nobody would read their comments.

Improving possibilites to interact with documentation of others offers a research opportunity.

Complementing Documentation of Others - Evaluation As described in section 4.2.2 participants chose to interact with documentations of others in different ways. However, there does not seem to be an ideal way to interact with documentation. Platforms often offer the functionality to comment on the content of others as a way to interact with documentation. However, participants stated that the possibility to interact with documentation of others through comments is unsatisfactory because they felt like nobody

read the comments. As described in section 4.2.2 improving interaction possibilities for makers through documentation offers a research opportunity.

4.2.5 Internal Problems of Documentation Processes

In this section we describe internal problems of documentation processes.

In the following paragraphs, we describe internal problems of documentation processes. That means we elaborate on the reasons why participants lacked motivation to create documentation. These reasons are unrelated to the actual process of creating documentation, but rather deal with thought processes of makers and the outcomes of having created documentation.

Six participants stated that their projects were not complex enough to be worth documenting.

Lack of Project Complexity - Results Six participants mentioned that some or all of their projects are not worth documenting because they are not complex enough. More precisely, these participants stated that a lack of project complexity, size, difficulty or a too-small number of steps in the project were the reason why they did not consider these projects worth documenting.

Makers could benefit from tool that help them to identify which projects are complex enough to be worth documenting.

Lack of Project Complexity - Evaluation Participants said that not every project was worth documentation because of a lack of project complexity. However, the results from section 4.2.3 show that makers can not always know when they will encounter a problem again and when a project is not complex enough. Aids that help makers to identify which projects are so complex that they could benefit from documentation in the future could improve this situation. Apart from personal benefits, makers can also not be sure whether their project is complex enough to be of interest to others. The implications of this fact are discussed in the paragraph about a *Lack of Interest of Others* in section 4.2.5.

Three participants said there was no advantage in writing documentation.

Lack of Need for Documentation - Results Three participants stated that they did not see any need to write documentation. One of them said that it was difficult to understand code after writing it, but in contrast, it was easy to understand hardware. This participant also said that the fabrication process itself is boring compared to the finished

product. Another participant stated that it was easy to remember all the steps of his digital fabrication project. A further participant stated that it is difficult to understand why there is value in documentations.

Lack of Need for Documentation - Evaluation The results about a lack of need for documentation indicate that some makers do not perceive any benefits that result from documentation. However, every single participant mentioned at least one motivation from section 4.2.3 other than being required to create documentation. This likely means that these makers are aware that documentation can have benefits, but they think that those benefits are too small. Overall, the problems of documentation processes described in section 4.2.4 seem to outweigh the benefits described in section 4.2.3 to such an extent that some makers do not perceive any benefit at all. It could be possible that there are projects that are not worth documenting at all because there is no benefit to documenting these projects in particular. However, as described in the paragraph about a *Lack of Project Complexity* in section 4.2.5 it can be difficult to identify situations where documentation could lead to a personal benefit or the benefit of someone else. Thus, it could also be difficult to tell when there is a need for documentation. Hence, tools or systems that help users to identify such situations could be beneficial.

The benefits of documentation should be more visible and more relevant to enable makers to see when there is a need for documentation.

Lack of Interest of Others - Results Three participants directly stated that there is a lack of interest in their projects by others. One of them attributed this lack of interest in the size of his projects. The other two participants stated that available documentation was abundant and thus their efforts creating documentation would be for nothing. Other participants mentioned reasons related to the disinterest of others. An example of such a reason is the lack of project complexity.

Three participants stated that others were disinterested in their documentation.

Lack of Interest of Others - Evaluation Participants perceived a lack of interest of others in their documentation

Tools that could assess interest in

documentation could motivate makers to create relevant documentation.

or projects. Participants listed reasons like a lack of project complexity as evidence for the lack of interest in their documentation. However, they did not have any numerical evidence of a lack of interest in their projects. Some makers may create projects that would be interesting to an audience, but those makers assess their project as not interesting enough, not complex enough or they do not see any benefits in documenting their project. If there was a way to measure the interest of others in a project, makers could make more informed decisions on whether it is worth it to create documentation. We discuss this idea in further detail in the paragraph about *Sharing Knowledge with Others* in section 4.2.3.

Five participants stated that their projects were not new enough to be worth documenting.

Project is not New Enough - Results Five participants stated that their projects are not new enough to be worth documenting. The first said that he uses well-established processes for his digital fabrication projects and thus there is no need for documentation. A second interviewee said it is redundant to describe basic tasks like using a molding cutter because they have been described in sufficient detail before. Two participants mentioned that documentation for very similar projects already exists. One participant stated that he probably never built something that was not built before by someone else.

Better ways to interact with documentation of others could help makers to gain some benefits of documentation with less time-investment.

Project is not New Enough - Evaluation Participants stated that their projects have already been fabricated previously. They did not mention how they verified that documentation about identical projects already exists and this poses the question of how makers can effectively evaluate whether a project is new. Moreover, a project may be similar to a project with existing documentation without being the same. This poses the question of whether it is beneficial to document the different aspects of the new project. If there is a benefit in documenting variations of projects the question of how those should be documented arises. In the paragraph about *Complementing Documentation of Others* in section 4.2.2 we discussed the unsatisfactory possibilities to interact with documentations of others. The findings about a perceived lack of newness of projects underline that con-

clusion that better ways to interact with documentation of others could benefit makers. Moreover, possibilities to interact with existing documentation instead of creating completely new documentation could help makers to overcome *Laziness* (Section 4.2.5) and to save *Time* (see 4.2.4).

Three participants said that they were too lazy to write documentation.

Laziness - Results Three participants stated that laziness prevents them from writing more documentation. One of them described himself as a ”lazy and bad person” who does not write documentation. He said that he would like it if documentation did not require any work. Moreover, two participants said that they would like to share more documentation online if documentation required less effort. One of them said that he would like steps of documentation processes to be automated.

Automation could help some makers to create documentation.

Laziness - Evaluation Some makers stated that they are too lazy to create documentation. Improving documentation processes or setting bigger incentives to create documentation could motivate these makers to create documentation. However, the statements of some participants indicate that automation of documentation processes could be beneficial for these makers . Especially if someone does not see documentation as part of their hobby (see section 4.2.5) automation offers a way to complete a task that is not worthwhile in itself but provides a beneficial outcome.

Four participants did not consider documentation being part of the hobby digital fabrication.

Documentation is not Part of the Hobby - Results Four participants did not interpret documentation as part of their hobby. One participant stated that he did not want to put a lot of effort into documentation for hobbyist projects. A further participant stated that in contrast to his digital fabrication projects documentation did not produce any lights or noises and it was difficult to find the motivation to write documentation. A different participant stated that there is nothing he likes about documentation, and he did not consider it to be part of his hobby. A further participant stated that documentation is boring to him.

There will likely always be a share of makers who are not interested in documentation as part of a hobby, but improving documentation processes could make it relevant as a hobby for more makers.

Documentation is not Part of the Hobby - Evaluation
Some makers have to create documentation in the context of a job or education. However, some makers are interested in digital fabrication purely as a hobby. By improving documentation processes and setting bigger incentives to create documentation some makers could start to see documentation as part of their hobby. However, there will likely always be a share of makers who do not see documentation as a part of their hobby. If creating documentation required considerably less effort, for example through automation, it is possible that these makers would consider creating documentation for altruistic reasons. Finding possibilities to asses the need for documentation as described in the paragraph about a *Lack of Need for Documentation* in section 4.2.5 could also help to motivate more makers to create documentation. Finally, each maker will have to decide individually whether he or she wants to spend *Time* (see section 4.2.4) with documentation. Nevertheless, the results from section 4.2 show that there are multiple opportunities for improvement of documentation processes that would facilitate the process for makers who are already interested in creating documentation and that would possible make documentation more appealing as a hobby for others.

Chapter 5

Summary, Contributions, and Future Work

In this section, we will summarize the findings and evaluation presented in chapter 4. Then, we will talk about possible future work that could be conducted based on our findings.

We investigated documentation processes through two studies.

Global exchange between makers is enabled through documentation. We decided to look at documentation processes of digital fabrication projects to identify their problems and find opportunities to improve them. Therefore, we investigated online documentations and conducted user interviews about documentation processes with 12 makers. We quantified the results from our investigation of online documentations by looking at formats and details found in documentations. We analyzed the user interviews we conducted through the use of coding methods as described in section 3.2.3. We found the four categories *Documentation Processes*, *Motivations*, *External Problems of Documentation Processes*, and *Internal Problems of Documentation Processes* that helped us to analyze user interviews by bundling codes and information in these categories.

Tool-support for documentation processes could be improved to facilitate creating documentation.

The goal of documentation processes is to create documentation. As described in section 4.2 this process can be facilitated by providing tools that makers can use for this process. Improving the quality, functionality, and availability of such tools can help to improve documentation processes. Such tools should include functionalities to adequately support multiple formats, file types, languages, and reduce uncertainty when creating documentation. They should also help to integrate documentation processes into the fabrication process better to avoid workflow interruption. Moreover, they should cater to the needs of different users. Makers who are required to create documentation might have needs like efficiency and a not too time-consuming documentation process. Others might be motivated by reasons like self-expression or the ability to reach interested readers with their documentation.

Publishing documentation is closely linked to creating documentation and should also be facilitated.

Our results also showed that the process of creating documentation is closely linked to the process of publishing documentation. Thus, facilitating the process of publishing documentation also facilitates the process of creating documentation as a whole. Concerns regarding publishing include the barrier of registering on a website, copyright issues, and internal problems like the fear that a project is not good enough to be interesting to others. Moreover, feedback mechanisms, possibilities to interact with documentation of others, and possibilities to address the right readers offer opportunities for improvement. Users who published their documentation often did not store their documentation elsewhere. Thus, features for personal use should also be implemented on platforms for publishing documentation to create more benefits for makers who publish documentation. Some tasks that users mentioned were version control, reviewing projects, and using documentation as reference for job-related opportunities. Besides, some makers use documentation as a base of work with others and thus support for creating and publication of documentation as a group is desirable.

In regard to internal problems of documentation processes, one of the biggest problems we found was that makers thought that their documentation would not be relevant. They feared that a lack of project complexity and interest of others would render their efforts to create documentation useless. However, interviewees had no way of actually measuring the relevance of their projects. Thus, mechanisms that helped makers to assess the interest in documentation of their projects would help them to know when the creation of documentation is beneficial. Moreover, tools that could help them to identify situations where documentation could help them to solve future problems could be useful because some makers thought that they did not need documentation but also encountered the same problems repeatedly.

Makers need ways to identify situations where creating documentation is beneficial for them or others.

For some interviewees the benefits of creating documentation did not seem to justify the necessary effort to create documentation. They might be motivated by incentives like monetary rewards or by otherwise improving the benefits of creating documentation. However, some makers do not see documentation as a part of their hobby. This poses the question of how documentation could be automated to make documentation possible for users who are not interested in documentation processes.

Some makers are not interested in documentation processes and automation could enable them to effortlessly create documentation.

To sum up, we identified three comprehensive research opportunities for future work related to documentation processes. The first research opportunity is the improvement and development of tools for the creation and publication of documentation. The second research opportunity is finding possibilities to help makers identify when creating and publishing documentation is useful. Finally, as some makers are not interested in documentation as a hobby, automation could help them to benefit from documentation without dealing with documentation processes.

We identified three comprehensive research opportunities related to documentation processes.

Bibliography

Fab academy. https://fabacademy.org/. Accessed: 2019-08-16.

Instructables. https://www.instructables.com/. Accessed: 2019-04-23.

Aachen maker meetup. https://www.meetup.com/de-DE/Aachen-Maker-Meetup/. Accessed: 2019-08-16.

https://www.wordclouds.com. Accessed: 2019-08-16.

Dries De Roeck, Karin Slegers, Johan Criel, Marc Godon, Laurence Claeys, Katriina Kilpi, and An Jacobs. I would diyse for it!: a manifesto for do-it-yourself internet-of-things creation. In *Proceedings of the 7th Nordic Conference on Human-Computer Interaction: Making Sense Through Design*, pages 170–179. ACM, 2012.

Dale Dougherty. The maker movement. *Innovations: Technology, Governance, Globalization*, 7(3):11–14, 2012.

Karen Holtzblatt, Jessamyn Burns Wendell, and Shelley Wood. *Rapid contextual design: a how-to guide to key techniques for user-centered design*. Elsevier, 2004.

Jarrod Knibbe, Tovi Grossman, and George Fitzmaurice. Smart makerspace: An immersive instructional space for physical tasks. In *Proceedings of the 2015 International Conference on Interactive Tabletops & Surfaces*, pages 83–92. ACM, 2015.

Stacey Kuznetsov and Eric Paulos. Rise of the expert amateur: Diy projects, communities, and cultures. In *Proceedings of the 6th Nordic Conference on Human-Computer Interaction: Extending Boundaries*, pages 295–304. ACM, 2010.

Anu Määttä and Peter Troxler. Developing open & distributed tools for fablab project documentation. In *OKCon*, 2011.

Bakhtiar Mikhak, Christopher Lyon, Tim Gorton, Neil Gershenfeld, Caroline McEnnis, and Jason Taylor. Fab lab: an alternate model of ict for development. In *2nd international conference on open collaborative design for sustainable innovation*, pages 1–7, 2002.

Catarina Mota. The rise of personal fabrication. In *Proceedings of the 8th ACM conference on Creativity and cognition*, pages 279–288. ACM, 2011.

Kylie Peppler, Adam Maltese, Anna Keune, Stephanie Chang, Lisa Regalla, and Maker Education Initiative. Survey of makerspaces, part ii. *Open Portfolios Maker Education Initiative*, 2015.

Johnny Saldaña. *The coding manual for qualitative researchers*. Sage, 2015.

Eldon Schoop, Michelle Nguyen, Daniel Lim, Valkyrie Savage, Sean Follmer, and Björn Hartmann. Drill sergeant: Supporting physical construction projects through an ecosystem of augmented tools. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems*, pages 1607–1614. ACM, 2016.

Cristen Torrey, Elizabeth F Churchill, and David W McDonald. Learning how: the search for craft knowledge on the internet. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pages 1371–1380. ACM, 2009.

Tiffany Tseng. Spin: a photography turntable system for creating animated documentation. In *Proceedings of the 14th International Conference on Interaction Design and Children*, pages 422–425. ACM, 2015.

Tiffany Tseng and Mitchel Resnick. Product versus process: representing and appropriating diy projects online. In *Proceedings of the 2014 conference on Designing interactive systems*, pages 425–428. ACM, 2014.

Ron Wakkary, Markus Lorenz Schilling, Matthew A Dalton, Sabrina Hauser, Audrey Desjardins, Xiao Zhang, and

Henry WJ Lin. Tutorial authorship and hybrid designers: The joy (and frustration) of diy tutorials. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*, pages 609–618. ACM, 2015.

Typeset September 4, 2019