
Documented
Embedding and Retrieving
Information from
3D Printed Objects

Documented: Embedding and Retrieving Information from 3D Printed Objects

by
Omid Ettehadi

A thesis exhibition presented to OCAD University
in partial fulfillment of the requirements for the degree of
Master of Design in Digital Futures

Toronto, Ontario, Canada, 2020

Documented: Embedding and Retrieving Meta Information from 3D Printed Objects

by

Omid Ettehadi

Abstract

Documentation is an essential aspect of building interactive physical objects. For makers, documentation serves as a record that can be shared with others to demonstrate a project's building (what and how) and decision-making (why) process. A documentation's end-users (i.e., the makers themselves or people interested in rebuilding or learning about the project) can then self-reflect on these records and take away their own lessons regarding the project. However, in the case of physical objects, we think that reflecting on their documentation can be challenging since the documentation and the object are two separate artifacts. We explore this assumption in this thesis. Specifically, we asked if embedding the documentation into the object being made will promote self-reflection and whether this facilitates a deeper understanding of the object and its design process.

We took three main steps to address our questions: (1) we used artifact analysis to identify the strengths and limitations of current documentation styles (i.e., text, picture, and video-based documentations) that makers typically use; (2) we conducted interviews and brainstorming sessions with professional and hobbyist makers, and asked them to determine the strengths and weaknesses of their current documentation techniques, and the improvements they envision regarding the connection between their documentation and the built object; (3) informed by our artifact analysis and interview sessions, we proposed a prototype that provides a new method to interact with an object's documentation, which allows people to embed and retrieve documentation-related data into and from the object, respectively.

Keywords: design process, documentation, data embedding, digital fabrication, self-reflection, reflective learning

Acknowledgements

I owe a debt of gratitude to many amazing people who inspired, motivated, and supported me during this thesis. I would like to acknowledge some of them here.

I feel very fortunate to have worked with my supervisors. I would like to thank my Primary Advisor, Dr. Sowmya Somanath, my Secondary Advisor, Dr. Adam Tindale, and my Industry Advisor, Dr. Fraser Anderson. This thesis would not have been possible without their mentorship, support, and guidance.

I am very grateful to OCAD University, the Digital Futures faculty, and my Digital Futures cohort, which are some of the brightest and most talented minds that I have had the pleasure of learning from. It has been an honour to be a part of this community. Special thanks to April De Zen and Veda Adnani Chatterjee for making the last two years so enjoyable.

I am also very grateful to all the designers, makers, and researchers who were involved in this thesis at any capacity. Without their passionate participation and input, I could not have successfully conducted this thesis.

A special mention to Tina, for all her support. For showing me what to do when I got stuck and giving me all the confidence that I needed to finish this thesis.

Finally, I would like to express my deepest gratitude to my parents, my sister, and my loved ones for providing me with unconditional support and continuous encouragement throughout my years of study and especially during this thesis. I would not have been who I am or where I am if it was not for them. Thank you.

Contents

THIS PAGE INTENTIONALLY LEFT BLANK

List of Figures

On the Use of the Pronoun ‘We’

I will be using the pronoun ‘we’ throughout this thesis and the reason for this is twofold. First, this is in recognition of the nature of making as an ongoing collaboration and the influence of other makers on my thinking process throughout this research. Second, I hope that doing so would promote ease of reading.

THIS PAGE INTENTIONALLY LEFT BLANK

Chapter 1

Introduction

Maker Culture is empowering an increasingly diverse audience to create artifacts. People from different backgrounds and varying levels of technical skills are building a wide range of projects, such as woodworking and smart interactive devices that use electronics [7]. Makers commonly share their projects and the related lessons that they learned with the broader community via online maker platforms, such as Craftster, Etsy and Instructables. Typically, documentation facilitates this sharing of knowledge and can include information such as text, images, and videos, which describe the procedures that the maker followed to create the final artifact. Moreover, these documents contain information regarding what, how, and why the object was built, which provides a clear insight into the project.

End-users (i.e., the makers themselves or people interested in rebuilding or learning about the project) use the documentation to reflect on these pieces of information and form their own understanding of the object and how it was built. Reflection is a cognitive process with either a purpose, or an outcome, or both, and is applied in situations where the material or the object being reflected upon is new [19]. Engaging in such reflective processes can be challenging when it comes to physical objects because the artifact and its documentation typically exist as two separate entities. When the users look at the physical object, they may be unable to obtain full information regarding how it was built and its design rationale. Currently, the users typically have to study the object and its documentation separately and form connections on their own. In this thesis, we ask if embedding the documentation into the object being made will promote self-reflection and whether this facilitates a deeper understanding of the object and its design process.

We think that by embedding documentation information in the object itself, we could gain in situ access to the information and thereby facilitate seamless reflections. Our assumption is motivated by previous research in the area of Tangible User Interfaces (TUIs) that have explored the importance of connecting physical objects with digital information [11]. This research found that such coupling between the physical and digital (referred to as level of coherence [13]) can help people with learning and reflection [20]. Tangible-mediated platforms seem to benefit children in the context of education as they encourage creativity and reflection [21]. We are interested in exploring if similar benefits can be leveraged in the context of documentation for digital fabrication-based making activities.

In this thesis, we investigate makers' relationships with documentations and reveal design opportunities for a new form of interaction with documentations that provide a more reflective experience by having more coherence between the physical objects and their documentations. To create this new style of documentation we: (1) expanded our understanding of current documentation practices by using methods such as artifact analysis and conducting interviews and brainstorming sessions with makers, and then (2) informed by what we learned, we built and evaluated a prototype tool that provides a novel method for interacting with an object's documentation by encoding that information within the object itself.

This chapter begins by discussing the motivation behind this thesis and the research questions. Then, it outlines the scope of this research, the methods we used to approach the research questions, and the contributions of this research to makers and researchers. Finally, it provides an outline of the different chapters of this thesis.

1.1 Research Motivation

Documentation is fundamental to making practices. A study conducted by Kuznetsov and Paulos [14] found that makers are motivated to join online maker platforms, such as Instructables, because it allows them to learn more by teaching and sharing with others. The process of sharing on these platforms is typically facilitated by posting documentations that include step-by-step textual descriptions, photographs, videos of the projects, and sometimes digital files [29].

In previous works, most researchers have focused on how instructional documentation is generated and how readers follow them [14, 24, 35]. These linear instructions help people rebuild their selected projects, but that is only one piece of the entire design process. Moreover, some research has looked at identifying the issues associated with this style of online instructional documentations [14, 24, 35, 32]. For example, Tseng states that the instructional documentation style does not provide a fully transparent view of the design process. To overcome this issue, she proposed Build in Progress [30], a web-based platform that focuses on providing a more complex and transparent view of the making experience without editing and cleaning it up; therefore, it leaves all the details that might be valuable to the reader's self-reflection. However, there is still the issue of lack of coherence, which may limit self-reflection.

We believe that combining physical objects and their documentations introduces a new tangible form of interaction that can enhance users' reflections about the built objects. Past research has introduced examples of this interaction, such as the Spyn project by Rosner and Ryokai [25] (other examples are discussed in Chapter 2.3.3) where they created an augmented reality (AR) experience around knitted objects. Their goal was to create a communication channel between the knitter and the user of the knitted object by connecting digital data to tags that were sewn into the knitted object. The end-user would then be able to view the data using the designed AR system. Through this system, they were able to relay the story that was being told through the object and facilitate reflection about the creation process. They found that this new richer contextualization, increased the users' reflection about the knitted object and and its creation process.

1.2 Research Question

The overarching goal of this thesis is to further understand the documentations for interactive physical objects and suggest a novel way of connecting online documentation to an artifact. To reach this goal, we asked two questions:

[1] In what ways do people currently document their making (i.e., creating interactive physical devices) practices, and what are the related challenges that they face?

[2] How might we build new tools that would facilitate a more reflective in situ documentation style?

1.3 Research Scope and Limitations

This thesis explores how people might embed and retrieve documentation information from a digitally fabricated object made using tools such as 3D printers, laser cutters, and CNC machines.

The main audience for this thesis are makers, people who build physical interactive objects using digital tools [4] and human-computer interaction (HCI) researchers. We hope that through this thesis and examining physical documentations in our research study and design exploration, we will inspire researchers and makers to develop new forms of interactions with documentations. Moreover, we hope that this creates an experience that increases opportunities for reflecting on the objects that become a part of our physical world.

The goal of this thesis is not to create a new documentation standard. Instead, we present one more potential approach to creating documentations. Additionally, our designed tool is only one of the possible outputs of this project and is in no way the only viable solution.

There are certain limitations that need to be addressed when it comes to physically visualizing documentation data. First, there is a hard limitation regarding how data can be physically visualized based on the type of machine that an individual is using to create an object. For example, 3D printers can only print using certain materials and a certain number of different filaments in the same print. Moreover, another limitation is the visualization's accuracy, which is also set by the machine that is being used in the fabrication process. For example, 3D printers have a minimum layer thickness that is based on the limitations of their hardware. These limitations can impact how the final object would look and the ways that data can be added to the object.

In addition, there are specific parameters that need to be considered when data is being codified to be added to an existing 3D model. We can already find certain data in a model, for example, the visible layers in a 3D printed object make it clear for the user to identify what tools were used in the fabrication process; however, there is also information that is missing entirely from the object, such as the designer's name. There is also the question of how far the new information can modify the object's original 3D model without changing the original object visually or changing its purpose and functionality.

Finally, a fabrication-ready file requires doing even more processing on the file, for example slicing of an 3D model in order to 3D print it. Although some of this processing can be automated, other parts, such as automatic placement of tags on the surface of a model, are challenging and require users to perform specific tasks manually, and this makes the task difficult for novice users.

1.4 Research Methodology

This thesis takes inspiration from the reimagined picture of HCI introduced by Liam Bannon [2], which advocates for a more human-centred approach towards research in HCI and employs a Human-Centered Design (HCD) methodology [1]. HCI researches the interaction between people and computers, highlighting the importance of understanding people to create better tools for them. Using HCD, researchers first gain a deeper understanding of the community that they are designing for. Then, they develop solutions for the community by addressing their specific needs and evaluating the systems to provide more feedback on how they can be improved [9]. The HCD approach is an ideal match when it comes to dealing with a multidisciplinary community, such as makers, where the community's expertise can assist with the design of the product.

This research can be broken down into five phases:

1. **Literature Review:** This includes a study of literature from the maker movement, reflection theory, interactions, and physical data visualization to contextualize the study.

2. **Artifact Analysis:** This includes a study of four existing documentations to identify what is being documented and how it is being documented, in addition to what is missing from current documentations and why.

3. **Interviewing and Brainstorming:** This includes a semi-structured interview with expert makers to understand their current documentation practices and the tools they use for documentation. After the interviews, experts will engage in a brainstorming session to identify what data they think is important to be documented in their making process and how the data can be captured and visualized in their final product. Accordingly, they create sketches to show what their ideal documentation tool would look like and how their final product would look like using their designed documentation tool.

4. **Prototyping:** This includes building of a prototype based on analyses of the data collected from previous stages. The prototype's goal will be to create a new form of interaction with documentation, and allow for testing of the system.

5. **Evaluation:** This includes an evaluation session for makers to test the built prototype and provide feedback about the strengths and weaknesses of this new form of interaction with documentation.

1.5 Research Contributions

To learn more about how self-reflection can be better supported, we developed a new form of interaction between the documentation and the physical object itself. Moreover, this interaction could enhance and deepen an individual's reflection about the documentation and increase the chance of forming lessons out of the building experience.

The contributions of this thesis are as follows:

1. Performing an initial analysis of current documentation practices.
2. Designing and developing Documented, a new tool designed to facilitate reflective learning experience for end-users through formation of a spatial link between a physical 3D printed model of the built object and its documentation.
3. Evaluating Documented and forming conclusion of the lessons learned through the evaluation.

1.6 Chapter Outline

This thesis is organized into seven chapters: *Chapter 2* discusses the background and literature that is relevant to this study. *Chapter 3* defines the methodology, the methods, and the techniques used in this study. *Chapter 4* discusses the analysis of the data collected from the artifact analysis, interviews, and brainstorming sessions. *Chapter 5* introduces the created prototype and describes its design process. *Chapter 6* discusses the prototype's strengths and weaknesses. *Chapter 7* revisits the goals of this thesis and concludes with future directions.

Chapter 2

Background and Related Work

With the rise of the do-it-yourself (DIY) approach to making with technology, the role of humans has shifted from the users of technology to the builders, modifiers, maintainers, and repairers of technology [28]. This has led to the introduction of terms such as "maker," "hacker," and "tinkerer" in this field. An area of research that is relevant to people who create with technology is the different ways of creating and interacting with documentation.

This research is focused on creating a new form of interaction with documentation and builds upon prior work in a number of domains, including design documentation, data visualization, and self-reflection through documentation.

2.1 Making and Makers

The Maker Movement is a social movement, and an international phenomenon characterized by a DIY attitude wherein people design, build, and share their creative production of artifacts with a broader community of makers. These projects include a variety of outcomes such as interactive systems built using electronics and coding, and physical objects built using materials such as wood and plastic [10].

The maker movement has had its ups and downs in the past 15 years. For instance, in June 2019, Make Media Inc., the company behind Make Magazine and Maker Faire shut down abruptly [16]. The company has since reorganized and resumed publishing its Make Magazine. However, the practice of making and documenting things is not limited to this movement. In fact, people have been making things all through our early and contemporary history, where they began by making objects to satisfy their daily needs and used cave drawings to documented and share their stories. In this thesis, we contextualize using maker culture, because, in recent years, the maker movement has brought about a maker culture that emphasizes learning-through-making in a social environment. Moreover, others have researched this maker culture, enabling us to borrow terms to explain our concepts and contexts.

The term "making" is associated with the birth of Make Media Inc., and in 2005, they introduced the term "makerspaces" in Make Magazine. They popularized the word maker, making, and makerspaces. Dale Dougherty, the founder of Make magazine, describes "make" as a more inclusive term for "hacking", without the negative connotations associated with this word [7]. While the precise definition of making is still debated, people generally characterize making as an activity that supports the design and production of material artifacts using a combination of digital and/or physical processes, which promotes creativity and engagement with technology [18].

In this paper, the term making refers to building interactive physical devices by oneself using digital fabrication tools.

Necessity is no longer the mother of all inventions. These days we can find and purchase almost everything that we need, and yet there are many people who are interested in making what they need for themselves, and these individuals are makers. Makers create things for a variety of reasons, such as self-expression, self-satisfaction, or sustainability reasons [23]. Makers are the creators, builders, and shapers of the world around us. They regard technology and any skills or techniques that we learn and use as an invitation to explore and experiment with objects in the world.

In this paper, the term maker refers to the capacity of any person to build physical interactive devices using physical/digital fabrication tools, programmable electronics (e.g., Arduinos) and computer programs.

Dougherty takes the different narratives of the maker movement and formalizes this concept and introduces the term "maker mindset". Martin [18] expands on Dougherty and presents a more specific list of what the maker mindset includes. This mindset is playful with how it engages with technology, is asset- and growth-oriented in developing capabilities, and has a failure positive attitude towards overcoming obstacles.

In recent years, there has been a considerable rise in the maker movement due to the development and introduction of two key technologies [7]:

1. New Personal Fabrication technologies

2. The Internet

On the one hand, the introduction of cheap programmable electronics (e.g., Arduinos) and less expensive and more accessible digital fabrication devices have allowed for prototyping and production outside of traditional mass markets. Furthermore, Desktop mills, 3D printers, and laser cutters have increased the power of makers and given them more options in the creation process. On the other hand, the internet has allowed makers to form online communities where they share their work and learn from each other. A distinct quality of the maker movement is the makers' sharing spirit, and documentation has a fundamental role in supporting this spirit.

2.2 Documentation

Documentation is not a new concept and has long been a valuable tool for showcasing, communicating, and self-reflecting in professional and educational contexts [33]. Unlike what people normally think, documentation is not just a description of assembly, but rather as Tiziana Flippini, coordinator of the Documentation and Education Research center of Reggio Emilia, described [34],

> Documentation is a narrative pathway with arguments that seek to make sense of events and processes.

Documentation is not just a record of what took place but is also a way to capture the personal decision-making process. A designer's sketchbook is a good example of how makers capture their personal decision-making through their building process. Such documentations capture three types of information [8]:

1. Thinking Sketches
2. Talking Sketches
3. Prescriptive Sketches

Thinking sketches are used by the designer for self-reflection, talking sketches are used to support inner-communication between designers, and prescriptive sketches are used to support the design team in communicating their design to stakeholders outside of the design team. All three types of these sketches help form the designer's sketchbook and capture all the design decisions. We can expand these categories of information as a way to classify documentations. Makers can use the combination of all three types of documentation as a valuable tool for showcasing, communicating, and self-reflecting.

The act of documenting involves reflecting through evaluation and communicating one's knowledge. In *How We think*, Dewey [6] defines reflecting as:

> Active, persistent, and careful consideration of any belief or supposed form of knowledge in the light of the grounds that support it and further conclusions to which it leads ... it includes a conscious and voluntary effort to establish belief upon a firm basis of evidence and rationality.

Reflection is a deliberate process by which a person considers their beliefs or understanding based on the evidence at hand, helping people learn new skills, build theories, and evaluate and make decisions [19]. In a design process, documentation logs all of the thoughts and decisions made during the process and acts as the evidence at hand.

There are many learning philosophies in which documentation is a pathway for engaging in reflective practices. A prominent one is the Reggio Emilia philosophy, which highlights self-guided learning in early childhood education and places a strong emphasis on documentation for creating "visible learning" that teachers can use to understand and support children's growth [36].

All these emphasize the importance of having the proper documentation for a project, especially in the maker community, where the emphasis is on learning-through-making [27].

2.3 Ways of Presenting Documentation

Documentations can have various formats. This thesis attempts to create a tangible method of interacting with documentation to create a more reflective experience.

2.3.1 Digital Documentation

Several online maker communities provide a platform to their members for sharing their DIY projects with others in their community by creating an online documentation for their projects. Instructables is a popular example among these platforms.[1] It was launched in 2005 by Eric Wilhelm of the MIT Media Lab and describes itself as a "web-based documentation platform where passionate people share what they do and how they do it" on their website. Using Instructables, makers can share a wide range of projects, from woodworking and Arduinos to gardening and cooking

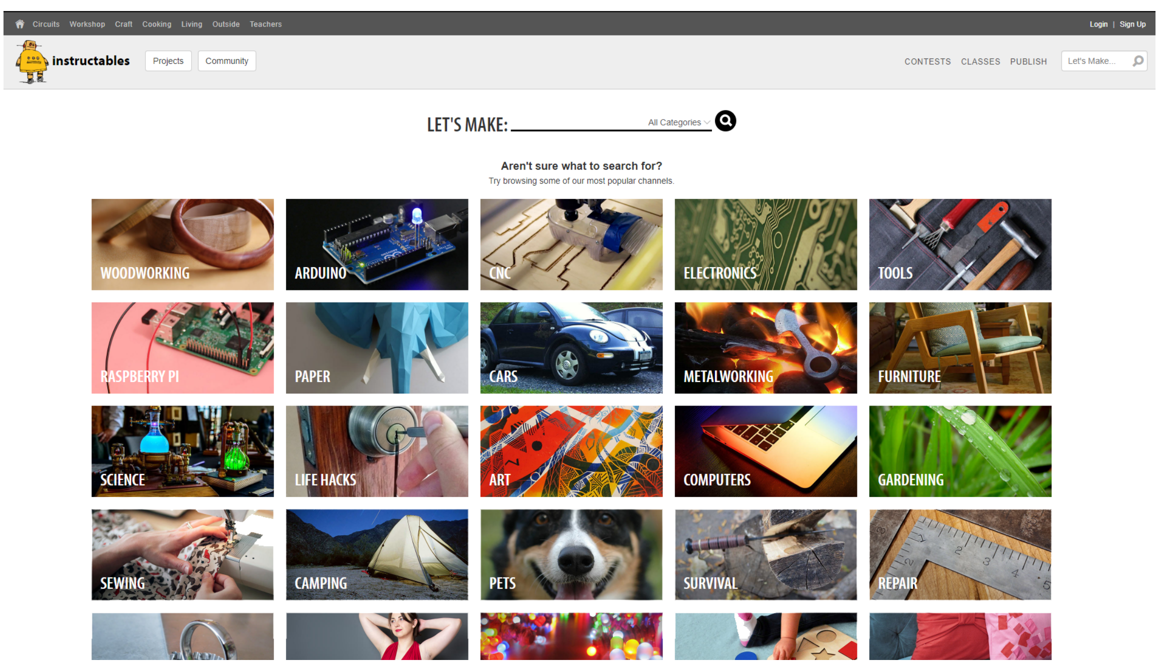


Figure 2-1: Instructables search page.[2]

[1] https://www.instructables.com/
[2] source: https://www.instructables.com/howto/

recipes. The platform divides the documentation into steps and allows the users to add text, pictures, videos, and digital files to each step. Viewers of the documentation can download it, like it, share it, comment on it, add tips, ask questions, and acknowledge if they have made it for themselves.

Instructables provides its members with a simple way to input their documentation data and allow their viewers to easily navigate through their platform and access the documents that they desire. In addition, the website holds special interest contests every month and awards the winners with badges and other types of equipment.

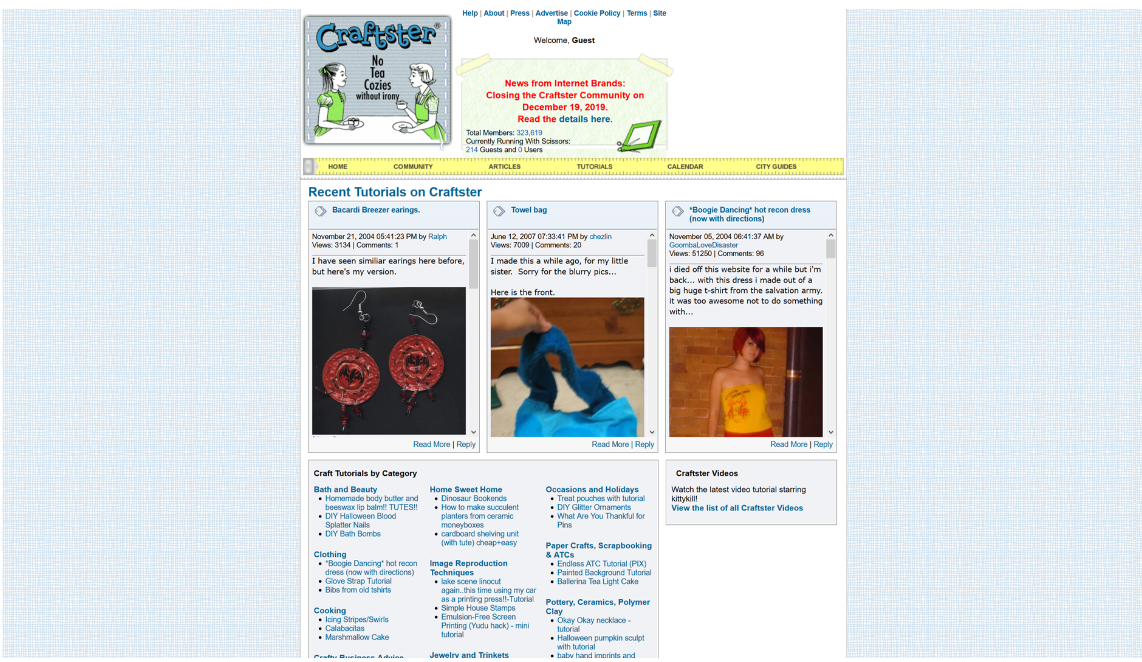


Figure 2-2: Craftster tutorial page.[3]

Another example of such a platform is Crafster.[4] This online community revolves arounds crafts such as knitting, pottery, and cooking. Founded by Lead Kramer in 2007, Craftster allows users to share projects and communicate with each other through more than 30 categories of forums. Members can share their making by uploading photos and instructional texts. Similar to Instructables, Crafster also or-

[3] source: `https://www.craftster.org/forum/?page=tutorials`
[4] `https://www.craftster.org`

ganises challenges for its users, where it places the winners' projects on the website's front page.

According to Kuznetsov and Paulos [14], makers are motivated to join online maker communities such as Instructables and Craftster, but find the task very time consuming, this sort of documentation is typically made after the object is completed and adds an additional task for the makers to do. These digital documentations are oriented towards providing users with step by step re-creation instructions. This can make it difficult for the audience to navigate through the documentation and identify reasonings behind certain decisions.

2.3.2 Physically Embedded Documentation

Some research in HCI has tried to physically document the building process because they believe that bringing data into the physical object eases the accessibility of the data for the everyday user. One example of this work is Process Products, where they

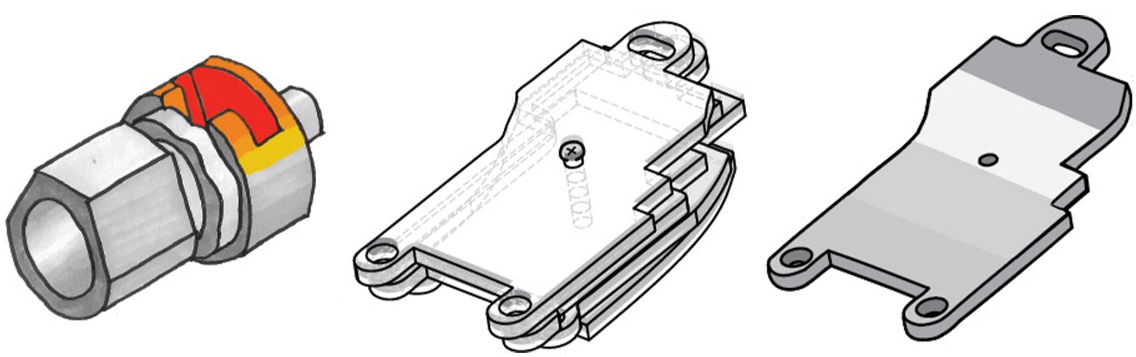


Figure 2-3: Process Product by Tiffany Tseng and Geoff Tsai [33].

focused on digitally fabricated objects and captured changes across different iterations of a design and visually embedded those iterations into the digitally fabricated objects [33]. They focused on digital fabrication processes as it enabled them to capture the different iterations both physically and digitally. They introduced three methods for performing this task:1) process heatmaps, where the iterations are presented as heatmaps in a 3D printed component, 2) process stacks, where the iterations are laser cut as different pieces and stacked on top of each other, and 3) process textures, where rather than showing the design iterations, it presents the various machine settings for the different sections of an object on the object's surface in a single laser cut piece.

While this project identifies the opportunity in visually representing aspects of design documentation, the new object created is only capable of showing physical changes in each iteration. This system does not provide any further insight into the reasoning behind these changes. Accordingly, in this thesis, we focus on ways to introduce physical presentation of documentations without limiting the types or amount of information that is being documented.

Figure 2-4: ListeningCups by Audrey Desjardins and Timea Tihanyi [5].

Another example is ListeningCups, in which the researchers were interested in embedding sound data into a 3D printed cup [5]. They developed a workflow to capture data, prepare datasets, transcribe data from decibels to G-code, and create a set of 3D printed porcelain cups that represent this data in a textural and tactile form.

While the project successfully shows the possibility of visually embedding data on top of a 3D printed item in a digitally fabricated process, the retrieval of the collected data is almost impossible for the users. In this thesis, we are focused on people authoring and retrieving documentation, whereas, in this project, the researchers were not focused on the users having the ability to retrieve the data that has been captured into the object.

Outside of the documentation of making practices, we can also look at works that attempt to connect other kinds of data to physical objects. One instance of this is in Trace-Maker by Moon-Hwan Lee, Oosung Son, and Tek-Jin Nam [15]. In this

Figure 2-5: Trace-Maker by Moon-Hwan Lee, Oosung Son, and Tek-Jin Nam [15].

project, they collected users' navigation data from their bicycle journeys and engraved the pattern in an abstract form on top of a bicycle bag. They found that by connecting users' personal data to the physical object, the users built a much stronger emotional connection with their bags. Furthermore, they found that the users developed a stronger understanding of the data by seeing it physically manifested.

This project shows that the physicalization of data promotes a deeper understanding of the data. However, the bag is customized for one person, and the project does not consider the other individuals who will see the visualized data. Additionally, the data have been abstracted to be more visually pleasing, but this makes the data retrieval by other users much more challenging.

2.3.3 Mixed Documentation

HCI researchers have attempted mixing digital and physical documentation so that they could attach a large amount of documentation data onto the physical object

Figure 2-6: Spyn by Daniela K. Rosner and Kimiko Ryokai [25].

without having to consider the size of the object.

In previous work, Rosner and Ryokai developed Spyn, which is an application for crafters to embed stories into knitted objects [25]. In Spyn, the craft's designers use a yarn with infrared ink, and then the craft's receivers use their cell phone with computer vision to detect tags and play back recorded stories that the designer left for them.

The project's main objective is to form a communication link between the object's designer and receiver that is beyond just the object's material and colour and digitally expands their communication by enabling them to send text, pictures, audios, and video recordings to the receivers. In this case, the designer has to intentionally weave markers into the product, which requires too much effort from the designer. While this project successfully attaches a large amount of information to the physical object, the tags are only machine detectable. In addition, in this project, the tags are added to the final object, without the final object, no user can access the attached information.

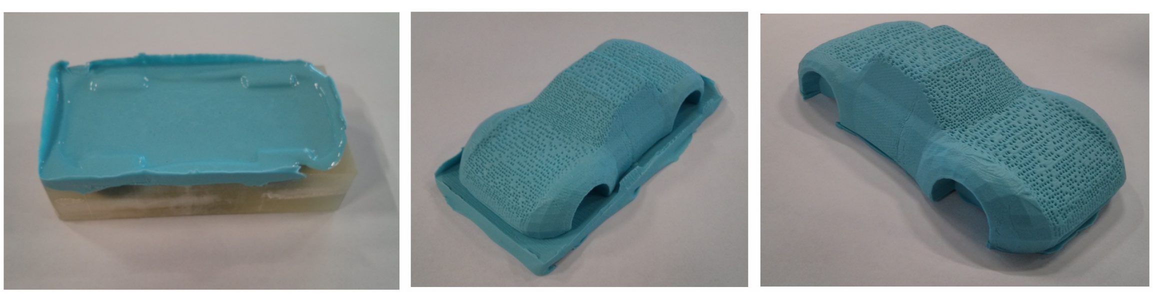


Figure 2-7: Encoding Data into Physical Objects with Digitally Fabricated Textures by Travis Rich [22].

Another example of exploring mixed documentations is "Encoding Data into Physical Objects with Digitally Fabricated Textures" by Travis Rich from the MIT Media Lab [22]. In his thesis, he attempts to encode objects with deterministic surface features that would then be detected using a mobile application. The mobile application will provide the users with information that has previously been attached to each part of the object. In his work, he explores both 2D and 3D objects by using laser-cutters and 3D printing technology.

In his system, the object's surface has to be modified to contain specific textures that the mobile application could detect, which impacts the project's aesthetics and possibly the object's functionality. In addition, the textures that are encoded onto the object's surface are only machine detectable.

2.4 Summary

The maker's mindset is what sets makers apart from other designers. A mindset that uses technology in a playful and experimental manner to test things on their own and learn from their own experimentation outside of the formal education structure.

Documentation is the main tool by which people communicate and share their learning. Online documentations normally contain the storyline of an object's building process, but the task of reflecting and forming lessons is left to the readers themselves.

Informed by examples such as Process Products [33], Spyn [25], and Rich's thesis work [22], we think that one way of assisting a documentation's end-users in reflecting and forming a deeper understanding of the materials is to link the physical object to its online documentation. By forming these connections, the user forms a deeper contextual understanding of the lesson, which might make it easier to use the lessons in future works.

THIS PAGE INTENTIONALLY LEFT BLANK

Chapter 3

Methodology

We employed a Human-Centred Design (HCD) in our methodology, which is a creative approach to problem-solving. HCD focuses on the individuals that the object is being designed for and develops solutions that are tailored to their needs [9]. HCD consists of three consecutive phases: inspiration, ideation, and implementation. During the

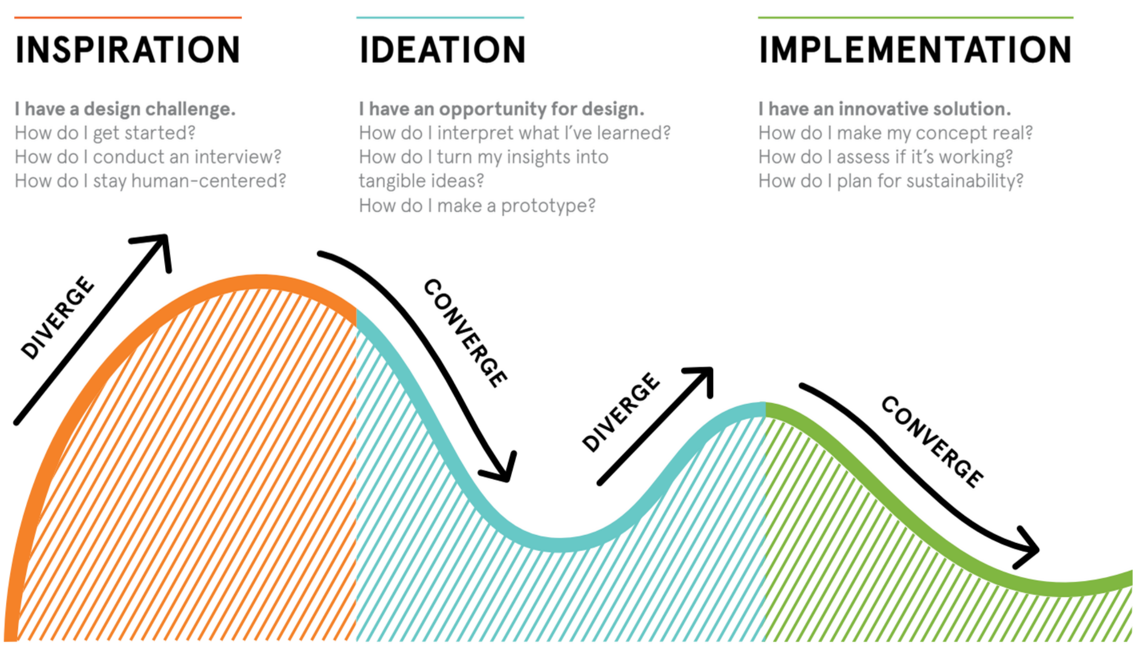


Figure 3-1: Three phases of HCD [1]

inspiration phase, researchers learn directly from the community that their research is focused on and step into their shoes to develop a deeper understanding of their needs. After, in the ideation phase, the researchers study and analyze the community's feedback to identify and envision opportunities for design and prototypes of possible solutions. Lastly, during the implementation phase, they bring the solution to life [1].

This methodology helps us gain insight from the maker community, which is highly active in problem-solving and solution-building. Furthermore, we can take advantage of the maker community's wide range of backgrounds, skills, and knowledge to identify design opportunities and evaluate the built prototype.

This chapter outlines the methods used in this thesis. It goes over the methods for each of the HCD phases and why and how we chose and implemented them, respectively. Finally, the chapter summarises this methodology's benefits.

3.1 Inspiration Phase

Our goal for this stage was to understand the makers' documentation practices, the types of data that they capture during the building process, and the different visualization formats of those data. We divided our inspiration phase into two studies. We first conducted an artifact analysis study on common documentation formats that exist in maker communities. After, we held interviews and brainstorming sessions with professional and hobbyist makers to finalize this phase.

Artifact Analysis is a process whereby a researcher asks questions about an artifact to better understand its users and the culture that it typically exists in. Artifact analysis can also be used as a source of inspiration for future designs [17].

The goal of this analysis was to explore the current documentation culture and the challenges of existing formats. For this analysis, we chose four different documentations from four different sources: 1) Instructables, 2) Make:Project, 3) Build in Progress, and 4) YouTube. These selected examples are from well-known platforms and cover a wide range of documentation purposes, such as remembering, storytelling, instructing, and showcasing. This range of artifact examples is by no means exhaustive regarding the factors that could be considered. This is because the goal of this analysis was highly exploratory and not intended to build the perfect list of examples, but rather to use a few common ones to begin understanding documentations in the context of making practices.

For the artifact analysis, we designed a questionnaire consisting of 30 questions (see Appendix A.1). The questions covered the documentation format, the type of media it used and why it was used, and how much information an expert or non-expert would be able to extract from the artifacts. During the analysis, we answered all 30 questions for each of the documentation examples. Accordingly, we used these answers to identify each documentation's advantages and disadvantages.

For the second part, we held interviews and brainstorming sessions with professional and hobbyist makers. Our goal was to better understand the makers' documenting practices and identify what they perceived as the best way to connect documentation-related information to the physical object being built.

We requested feedback from five participants belonging to our institution and local maker spaces. Participants were at least 18 years old (3 males and 2 females) with a minimum of 1-year experience with digital fabrication tools (e.g., 3D printers, laser cutters, and CNC machines) and documentation.

We organized a 1-hour long session with each of the participants. Each session was divided into two sections. In the first 30 minutes, we conducted a semi-structured interview (see Appendix A.2) and asked questions about the participants' design processes, documentation processes, and their opinion regarding the strengths and weaknesses of their documentation style. In the second half of the session, we held a brainstorming workshop where we asked each of the participants to perform two tasks (see Appendix A.3). For the first task, participants brainstormed and created a list of the data that they would like to be captured, how they would want them to be captured and then visualized. For the second task, we asked the participant to sketch their ideal documentation tool and to show how the final object would look like if it had been documented using their tool. At the end of the session, we briefly discussed any final thoughts and questions that they had.

3.2 Ideation Phase

We combined what we learned from the artifact analysis, interviews, and brainstorming sessions with our own experiences and formed a list of design opportunities that could lead to a more reflective in situ documentation style. We developed our particular prototype by making smaller prototypes that were designed to test the specific parameters that we identified as potential ways to enhance interaction with the documentation. Furthermore, we created multiple iterations and tested them thoroughly to figure out the limitations of the technologies at hand.

Our goal was to design one final prototype that individuals could use with an object's existing documentation. Moreover, we wanted to test the new form of interaction with the documentation that we had created. To do this, we combined all our smaller viable prototypes into a bigger low fidelity prototype (Explained further in Chapter 5). Importantly, we focused on the system's functionality rather than its user interface design, and then we ran a study to test the concept behind our prototype and its effects on the users' reflection process.

3.3 Implementation Phase

To test our built prototype, we ran an evaluation study with professional and hobbyist makers. Our goal was to evaluate the functionality of our proposed solution and measure how successful it is in promoting more reflective learning from the project documentation.

We invited 12 participants from a broad audience within our institution and local maker spaces. Participants were at least 18 years old (6 males and 6 females) and had previous experience with building physical interactive devices and their respective documentation processes.

We organized a 30-minute session with each of the participants. Prior to each session, we provided the participants with a questionnaire regarding their background and current documentation practices (see Appendix B.1). During the sessions, we introduced the participants to a pre-built project (i.e., an amplifier box) and provided all the documentation materials that we had collected for that project. The documentation consisted of: 1) audio recordings regarding critical design decisions that were made during the design process, 2) pictures of every step of the building process, 3) videos of other projects that had inspired this project, 4) digital files containing the 3D model and SVG files for laser cutting of the different iterations, and 5) a fully written documentation text on the project's objective, inspiration, background information, tools and materials used, step-by-step instructions, and an evaluation of the final design. We asked each of the participants to use our prototype documentation tool for this pre-built project. Moreover, we asked the participants to embed, interact, and retrieve the pre-collected documentation information using the 3D printed amplifier box (see Appendix B.2).

We divided each of the sessions into three sections. During the first 5 minutes, we introduced our prototype (i.e., the amplifier box) and all of its documentation materials. We ran through the three main features of the prototype: 1) encoding data, 2) embedding tags, and 3) retrieving data with the participants and showing them how to use our system. For the next 15 minutes, we asked them to try out the prototype on their own. While they tried out the prototype, we conducted a semi-structured interview and asked specific questions regarding each of the prototype's features (see Appendix B.3). Finally, we completed each session by asking the participants to fill out a short questionnaire on self-reflection (see Appendix B.4).

3.4 Summary

We followed an HCD approach for this thesis. Through this approach, we gained insight into current documentation practices, which helps with identifying design opportunities regarding a new tool that could assist with a more reflective experience. We used artifact analysis, semi-structured interviews, and brainstorming sessions to collect data on makers' documentation practices. Additionally, we conducted a survey, semi-structured interview, and user-testing to receive direct feedback on all the features of the prototype we designed.

Chapter 4

Preliminary Design Studies

In this chapter, we discuss the data that we collected and analyzed during the inspiration phase of the thesis. It will start with the artifact analysis that we performed to understand current online documentations available in maker communities. It will then discuss the data we collected during the interview and brainstorming sessions. Finally, it will summarize our findings from the inspiration phase and lead to our built prototype.

4.1 Artifact Analysis

As previously discussed in Chapter 3, we selected four examples of documentations for our artifact analysis. We took four artifacts from Instructables, Make:Projects, Building in Progress, and Youtube. Each of these platforms are designed with a specific purpose in mind. Instructables provides its users with a clear format to create polished instructions on how to rebuild their projects. On Make:Projects, users submit blog-type documents, which provides a bit of creative freedom regarding how to structure the documentation. Building in Progress allows for a non-linear documentation format and a transparent view of the project where things happen simultaneously, and YouTube allows for video submissions. Even though YouTube might not be considered a documentation platform, we argue that it is a platform designed for sharing ideas, and many makers use it as a way to showcase their projects. For instance, all of the four artifacts that we analyzed had a video section that was uploaded to YouTube.

4.1.1 Artifact I: Silver RFID Ring

We took this artifact from Becky Stern's Instructable channel [3]. Becky Stern is an American expert in DIY technology and is based in New York City. She makes very well organized documentation of her projects on her Instructable, with most of her projects being featured on the main page of the website. She uses text, pictures, and videos where she goes over her building process. In this project, she builds an RFID

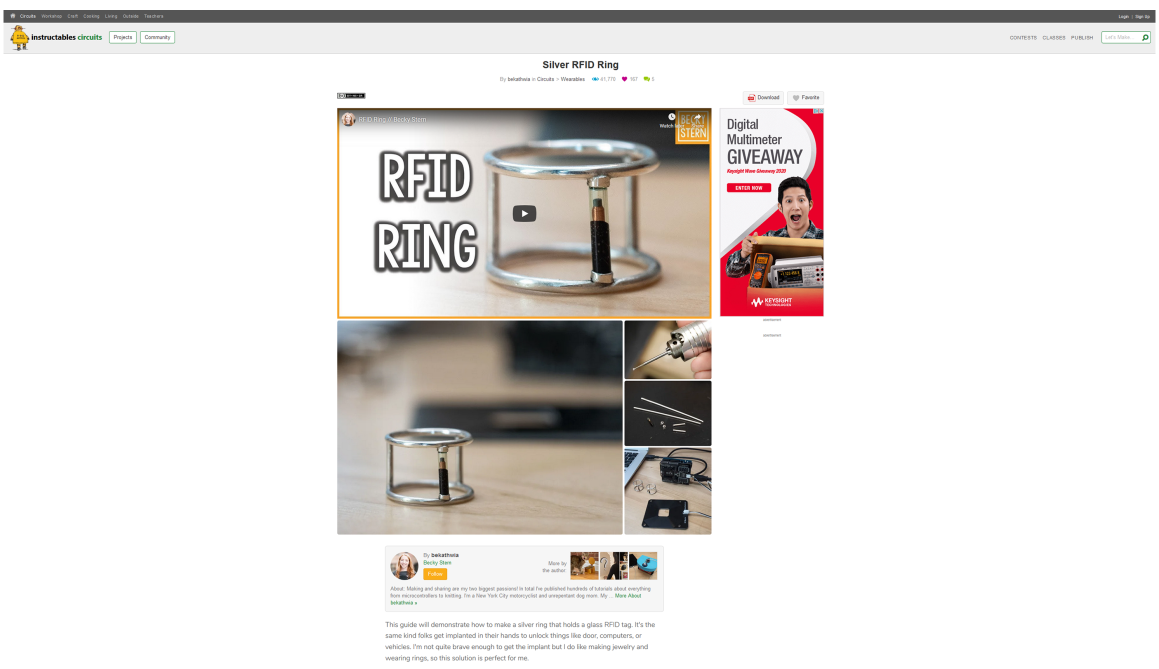


Figure 4-1: Screenshot from Silver RFID Ring by Becky Stern on Instructable.[1]

[1] source: https://www.instructables.com/id/Silver-RFID-Ring/

ring using metalworking techniques and a small RFID tag. Then she uses an Arduino with an RFID shield and sample code from the library to create a system whereby scanning her ring she can unlock her laptop.

In her documentation, she provides clear step by step instructions on how to rebuild this project. She uses texts, photos, and animations to describe what needs to be done in every step. Furthermore, she provides a list of all the materials and coding that the system requires to run. Lastly, she shares a full video of her building process that highlights the motivation behind the project.

Although Becky's documentation is extensive, there are still certain limitations for a user to recreate the project. For instance, Becky uses metalworking skills to create the ring, which is only doable if you already know how to use those tools. She does provide a link to previous tutorials where you can learn these skills, but it needs to be highlighted that a novice maker will be unable to recreate this object based on only this tutorial. While a simple tutorial shows how to perform the tasks, being able to successfully perform the tasks requires the users to have prior experience using those techniques. Moreover, the process has been cleaned up to make rebuilding the project easier for users of the documentation. By doing this, a layer of information is inaccessible to the users, such as her initial attempts at the project or mistakes that she made throughout the building process. The users' inability to access this information reduces the amount of reflection that they can do and learn from.

Finally, if you are given the final product, it is quite challenging to identify which part of the documentation is related to the specific design choice that the reader is interested in further exploring. The documentation is organized by which steps should be performed first, whereas those steps involve a combination of activities on different parts of the object.

4.1.2 Artifact II: A Secret Light Up LED Ring

This artifact is from Make:Magazine, written by Clarissa Kleveno [12]. Clarissa Kleveno self-describes as "a techie" working in the greater Seattle area. She likes crafts and coding. Preferably at the same time." She makes organized project documentations on her Make:Projects and uses text, pictures, and videos that go over her building process.

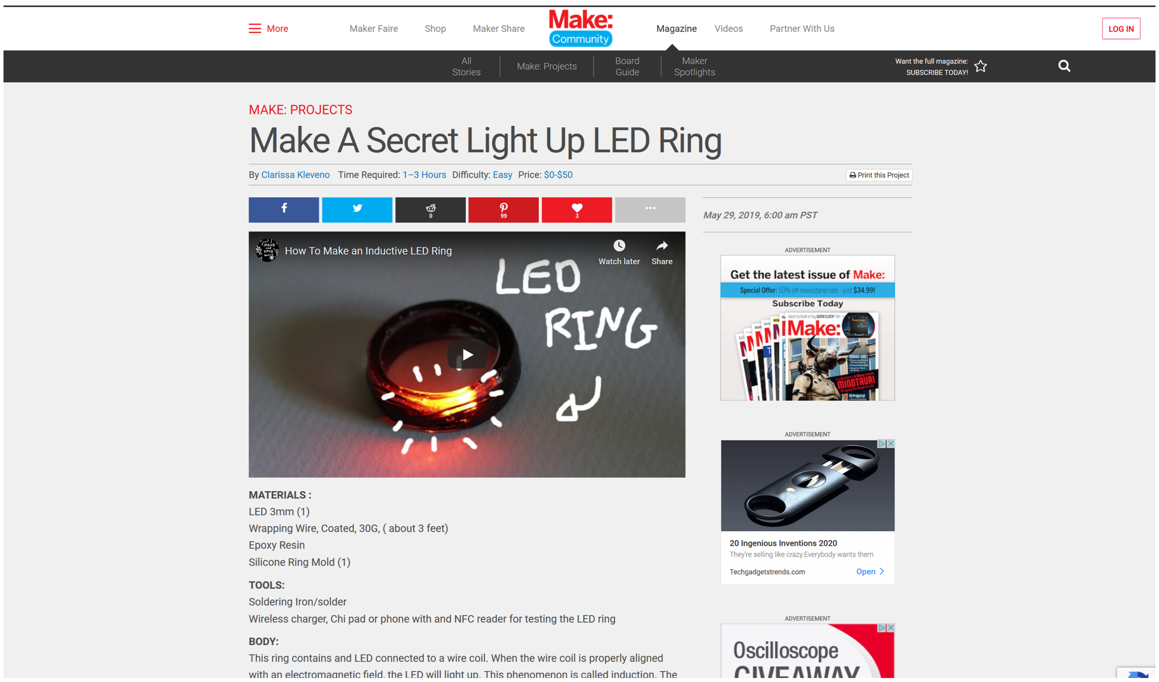


Figure 4-2: Screenshot from Make A Secret Light Up LED Ring by Clarissa Kleveno on Make:Projects.[2]

In this project, she makes an LED ring that lits up when it is correctly aligned with an electromagnetic field. Similar to Becky's project, Clarissa provides a clear step by step process for rebuilding the project. She uses photos and text to describe what needs to be done in every step and provides a list of all the materials and coding that is required to run the system. Additionally, she shares a full video of the object's creation, where she goes through the steps and suggests solutions for the problems that documentation users might face when rebuilding the project. The

[2] source: `https://makezine.com/projects/make-a-secret-light-up-led-ring/`

project uses elementary skills; therefore, during each of the steps, Clarissa provides guides for performing those skills to increase the likelihood of novice users to recreate the project successfully. What is missing from this documentation is the lack of information regarding the motivation behind the project.

Finally, similar to Becky's documentation, if you are given the final product, it is quite challenging to identify all the information you need about the different parts of the object. This is because the documentation is organized based on the steps required to rebuild the object rather than the different parts of the object. Furthermore, in Becky's case, the RFID tag is visible on the ring and provides users with ideas of things that they can do with it, but Clarissa's ring includes no visual cue regarding the ring's purpose. In this case, unless the user reads the documentation or is informed by someone else about the object's function, the user would not be able to use the object in the manner that it is designed for.

4.1.3 Artifact III: Spin Turntable

This artifact is from Building in Progress and is built by Tiffany Tseng from the MIT Media Lab [31]. She created Spin Turntable as part of her dissertation in addition to sharing it on Building in Progress. On Building in Progress, she focused more on the "why" aspect of building rather than the “how”, and provides a non-linear documentation of her building process.

The documentation contains a large amount of information, which makes it difficult to navigate. While the documentation's non-linear structure clearly shows a fully transparent view of everything that has happened during the project, it is not easy to find the steps and the respective order that is required to rebuild the object. This type of documentation provides a large amount of information for its end-users, which allows them to reflect on and form their own lessons. However, the difficulty

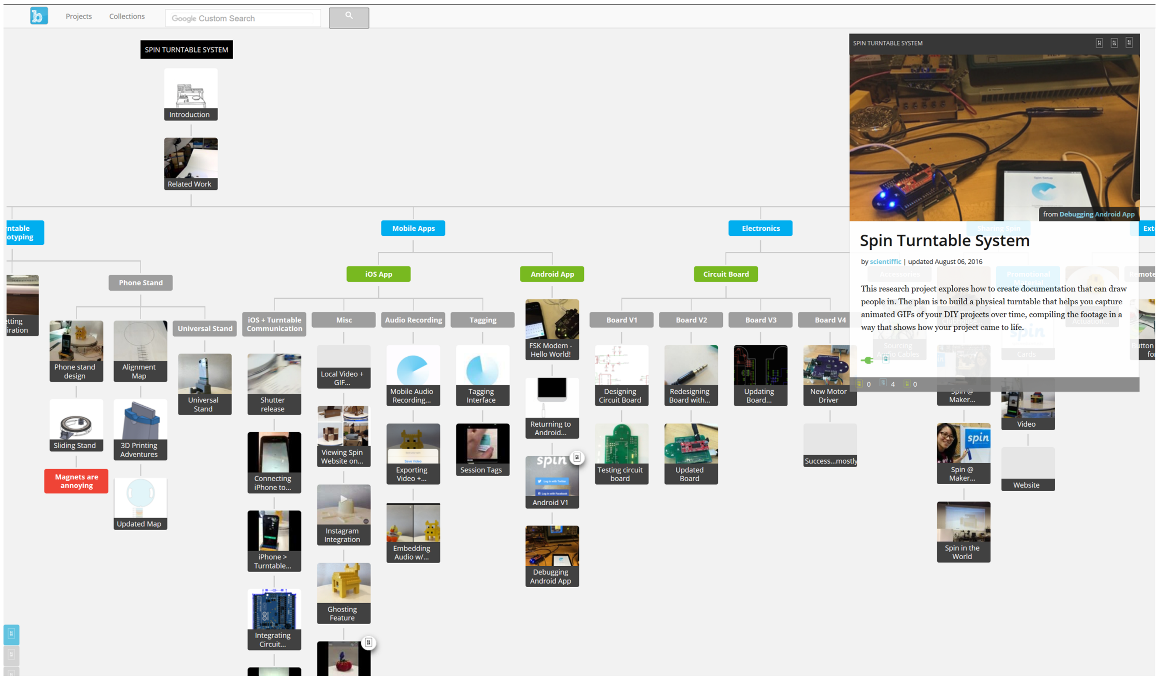


Figure 4-3: Screenshot from Spin Turntable by Tiffany Tseng on Building in Process.[3]

in navigating between the parts makes it challenging to easily find the information that the user is looking for.

The documentation clearly shows the iterative process of making the object. It divides all the information based on which parts of the project they are related to and presents their sequence and the timeframe of the events.

Looking at the final object, you can trace back and relate certain parts of the object to specific parts of the documentation. However, because of the vast amount of data that you need to navigate through, it is very time-consuming to locate the precise information that you are looking for.

[3] source: `http://buildinprogress.media.mit.edu/projects/2330/`

4.1.4 Artifact IV: Overengineered Bottle Opener

This artifact is from Adam Savage's Tested channel on YouTube [26]. Adam Savage is an American special effects designer, fabricator, educator, and television personality and producer. He currently produces content for Tested.com, and posts documentations of his projects on Adam Savage's Tested Youtube channel. We chose one of his One Day builds projects where they make a novel over-engineered bottle opener in collaboration with Laura Kampf, another YouTuber and maker.

Their project's documentation is collected all in one video, where they have captured the journey from ideation to the building of the device. For instance, filming themselves as they have conversations about design options and motivations behind the project.

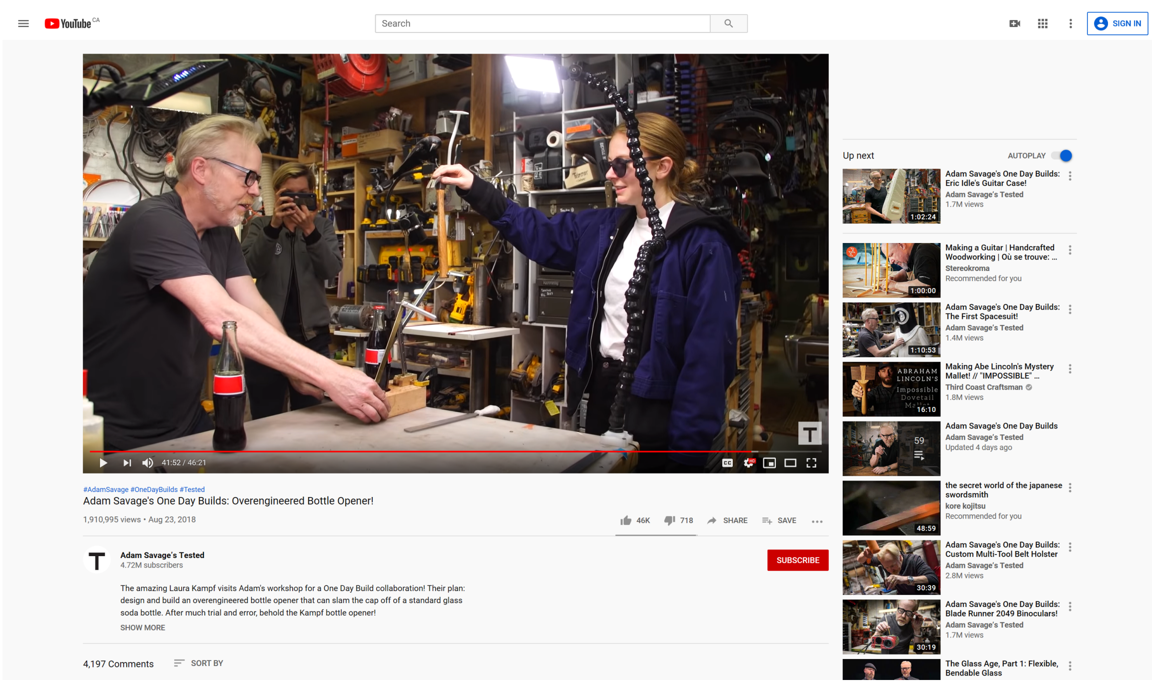


Figure 4-4: Screenshot of Adam Savage's One Day Builds: Overengineered Bottle Opener! from YouTube.[4]

While the video demonstrates each step of the project and the materials that

[4] source: https://www.youtube.com/watch?v=MxL0oriXkMc

are being used for building the device, the ability of viewers to replicate the build is hindered by many factors. First, most of the materials are only verbally described without precise measurements of any of the parts. While the video format makes it more entertaining to watch, it is clear that videos support the qualitative data much better than the quantitative data. Second, Adam and Laura use a wide range of skills, such as working with wood and metals, which are quite hard to master. With no accurate description of how to use each of the tools, it is almost impossible for a novice maker to be able to repeat any of the activities that they perform in the video.

On the other hand, the video clearly captures the decision-making process, such as discussing the inspiration behind the product. For example, they mention in the video that the product is just a novel product and is not made as a solution to any specific problem. Moreover, the video shows the moments when they faced challenges and how they dealt with them.

Therefore, the video format provides the aforementioned advantages; however, if you are given the final product, it is quite challenging to locate the parts of the video that provide information about a specific part of the product that you are interested in. Information about the specific parts of the product is distributed across the video and it is not easy to locate all at once.

4.1.5 Reflection

The documentations of all the artifacts that we examined used texts, pictures, videos, and digital files. However, the way each of these formats were used were different based on the platforms and the makers' preferences. For example, Becky uses her video to explain her inspiration for the project in addition to a video of her making process, while Clarissa uses her video to only provide a quick how-to instruction on building the project. One can claim that the Overengineered Bottle Opener is more for entertainment, but at the same time, it does provide a very transparent view of the decisions that went into making the final product. Tiffany uses videos to capture her process of testing and implementing specific features.

Each of the artifacts contain a different level of knowledge about the projects. Adam Savage's video focuses on storytelling and does not provide details about the specifics of how to build the object. Clarissa attempts to provide a short and quick instruction on how to build her project, while Becky provides instructions and an explanation of her motivation and inspiration. Lastly, Tiffany shows every single decision that she made throughout the project, from inspiration to different iterations, challenges, and so on.

We did not identify any direct connection between the built objects and the documentation we found. While there are visual signs of the type of fabrication techniques used on each of the objects, (e.g., the metal joint on the ring in the Silver RFID Ring project visually portrays what technique was used in the ring's assembly), there are no other connections between the physical objects and their documentations.

From the data we collected in this step, we realized that there is clearly a lack of connection between physical objects and their documentation. We found that in some cases, either the quantity of the data or the how-to structure of these platforms made it difficult for users to access information about specific design decisions. Becky and Clarissa's focus on step by step instructions make it hard to find details on the inspiration of each aspect of the project, and Tiffany's transparent style provides too much information on the process that might make it difficult for the user to narrow down on the specific information that they are looking for.

4.2 Interviews and Brainstorming Sessions

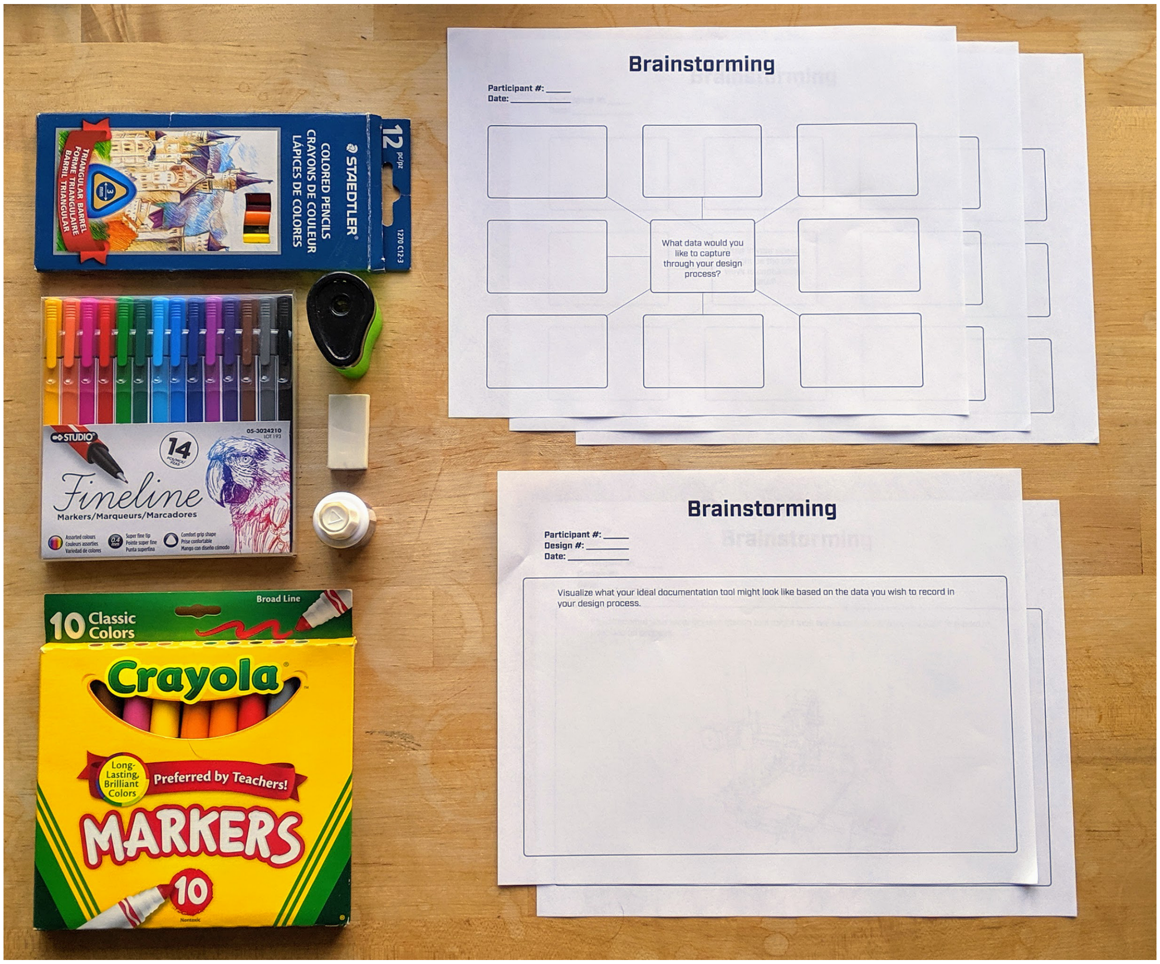


Figure 4-5: Interview and Brainstorming sessions set up.

During these sessions, we wanted to focus on identifying makers' practices. We wanted to learn about what data makers want from their making process and how they want to capture and visualize this data. We divided their feedback into three topics, capturing data, embedding data, and retrieving data.

Four out of the five participants identified that attaching documentation data to the physical object as highly beneficial for them as makers, and argued that it would help them better understand the documentation. They pointed out that the pictures that are typically used in online documentations do not allow them to fully understand what is happening in the object. Participant 5 highlighted that "having the physical object really lets you explore the issue in the way that you would want to view it", whereas photos limit your interaction and only allow for you to look at the object from certain angles.

Importantly, the participants raised two particular points that need to be considered when data is being embedded onto an object. Participant 1 raised the issue that "not all the data should be shared with anyone who has access to the physical object." Participant 2 stated that documentation should not disturb the physical object's aesthetic.

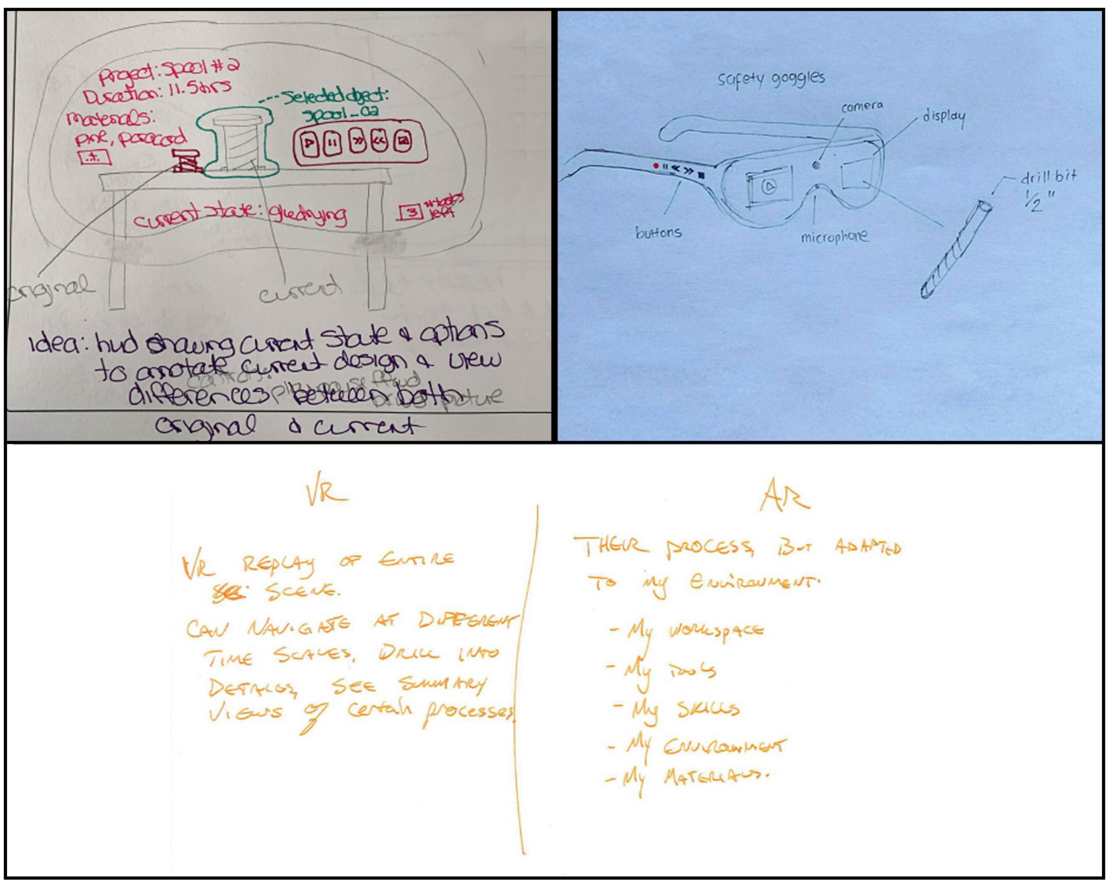


Figure 4-6: Sample brainstorming of AR and VR solutions by participants.

For data visualization, participants 2, 3, 4, and 5 recommended an AR system to present data on top of the physical object. Participant 4 suggested an AR system that "replays the entire scene" with the ability for the users to "navigate at different time scales, drill into details," and "see summary videos of certain processes." Participants found this especially useful as it placed the documentation data next to the object, allowing for a side by side view of both objects at the same time. They also pointed out that seeing an example of the activity happening live would help them while they are building their own version of the object.

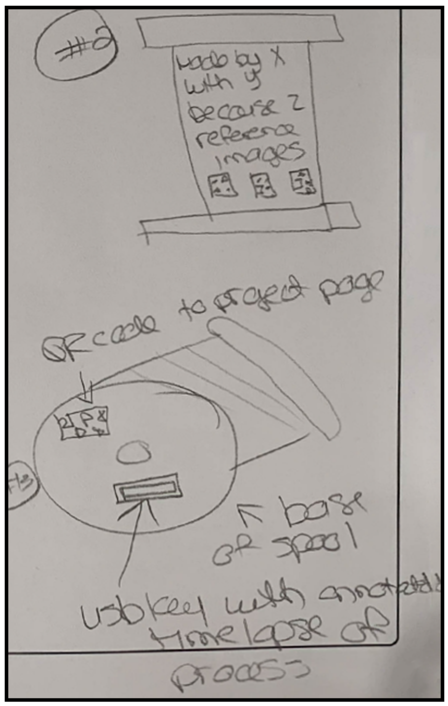


Figure 4-7: Sample brainstorming of tags embedded onto objects solution by partic ipants.

Participants 1, 2, and 5 proposed using tags that are embedded into the physical object to connect the object to its documentation. The tags need to be hidden so as to not impact the object's aesthetic. In addition, participant 2 suggested that underneath the object or hidden inside it, we can place "engraved info about the materials and software tools." Participants identified that the tags would allow them to attach any form of data to the physical object, and that the shape of the tags can inform the users about the kind of data they should be expecting when scanning the tags.

Furthermore, all five participants pointed out that they only begin building documentations after they finish their project. During building, they try to capture as much data as possible by saving the different iteration files, taking photos of their steps, or recording videos of their testing. When the participants are busy building their physical product, they tend to forget about capturing data, and the more complicated the process, the less likely they are to remember to capture data. In addition, the constant switching between making and capturing data slows down their building speed, which might cause them to make more mistakes when they switch back to their making mode.

Participants 1, 4, and 5 stated that they also use photos and videos throughout their process, but that by the time they get to documentation building, they normally forget the reason that they had captured those data. Additionally, they mentioned that during documentation building, they might realize that they forgot to capture certain data or that their documentation does not easily convey the point that they are making.

Overall, informed by the ideas that the five participants suggested, we came up with a workflow for documentation of physical interactive devices that consists of three separate sections. The first section is an application that would provide a layout for the documentation and allow users to attach the data that they are collecting during their making process to the appropriate section in their documentation. The application should also prompt users at different stages to collect appropriate data during making that is based on the task they are performing. This section would allow makers to collect appropriate and organized materials for creating strong documentations. The second section is a web-based application that would connect the collected data from the first stage to tags, and these tags would then be embedded onto the physical object. The final stage of the application would be an AR system that detects the embedded tags and retrieves the data that pertains to each tag.

Each section of the solution we came up with required a large amount of research and testing. However, because the goal of this thesis was more on testing the effect of connection of physical devices to their documentation, we decided to build a simple prototype that would allow connecting the collected documentation information to tags. The tags would then be embedded onto the 3D model of the built object. Then, using a web-based application to detect the tags and retrieve the data associated with them.

Inspired by the brainstorming data we collected, we decided to build a web-based application that would allow users to add information to tags and then scan the tags to retrieve the information. In this way, the users will have the ability to attach any data format to the object, and by examining the object and the tags placed on it, the user can know what kind of data to expect. We decided to develop a web-based solution as they are more accessible to makers than AR glasses. We will elaborate more on the actual design and implementation of the prototype in Chapter 5.

4.3 Summary

Through our artifact analysis, we realized that makers use text, photos, videos, and digital design files in their documentation. Most of the documentations are focused on instructions for rebuilding the object, with a new form of documentation that is more transparent about the design decisions that were made. In addition, we identified that there is no existing platform that allows for any connection between the physical model and its documentation.

After interviewing and brainstorming with makers, we identified a series of issues regarding collecting data, embedding the data onto the physical objects, and retrieving back that data from the physical objects. We came up with an application to address all these issues. However, to specifically focus on how the connection of the physical objects to their documentation influences the reflective experience, we narrowed down our suggested solution to a web-based application that provides the main workflow for a documentation tool.

THIS PAGE INTENTIONALLY LEFT BLANK

Chapter 5

Documented: Design and Implementation

Documented is a web-based application designed to create a new form of interaction with the documentations of interactive physical objects.The goal of this prototype is to create a pipeline, which begins from the creation of the documentation and finishes with the document being ready to be viewed and shared through a 3D model of the object. The application consists of three sections, encoding, processing, and retrieval of data.

In the first section (Figure 5-1 (b)), the application provides users with four tags. The users are allowed to connect text and up to four files to each of the tags, and these files could be picture files, audio files, video files, or design files. We chose four files because it allows the users to attach one of each type of file to each tag and lets the user be creative in how they want to organize their documentation data. After the completion of the first task, the users are navigated to a 3D modelling sketch in Tinkercad, a 3D CAD design tool (Figure 5-1 (c)). In this step, the users position the four tags onto the 3D model of the object they are documenting. The model

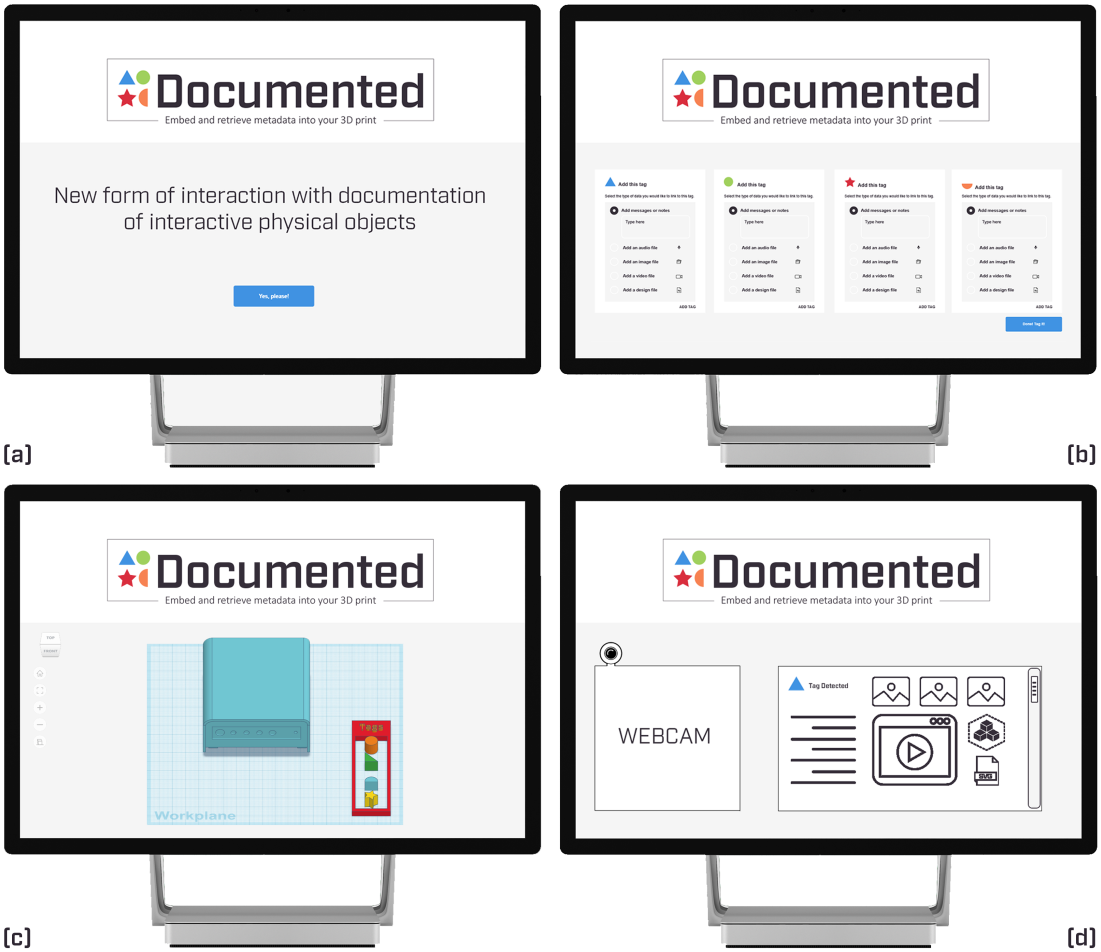


Figure 5-1: Documented pages: (a) Startup (b) Data attachment to the tags (c) Embedding tags onto the 3D model of the object(d) Data retrieval.

can then be printed with the embedded tags using any 3D printing technique. In the final stage of the application (Figure 5-1 (d)), users scan the tags using a webcam, and upon detection of the tag, all the information associated with those tags will be displayed on the screen for the users to navigate through.

In this chapter, we discuss some of the design decisions that were made during this prototype's building process, as well as some of its strengths and weaknesses. We will also talk about the technologies used and their limitations.

5.1 Encoding Data

We created this application using P5, which is a JavaScript library. P5 allowed us to quickly create a simple user interface (UI) for the application so that users could upload their files to each tag. The library contained predefined features that could be used, but there were certain limitations associated with them. One example of a limitation was the file upload button because while its function is predefined in the library, there is only one type of interface for the button. In addition, the function for the button only allowed certain types of files to be uploaded, such as pictures, videos, and audios. We wanted to be able to attach design files as well and to get around this issue, we decided to provide the address for the design files rather than the files themselves.

We chose to use 3D printing technology to embed tags onto 3D models of the objects. To make sure those tags are printable with the common printers that are accessible to most makers, we used a Prusa i3 MK3S printer and ran a test on what types of tags we can use. We were looking for tags that would be both human-readable and machine-detectable. We want users to understand what data they should expect to find on the object by just seeing the object's 3D model. At the same time, the tags should be easily scanned by our built prototype so the system can retrieve the information that is attached to them (See Section 5.3 for more details).

We tested three types of tags. In the first series, we added a simple shape embedded on top of the 3D model of the object (Figure 5-2 (a)). In the second series, we added simple shapes as engravings on the 3D models (Figure 5-2 (b)). And finally, for the third series, we tried adding patterns onto the 3D models (Figure 5-2 (c)).

We found that simple shapes in the first series we tested, such as the semi-circle, the star, and the heart, were the best options and worked both when they

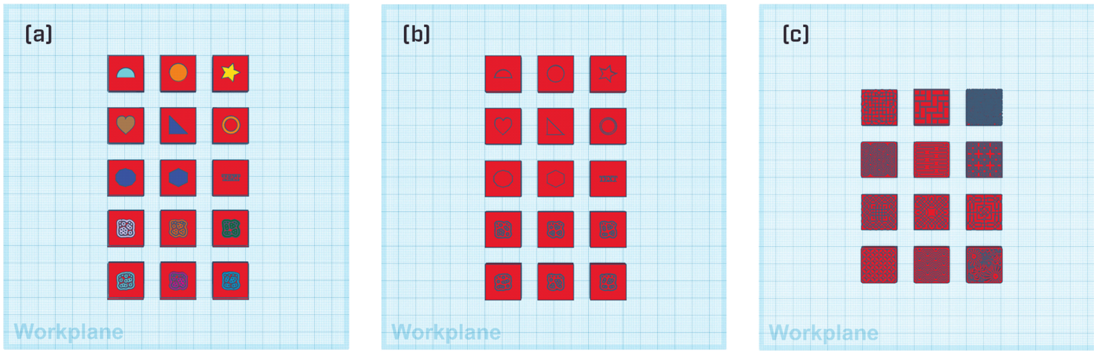


Figure 5-2: Tested tags: (a) Simple shapes (b) Simple shapes as engraves (c) Patterns.

were embedded on the object and when they were attached as engravings. The more complex the shape became, the less accurate the 3D printed tags were, and this was due to the limitation of the 3D printer. Each printer has a certain level of accuracy, and in our case, the printer could not manage all the small details of some of the shapes. For instance, some of the patterns came out as flat surfaces because they were too thin and narrow for the 3D printer to detect and print.

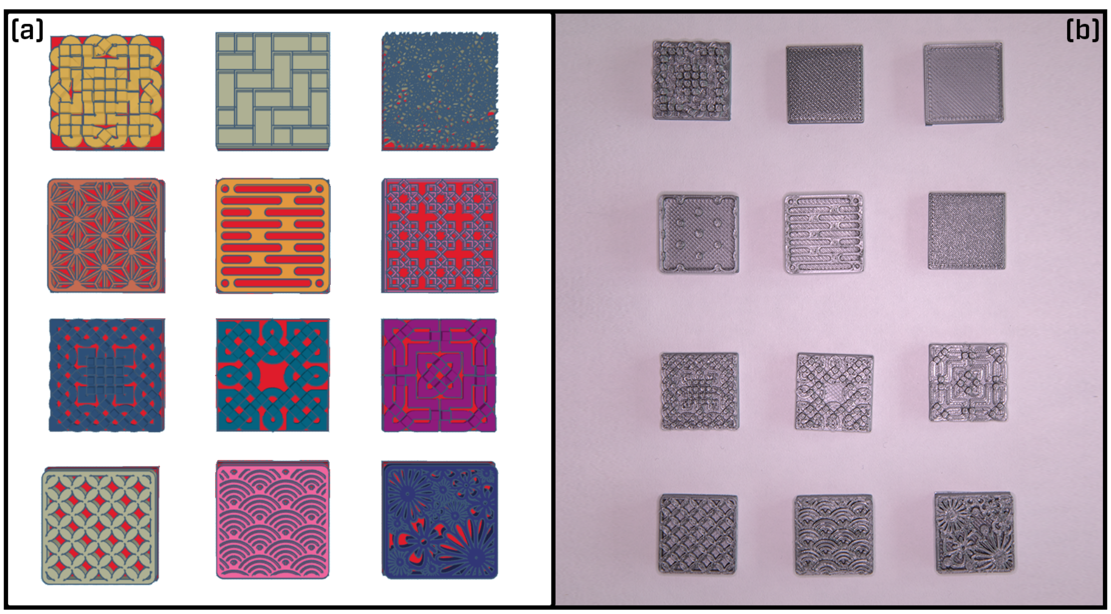


Figure 5-3: Difference between designed pattern and the printed objects: (a) 3D models of patterns (b) 3D printed patterns.

We noticed that the engraving allowed more details to be added to the object.

For instance, the text object was only visible when we engraved it into the model, whereas when the text object was embedded, the two ‘T’s were printed as “I”s.

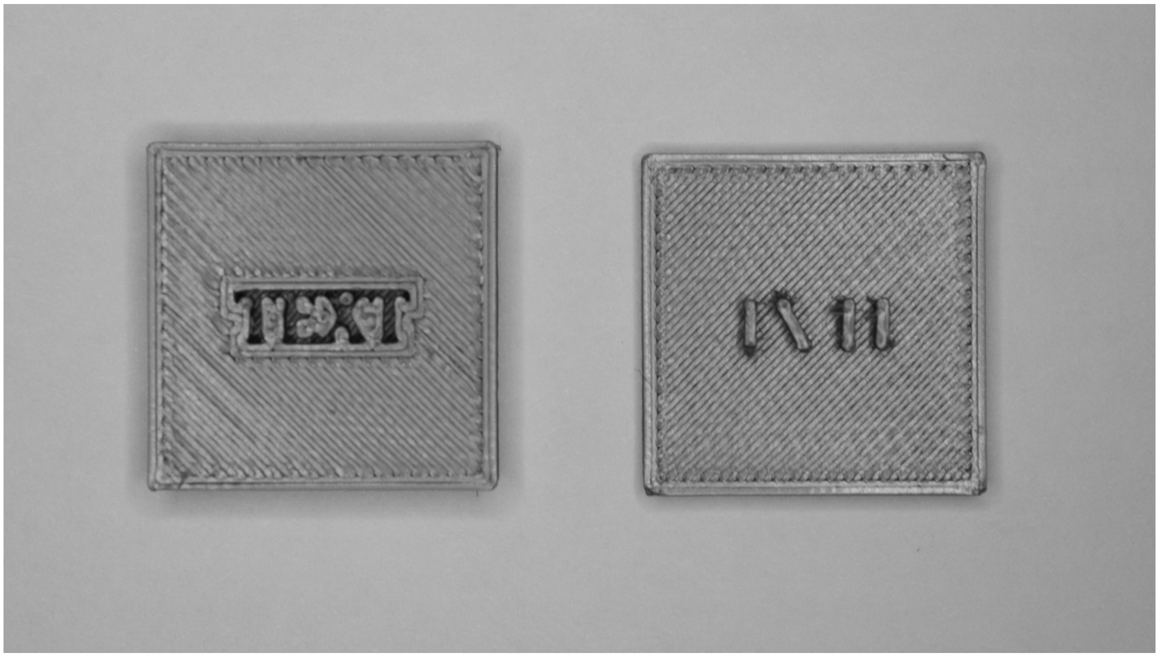


Figure 5-4: Difference between text being protruded vs engraved.

As our primary question relates to exploring the benefits and limitations of directly embedding documentation-related information onto the object being created, we focused on using simple shape tags. Further, during our evaluation study, we asked our participants about the kinds of tags they prefer to use in their work.

5.2 Embedding Tags

The next step was to attach the selected tags onto the 3D models of the objects. We needed the system to be user-friendly so that all the makers, including those with limited knowledge of the technology, could be able to move the tags on the object and place them on their desired locations.

Tinkercad provided us with a user-friendly way to model the object. Currently, users are navigated to a premade sketch on Tinkercad that includes an example 3D model and some tags models. Users are also able to import other objects 3D models and attach the tags onto them.

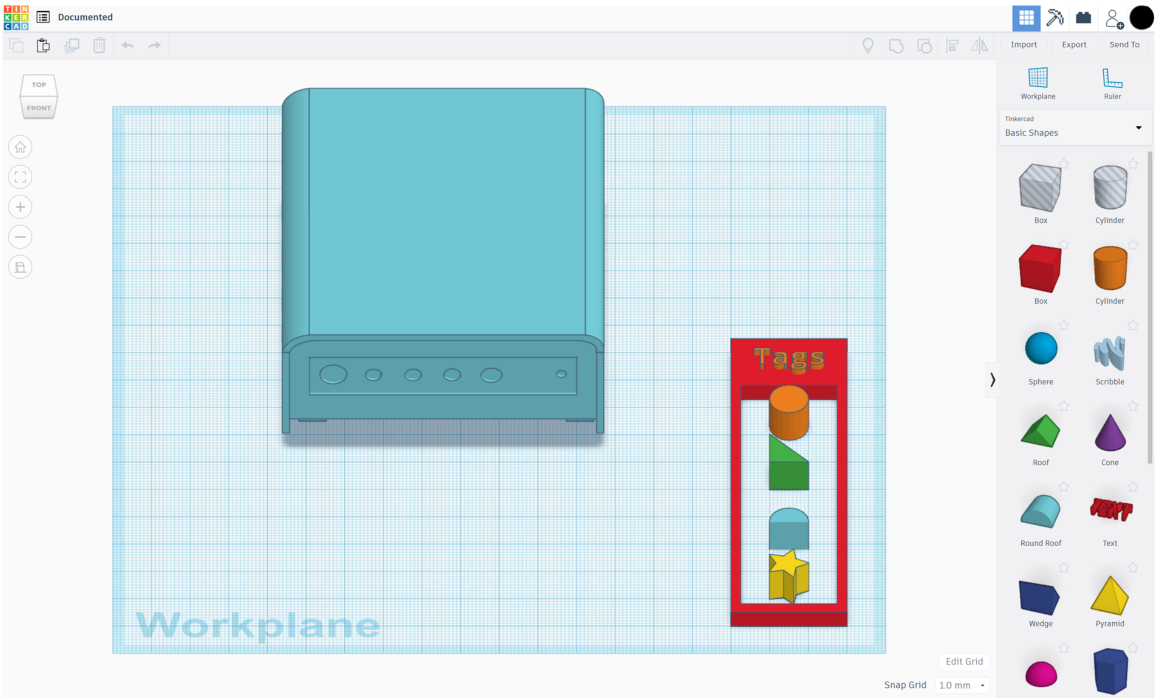


Figure 5-5: Screenshot from our designed Tinkercad with a 3D model.

We wanted to experiment with various factors, such as the tags' locations and their level of permanency. For example, we wanted to know if the users preferred the tags to be engraved into the object or rather protrude out of it, and if so, to what degree. Tinkercad provided us with the perfect tool to experiment with all these options.

In the study, people did not print objects and instead thought about premade options. We showed four examples of the tags to all our users: 1) all four tags placed underneath the object and protruding out, 2) all four tags placed underneath the object and engraved, 3) four tags placed at different locations protruding out, 4) and four tags placed at different locations and engraved.

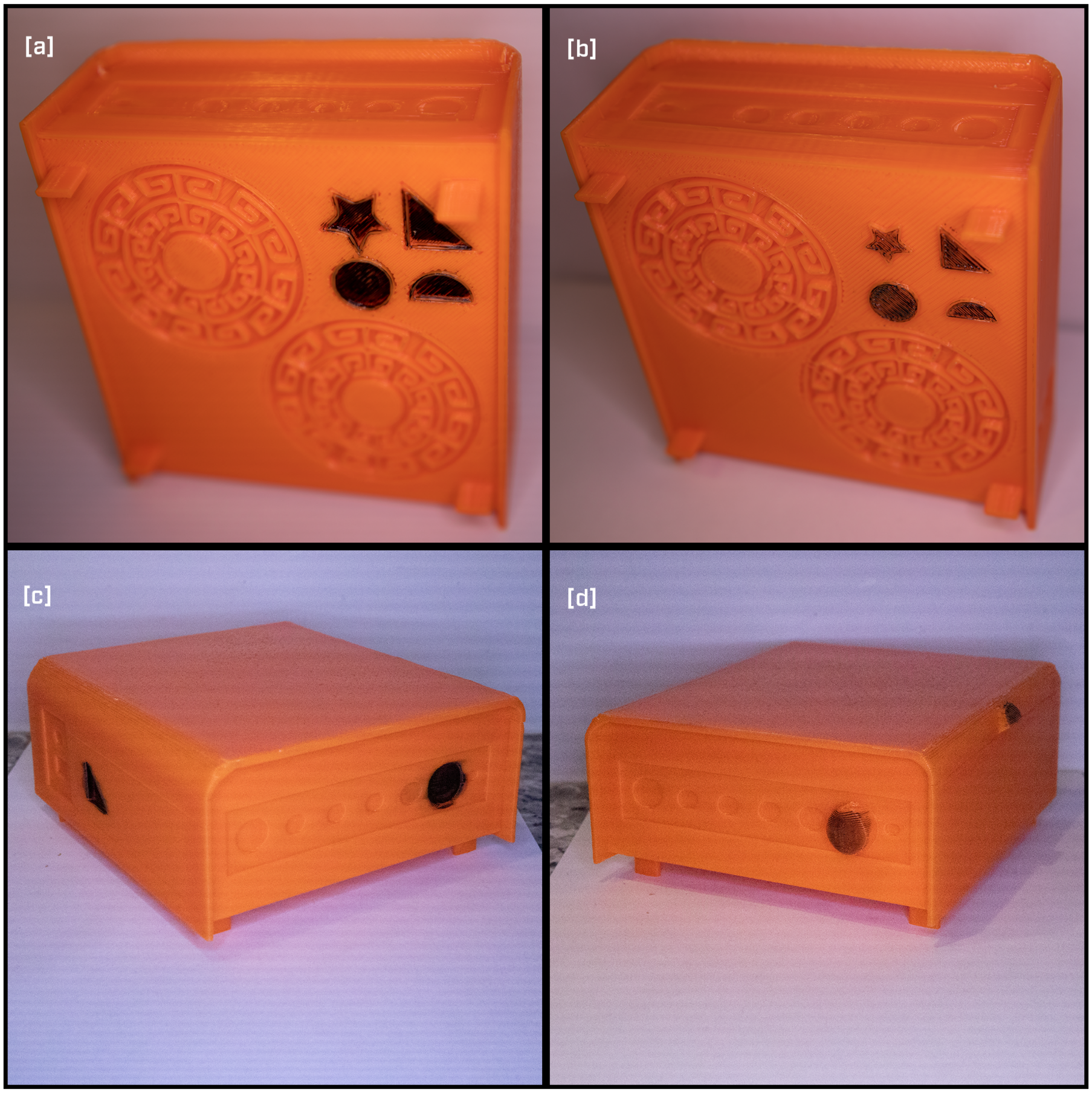


Figure 5-6: Printed Models with tags: a) engraved on the bottom, b) protruded on the bottom, c) engraved at different locations, d) protruded at different locations.

We wanted to test and see if users found engraved tags more visually pleasing since they do not clash with the 3D model, or if they preferred when the tags were protruding out. In addition, we wanted to see if the users preferred the tags to be spatially located, or if they wanted all the tags to be in one place hidden from the user.

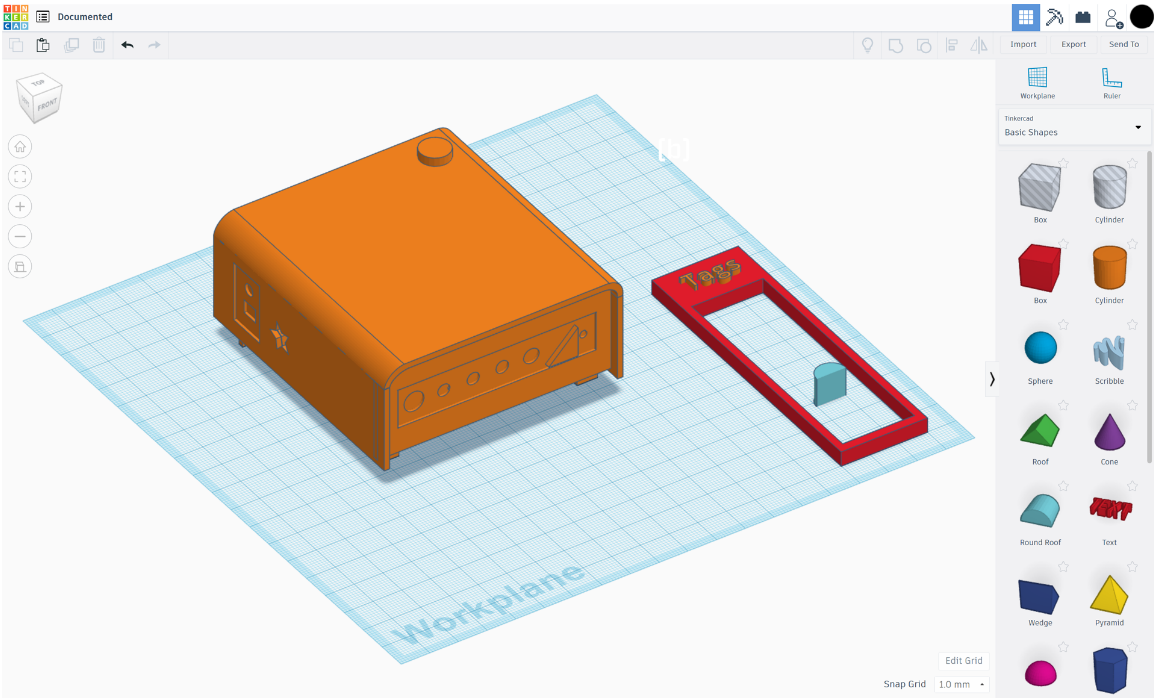


Figure 5-7: Screenshot from our designed Tinkercad with an embedded 3D model.

5.3 Retrieving Data

The final step that we needed to address was how to detect the embedded tags and display the information associated with them. We decided to use Teachable Machine, which is a software developed by Google that allows people to create machine learning models for their websites. They can teach the machine to recognize artifacts by uploading an unlimited number of pictures, audios, and poses. We then used ML5, another JavaScript library that focuses on machine learning, to create a webcam. The webcam would then detect the tags embedded onto the built model. After, the system detects the probability of each of the cases defined in the Teachable Machine and matches the tag to the item with the highest confidence rating.

To test the tags used on the object, we started with nine simple shape tags. The tests found that only a few of the tags were distinct enough to be detected with

[1] source: https://teachablemachine.withgoogle.com/

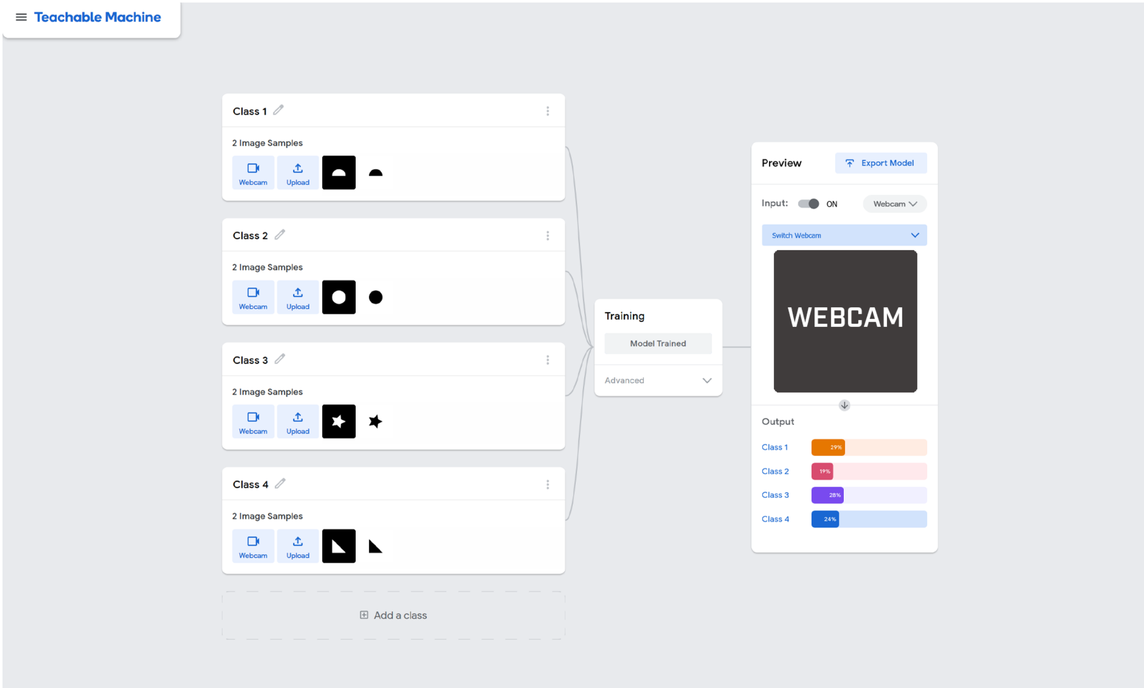


Figure 5-8: Screenshot from Teachable Machine. [1]

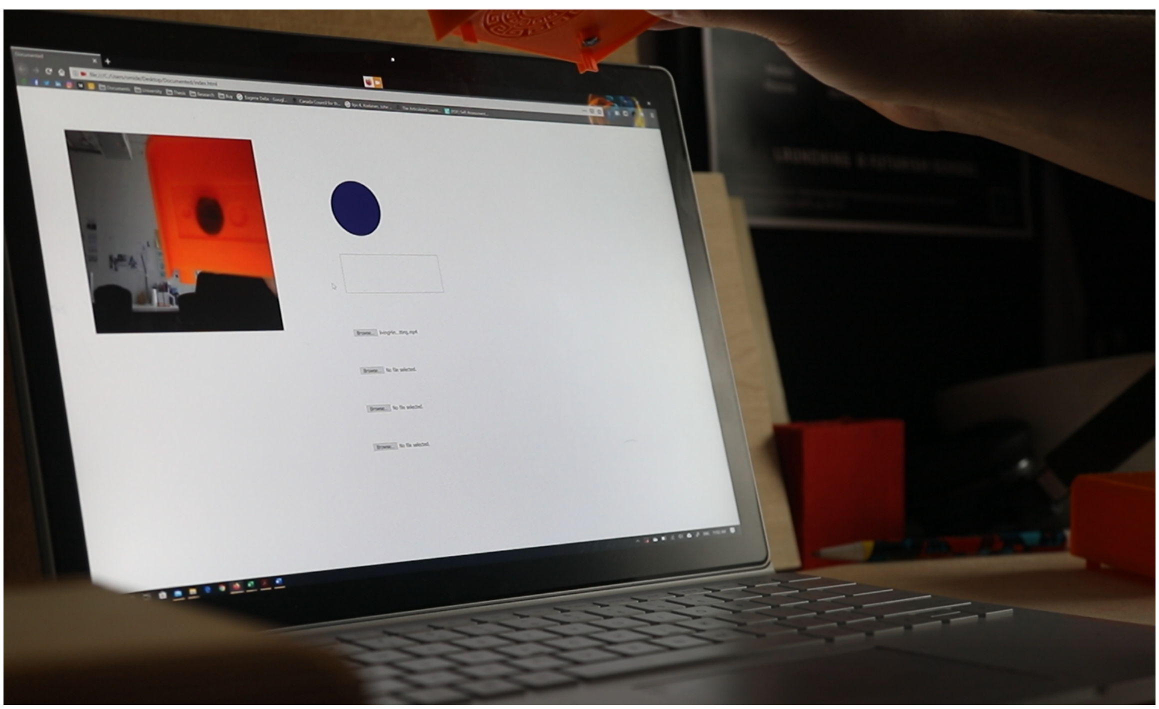


Figure 5-9: User testing the retrieving process.

high accuracy. To address this problem, we chose four of the tags that the system accurately detected with a high confidence rating, which included a circle, a semi-circle, a triangle, and a star. One limitation of our prototype is that it can only recognize one tag at a time. In addition, the system is unaware of the position (x,y,z) of the tag on the object.

Another problem we noticed was the effect of lighting on tag detection, such that changes in lighting created different shadows on the model and hindered detection in some scenarios. To resolve this problem, we trained the machine with 200 pictures of each of the tags in different lighting conditions.

5.4 Summary

The main goal of our prototype was to create a system that we could use to run a study to evaluate our new proposed form of documentation interaction. We used P5 and ML5 JavaScript libraries to build our prototype, Tinkercad for 3D modelling needs, and Google teachable machines to create a model for our camera to detect the tags.

We did not focus on the system's interface, but rather on building a system that would allow the users to go through every step of the project. Although the technologies we used had certain limitations, we were still able to create the overall workflow.

Chapter 6

Evaluation

In this chapter, we discuss and analyse the data that we collected during the implementation phase of the study. We will then talk about the feedback that we received about the entire experience. Finally, we will summarize our findings from the evaluation study and discuss our future work.

6.1 Results

We were interested in evaluating if our prototype promoted the end-users to self-reflect about the documentation (i.e., the makers themselves or people interested in rebuilding or learning about the project), and whether this facilitated a deeper understanding of the object and its design process. Through our post-study survey, we found that all participants confirmed that the prototype helped them gain an understanding of the object, and the experience as participant 7 phrased it was, "eye opening". All participants indicated that they would be interested in using this prototype to document their future projects.

6.1.1 Data Organization and Tag Shapes

Our participants identified three main strategies in categorizing their documentation data:

1. by their media (video, photo, audio, and text);
2. by design process stages (ideation, iteration, instructional steps, and evaluation)
3. by the level of knowledge (technical challenges, engineering challenges, and design challenges)

Participants 2, 3, 4, and 10 said that they would prefer to categorize the data based on their media, and stated that they currently follow the same structure but digitally. For example, participant 10 pointed out that during their documentation process, they already "put all their documentations into separate folders based on the media." This helps them navigate through all the documentation data. While participant 3 was happy with using simple shapes for the tags, participant 10 said that it would be nice to have tags that are icons for the type of data being presented, for instance, a camera icon to represent photos. Participant 10 also added that it would be nice if they "could have multiple copies of the same icons for cameras at different places and the machine should be able to detect them."

Participants 1, 5, 6, and 12 suggested organizing the data based on design process stages. As participant 6 pointed out, those are typically the "type of data they want to know about." In addition, participants 8 and 11 suggested organizing the data based on the level of knowledge, as this is how they divide the project in their mind. Both groups wanted to categorize the data base on the specific topics that they related to. The first group, as participant 6 suggested, focused on stages of design, such as "how-to", "inspiration", "testing", and "iterations." Whereas the second group, as participant

11 suggested, focused on different levels of knowledge, such as “engineering/skeleton” and “design decisions”. The participants formed these categories based on their ideas of what a design process and its various components looks like, which differed among participants due to their unique design processes.

When organizing data based on a specific topic, some participants were happy to use the simple shapes as long as there was some standardization. Participant 12 pointed out that the tags would become a barrier if the users had no idea what each of the tags meant,, and they stated, “but if that [the tags] is mentioned beforehand, then it probably solves the problem.”

6.1.2 Tag Placements and Style

Another parameter that we wanted to test was the placement of the tags and we explored two options. We wanted to see if there was a difference in how the users would place the tags if they were placing them on the final product that would be given to other people, or if they were placing them on a 3D printed model of the object that would be used only for documentation. All participants found both options useful in different scenarios, but they felt that they would place the tags very differently depending on the case.

When it came to the placement of the tags on the final physical object, all participants wanted the tags to be hidden, either by strategically placing them in a location on the object that will not be visible at first glance. Participant 12 suggested that a sticker mechanism can be used that can be taken of the object when the user is done exploring the documentation. The latter example is similar to the idea of a barcode sticker that can be taken off if the user desires. Lastly, participant 8 mentioned that the tags should not be “clashing with the design.”

On the other hand, when it came to placing tags on 3D models that are used only for documentation, all participants wanted the tags to be fully visible and placed at strategic points on the object. These locations would depend on the type of information that they wanted to encode.

Participant 7 suggested an alternative. They stated, "if there is something important about the functionality [of a part of the object] or the making process... I want to document about this specific part. So probably the tag will go here [pointing at a specific part of the object]." But otherwise, the participant preferred it if the tags were all together on a specific part of the object because it will show the individual that "there are four pieces of important information that they need to know."

Additionally, participant 3 highlighted that we can give more precise definitions to each of the tags by having tags with varying sizes and colours. For instance, participant 3 stated, "if they [the tags] are smaller, then it may mean subcategories." Therefore, in this way, the information can be taken in by just glancing at the tags. Moreover, the participant raised the issue that the experience needs to be much more streamlined for it to become more widely used, which is something that is currently missing from the prototype's UI.

6.1.3 Data Retrieval

All participants found the data retrieval process enjoyable. Participant 2 even described the interaction as a kind of game that made the process of reviewing the documentation more entertaining. They added that if documentations were this entertaining, they would have gone through more documentations in the past.

Participants found it quite difficult to use the webcam on the computer. Participant 10 noted that the view of the webcam was distracting and they prefered to "only see the tag and the data." Participant 9 stated that they felt uncomfortable with the camera pointing at their face. Additionally, we observed that all the participants found it quite difficult to navigate the physical object in front of the webcam. This was because of the webcam's mirror effect and the fact that the object had to be placed very close to the webcam for the system to detect the tags.

6.2 Participant Recommendations for Prototype Improvement

The participants had a few recommendations regarding potential future works. The point that the participants stressed the most was that the whole process required a lot of effort on their part. Participant 1 mentioned that "too much work effort needs to be done in order to get to use this system." The participant expanded on this by adding that, "if it's industry, they will have a person who's dedicated basically to look after the documentation process because they have people. And for them this would be fantastic."

Another suggestion by a few of the participants was to use an AR system rather than the web-based application that uses a webcam to show the results of each tag on top of the object. However, regarding the web-based application, participant 12 highlighted that, "[the web-based application] makes the navigation through files easier...you can open all different formats of files". This would be more difficult when using an AR system.

One thought that all the participants shared was the need for a better UI for the web-based application that would streamline the experience. Participant 7 stated that they "wanted to do the second step [embedding of tags] at the same as the first one [attaching data to the tags]" because both steps affect each other. In addition, the method for uploading the files was very time consuming, which is clearly a step that could be addressed in future work.

Participant 8 also informed us that this system could be expanded to 2D works. If the same system could be used to add tags to 2D objects, such as websites or graphical designs, it would help the participants in their professional work.

6.3 Discussion

In this thesis, we set out to explore an in situ documentation format that would facilitate a more reflective experience for end-users (i.e., makers themselves or other people who are interested in rebuilding or learning about the object). We wanted to examine 1) the users' interactions with the system, and 2) how effective the system was in facilitating a more reflective experience.

Regarding the users' interactions, participants described their experience as insightful, engaging, entertaining, and meaningful. One participant (participant 2) reflected on the interaction and described it as "fun", "easy", and "less intimidating". Participants pointed out that using the tags and the simple retrieval process made the object's documentation more accessible and made it easier to navigate through the documentation.

The documentation's entertaining interaction and easy accessibility allowed the participants to gain a deeper understanding of what the object was and how it was created by just examining the physical object. Overall, this would increase the probability of people exploring an object's design process, and we see this as an opportunity to increase consumers' knowledge about the objects that they use.

Similar to the results of previous work in this field, our participants reported that the invitation to explore the documentation and its easy accessibility, helped them gain a deeper understanding of the object and how to use it, while also forming a deeper connection with the project. Overall, this increased their recognition and enjoyment of the object. This is similar to Spyn and Encoding Data into Physical Objects with Digitally Fabricated Textures, where individuals found that the association with a physical garment enhanced their appreciation of the process and the created product.

Regarding the users' level of reflection, our survey (Appendix B.4) found that all 12 participants felt that the experience provided them with an understanding of both the object and the fabrication techniques used in building it. The system provided them with information behind the inspiration, motivation, and goal of the project. Furthermore, the direct relationship between the object and its documentation allowed them to directly look for specific fabrication techniques that they were interested in and reflect on those techniques. As participant 9 pointed out, "the hinge mechanism is very interesting, and I want to learn more about how that was done." This is a new level of reflection that is promoted by our prototype. In existing documentations found on online platforms (e.g., Instructables), the data are organized based on the final projects, which allows for reflection on the general object but does not provide direct insight into the fabrication technique.

Figure 6-1 shows all the participants' answers to the survey. We designed the survey with the first four questions focused on the reflection on the object at the hand of the participants, and the last four focused on the documentation style and how much reflection it promotes. In most cases, all participants agreed with our statements on having a certain amount of reflection about the documentation. Furthermore, they reported that they gained a deeper understanding of the object and the techniques used to build the object. There were certain cases where participants disagreed with the statements, such as participant 9, who disagreed with our critical

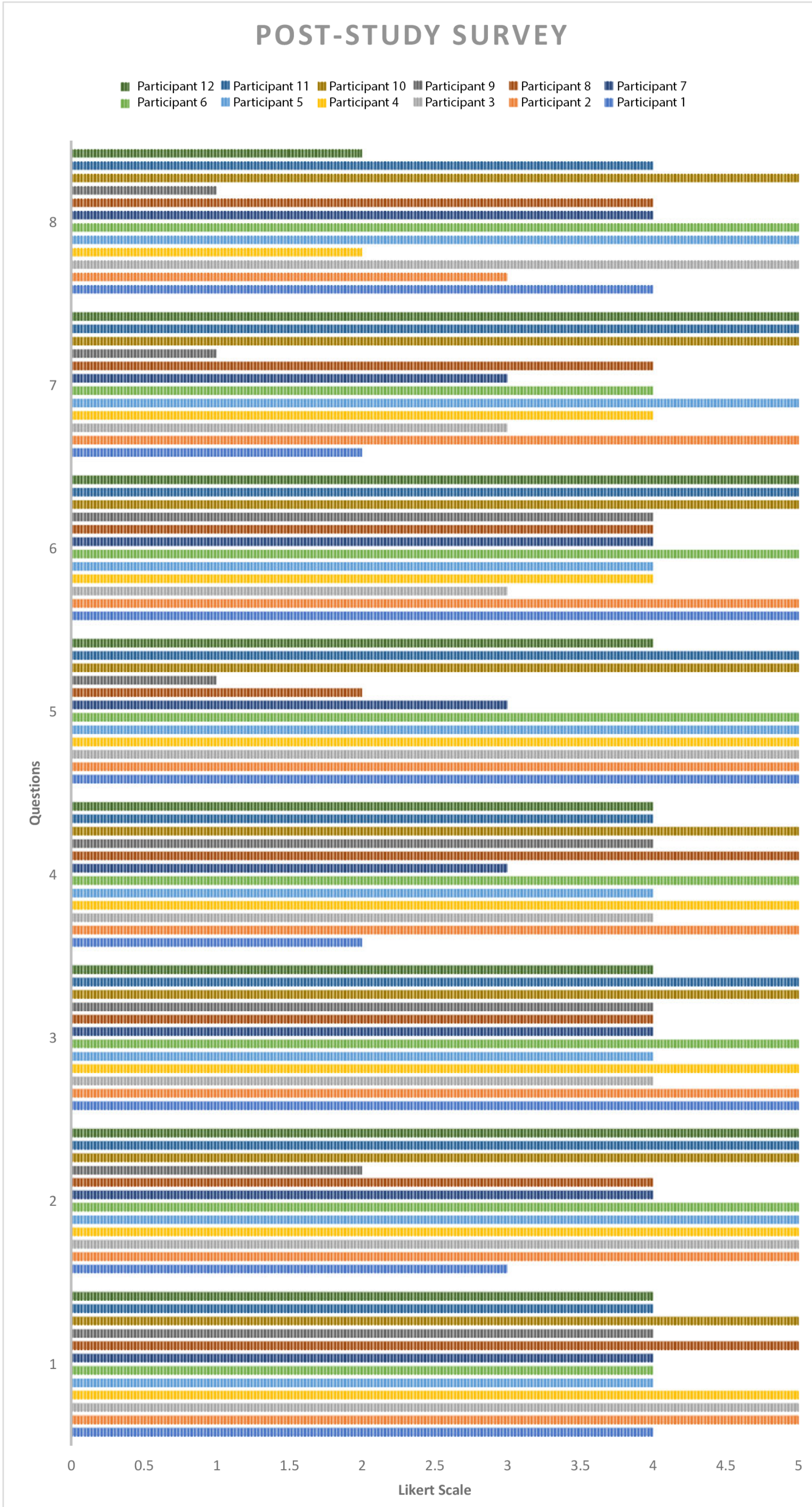


Figure 6-1: Post-study survey result.

reflection questions. They stated that this was only due to the limited time that they spent with the project, and mentioned, "this was too little time with the documentation". Accordingly, they reported that they believed that the experience would have facilitated more reflection if they had more time with the documentation or a chance to compare it with typical instructional documentation styles.

Participants confirmed that our prototype promotes a more reflective experience, but they claimed that they needed to spend more time with the prototype in order to identify their old way of documentation as a "faulty system". This is why many participants disagreed with question 8.

We also received feedback on issues that were not the primary objective of this thesis. Participant 10 reported that this form of interaction addresses his issues with typical documentation layouts. With this prototype, he can easily divide his information without worrying about the order of materials in the documentation. This shows the other benefits of this system beyond increasing people's understanding of objects.

6.4 Summary

From our study, we found that many of the choices depended on the object the user was prototyping. All participants agreed that the tags should be standardized because it will help the user immediately understand what information they can expect to find on the object before scanning them. Participants found it useful to embed tags onto the final physical object as it provided them with more information about the object by just seeing the tags on the item; however, in that case, they require the tags to not disturb the object's aesthetic. Therefore, the tags should be hidden or be removable so that the object's aesthetic would not be impacted by the tags. Participants also found that embedding tags onto a 3D model of the object to be useful because it helped them navigate through the documentation without worrying about the limitation of working with the final object. In the case of a 3D model of the object, participants wanted the tags to be placed at a certain location and wanted them to be bigger and easy to find as it would make it easier to access the information. The participants also confirmed that their only reservation is the system's UI, but that if improvements are made to the UI, they would want to use the system for their own documentation practices.

Chapter 7

Conclusion

In Chapter 1, we introduced the overarching goal of this thesis as furthering our understanding of documentation for interactive physical objects and suggesting a new way of connecting online documentation to the physical artifact.

In this chapter, we will first revisit the goals of this thesis, discuss what we found, and conclude with suggestions for future research. Finally, we will highlight the importance of this work and draw a picture of the future of this research.

7.1 Revisiting Thesis Objectives

In this section, we review the progress we made towards answering our research questions.

Question 1: In what ways do people currently document their making (i.e., creation of interactive physical devices) practices, and what are the related challenges they face?

Our preliminary studies introduced in Chapter 3.1 and further discussed in Chapter 4 display our attempt at understanding current documentation practices and the challenges that makers face. In this thesis, we make an attempt to address this question by performing an artifact analysis (Chapter 4.1) on four documentations of physical interactive devices, where we found that most current documentations are focused on instructions for rebuilding the object, with a new form of documentation that is more transparent about the design decisions that were made. We found that none of the existing styles allowed for any connection between the physical model and its documentation. We expanded on our finding by interviewing five professional/hobbyist makers (Chapter 4.2). During those sessions, the makers gave detailed information about their own practices, what type of information do they document, how do they collect those information, and how they then visualize the information in their documentation, and provided us with solutions to what they thought was missing from their current documentations and what they envisioned as the perfect documentation, having a physical or virtual copy of the object to explore the object and its documentation.

Question 2: How might we build new tools that would facilitate a more reflective in situ documentation style?

In Chapter 5, we introduced our proposed tool, Documented, a web-based application that introduces a new method of interacting with documentation by creating an in situ documentation style. We then conducted an evaluation study on the built prototype (Chapter 6), where we asked makers to evaluate the workflow of the prototype and asked about their reflection about the object. We found that the system makes it easier to access the object's documentations, which facilitates a deeper understanding of the object. In addition, the users reported that the system enhanced their level of reflection on the object. They were also invited to explore and reflect on the fabrication techniques that were used in the building process.

7.2 Limitations

We found two different levels of limitations in this thesis:

Limitations of the prototype: As discussed earlier in Chapter 5, the existing prototype is limited in the type of interaction that it allows. The system allows the users to only attach up to four files to the object. Furthermore, the system can only play back photos, audios, and videos, and only provides the digital address for other types of file (more details in Chapter 5.1).

The accuracy constraints of the 3D printers we were using for this study put limitations on the types of tags that we could use. After experimenting with different tags, we chose tags with simple shapes because we found that highly detailed tags are not printable (more detail in Chapter 5.2).

Moreover, the webcam system is only capable of detecting certain shapes. We had to manually take photos of the tags under different lighting conditions so that the webcam could accurately detect them; however, some of the tags remained undetectable under certain lighting conditions (more detail in Chapter 5.3).

Limitations of the study: Due to the lack of time, we had to limit the number of participants that we conducted interviews with in the ideation phase. By conducting more interviews, we could have better understood the challenges and difficulties that makers face when documenting their projects.

For our evaluation study, all our participants were design students and were not a representative sample of makers. Although the participants had a wide range of practices, they were from a narrow field of makers with common background experiences. This narrowed the type of feedback that we could have received from our evaluation study. Most of our participants used documentation for similar reasons in similar formats. Because of that, participants were typically interested in the exploration of similar ideas. If time permitted, we would have expanded the study to other makers to receive a wider range of practices and more extensive feedback on the type of interaction with the prototype.

7.3 Future Directions

In this thesis, we studied the impact of embedding documentation into the object being made and how this would promote self-reflection and possibly facilitate a deeper understanding of the object and its design process. We previously (Chapter 6.2) discussed the immediate future directions that are specific to our built prototype. In this section, we discuss general directions for future work that go beyond the changes to our current prototype.

Expanding on reflection: This system is focused on gaining an understanding of the object, which is only one of the many aspects of self-reflection. Reflection also occurs when the users consider their understanding of the documentation to learn new skills, build new theories, and evaluate their decisions [19]. The task of reflection is then expanded to learning. One of the main future directions is to expand on the type of reflection that this prototype promotes and examine if the prototype can be beneficial in educational contexts.

Currently, in this thesis, we only ran an evaluation study looking if users gain an understanding of the object using our prototype. By running a longer study, where the users get to explore documentation of a prebuilt prototype, and then asked to create a product of their own inspired by the prebuild object provided to them, we can check for more type of reflection promoted by our prototype. In addition, we can use the same prototype and run a comparison study, where users are divided into two groups studying the same object, where one group uses the typical instruction style documentation, and the other use our built prototype. We can then test the users' reflection on the object and compare the amount of reflection that happened during each one of them.

Expanding on the making process: The making process and the task of documentation begins from the moment that the maker is inspired to build an object. The users go through a series of different steps until they get to the final object. As discussed in Chapter 4.2, there are a series of design opportunities that can be addressed. Our current prototype is only focused on a narrow scope of the documentation process, which is when the user wants to connect the documentation to the physical object and retrieve the data. Therefore, there is still a need for systems that help with documentation from the beginning to the end of a project.

7.4 Epilogue: the Future of Learning

Making and the documentation of making is something that people have always done. Although we no longer have to build things to address our primary needs, many still find that they can learn a lot through making. Accordingly, documentation is one of the main ways of promoting learning from the building experience. Researchers and interaction designers should think about how such tools can be used to enhance users' understanding of projects and foster a more reflective experience.

In this work, we envision a novel addition to the current documentation styles that can be found online on various maker platforms (e.g., Instructables). For instance, the next time that you decide to build an object, you can first start by 3D printing a model of the object to explore its documentation and reflect on the object before building it. Imagine having a bookshelf, where instead of books, you have 3D models of projects that you previously built, projects you were inspired by, or projects that you learned something from. When you decide to begin your next project, you can walk up to your shelf, look through the models, and easily access the documentation and the corresponding design decisions that went into building a given object.

We cannot ignore the relevance of this work in the current global public health crisis. The emergence of the COVID-19 pandemic has had large-scale effects on both local and global education systems; therefore, we need to address the necessity for new systems that can support learning inside the digital world. The consequences of this pandemic, such as social isolation and massive shifts in the dynamic and makeup of the workforce,, is changing the current zeitgeist and the public's expectations.. People have started reflecting on what information and skills are essential for them to know or learn versus the things that they can live without. We believe that we will see a change in the line between what was considered formal and informal learning and a substantial shift towards the maker's mindset, which will require new hybrid systems that would promote those learning styles.

We hope that the work presented in this thesis will inspire researchers and interaction designers in the future to focus on the importance of documentation in learning, and develop tools that use these technologies to enhance end-users' reflections about the making process.

Appendix A

Additional Materials for Inspiration Phase

A.1 Artifact Analysis Questionnaire

1. What material is the artifact made of?
2. What function does it serve?
3. How long might it take to make this?
4. Can any of its parts be replaced?
5. Are all of its parts necessary?
6. Does this artifact have any functionality that may not have been intended by its designer?
7. Where would someone use this, and what other artifacts would they have access to?
8. In detail, what is the stereotype of this artifact's user?
9. How does this artifact feel?
10. How does this artifact make you feel?
11. How easy would it be to modify this artifact?
12. Could this artifact be customized by its owner?

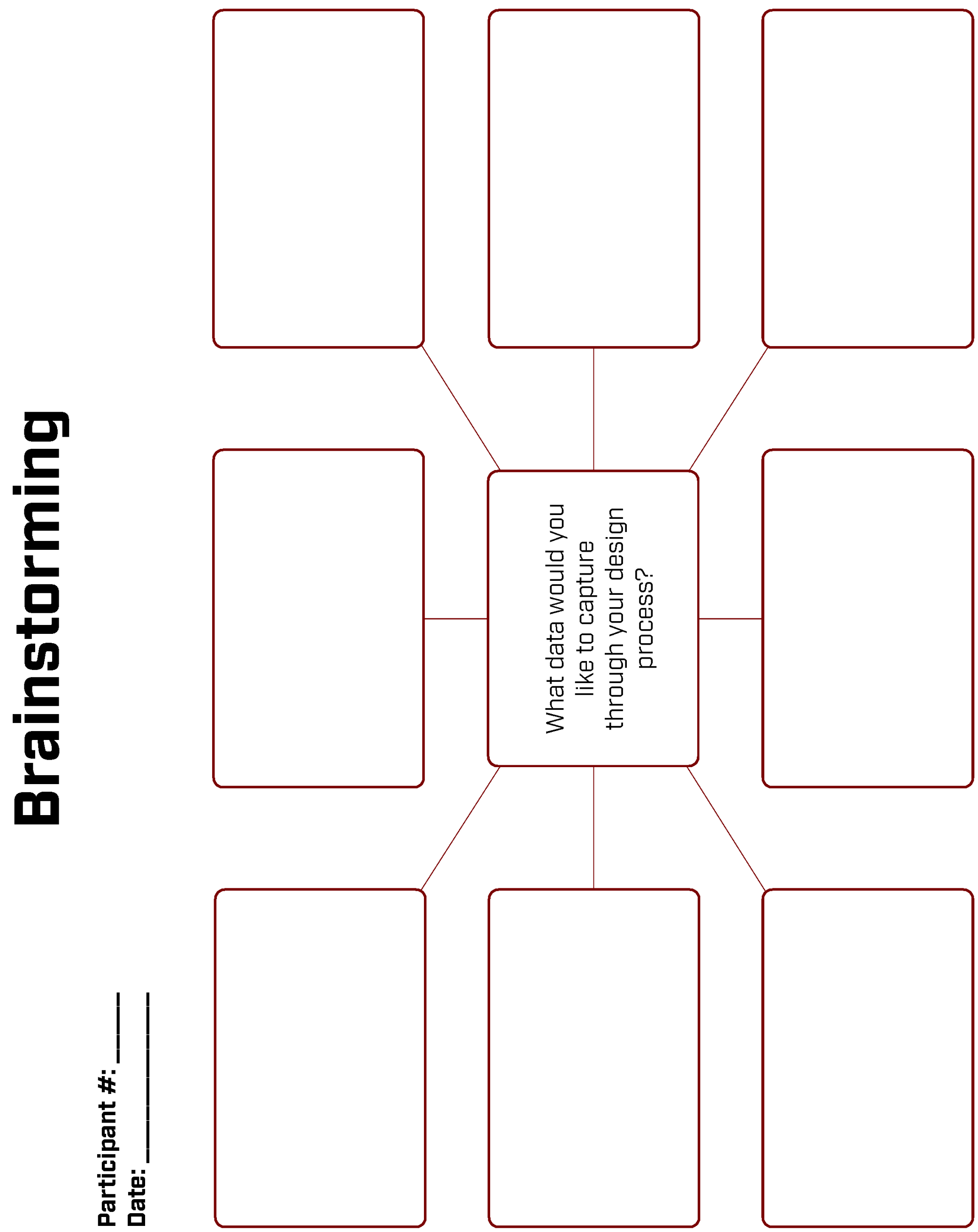
13. Has it been altered since its creation?
14. How would you judge whether another artifact was superior to this one?
15. Does this artifact encourage its users to engage in social interaction?
16. Is there another artifact you would expect to find kept with this one?
17. How valuable is this artifact, and to whom?
18. What sort of special knowledge, if any, would possessing the artifact imply?
19. Would there be any reason to collect multiple copies of this artifact?
20. Does a user need to actively engage with the artifact to make use of it?
21. Is this artifact currently "trendy," or could it ever have been?
22. Could the style of the artifact be appropriated for other uses?
23. How would you describe this artifact in one sentence?
24. Would this artifact be perceived differently by someone with a disability?
25. Could this artifact have inspired anything in contemporary culture?
26. Could you play a game with this artifact?
27. Could you imagine a world in which this type of artifact never existed?
28. Given the opportunity, would you save this artifact from a house fire?
29. Is this artifact dependent on other artifacts to function?
30. What expertise do you need to be able to use this artifact?

A.2 Sample Questions for the Semi-Structured Interview

These are sample questions that were asked during the interviews. Additional questions were asked based on the interviewee's responses.

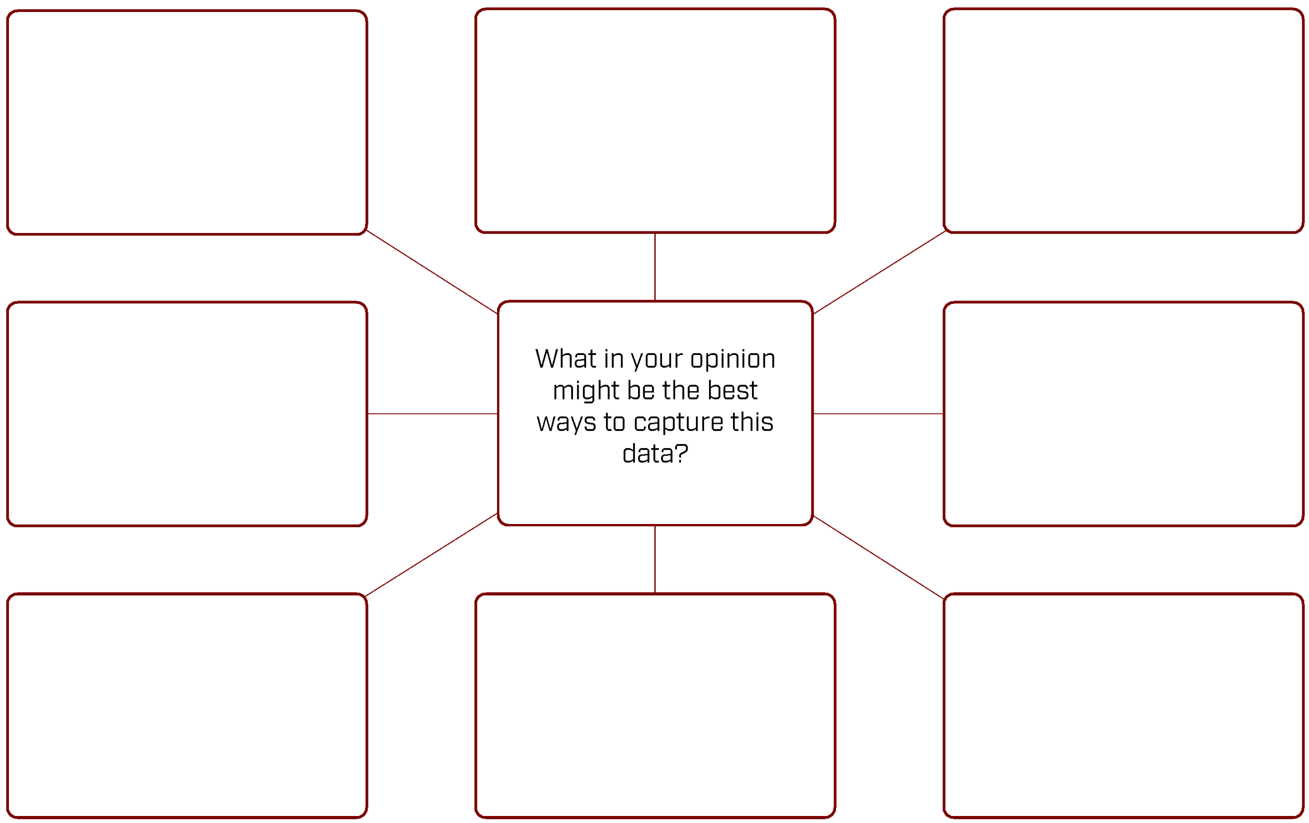
1. Can you please walk me through a typical design process?
2. How do you document that process?
3. What is your main purpose of documenting your projects?
4. Do you share your documents with the persons/groups that are going to use what you have built?
5. What kind of data do you usually collect during your design process?
6. What tools do you use to help you document your design process?
7. What do you like about your documentation? What do you think are the strengths of your documentation and what are the weaknesses?
8. If you were not limited by time/tools, what do you wish your documentation would look like?

A.3 Brainstorming Worksheets



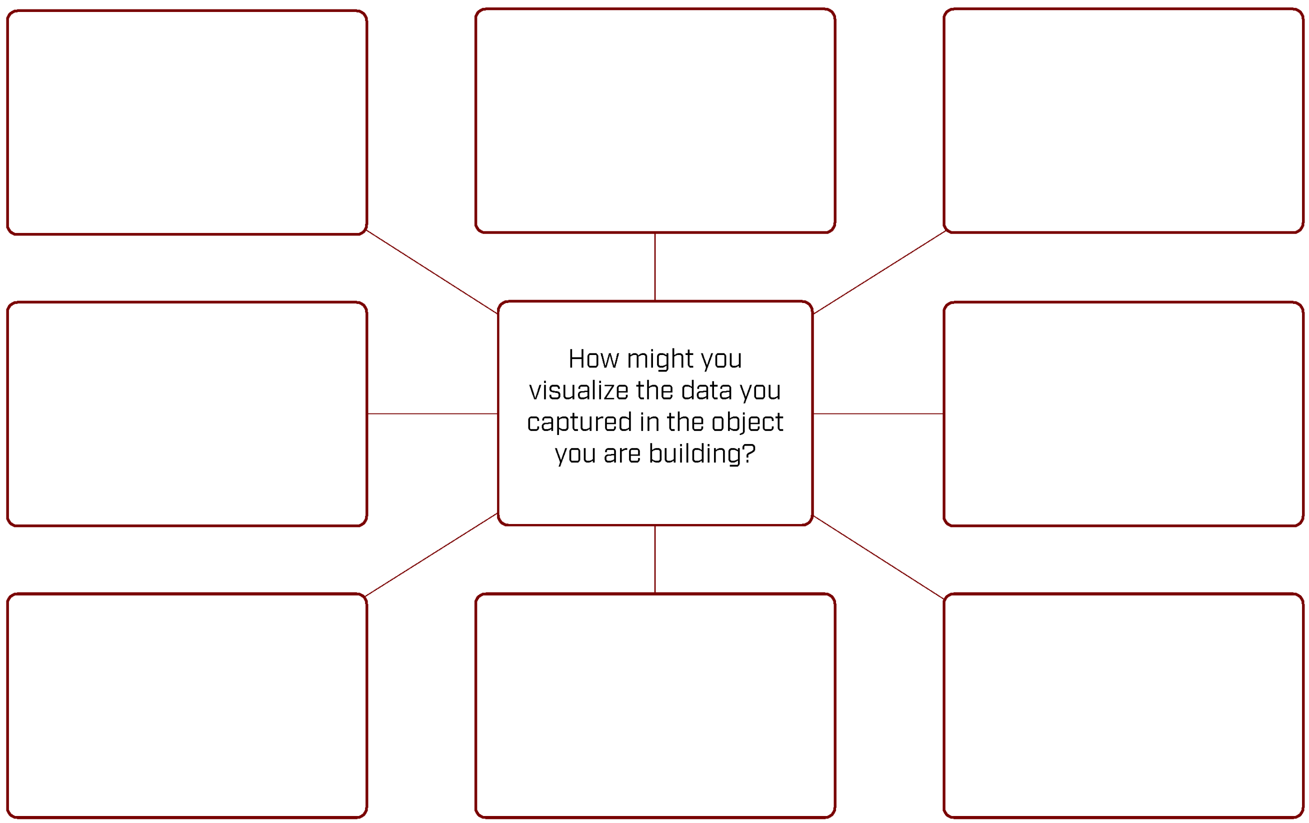
Brainstorming

Participant #: ______
Date: ______________



Brainstorming

Participant #: ______
Date: ______________



Brainstorming

Participant #: ______
Design #: _________
Date: _____________

Visualize what your ideal documentation tool might look like based on the data you wish to record in your design process.

Brainstorming

Participant #: ______
Design #: __________
Date: ______________

Visualize what your final product might look like based on the tool you have designed.

Appendix B

Additional Materials for Implementation Phase

B.1 Pre-study Questionnaire

1. Gender: ______________________
2. Age: ______________________
3. What type of projects do you usually make?

4. What tools do you use in your projects?
   - ☐ 3D Printer
   - ☐ Laser Cutter
   - ☐ CNC Machine
   - ☐ Manual Fabrication Tools
   - ☐ Other: ___________
5. How many years have you been making projects?
   - ☐ Less than 1 year
   - ☐ Between 1 to 3 years
   - ☐ Between 3 to 6 years
   - ☐ More than 6 years

6. What proportion of your projects do you document?
   - ☐ All of my projects
   - ☐ 75% of my projects
   - ☐ 50% of my projects
   - ☐ 25% of my projects
   - ☐ Less than 10% of my projects
7. How do you document your projects?
8. Why do you document your projects? (e.g. showcasing, self-reflecting, instructing, or remembering)
9. How many years have you been documenting your projects?
   - ☐ Less than 1 year
   - ☐ Between 1 to 3 years
   - ☐ Between 3 to 6 years
   - ☐ More than 6 years

B.2 Amplifier Box: Documented Object

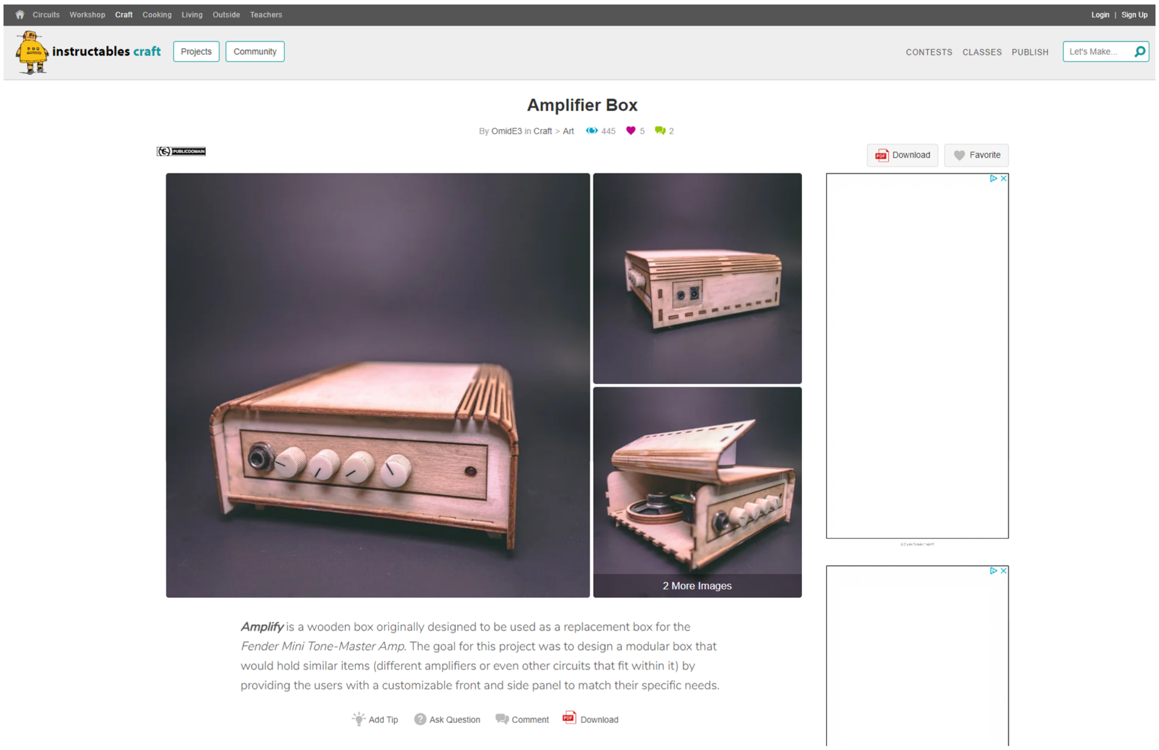


Figure B-1: Screenshot from Amplifier Box project on Instructable.[1]

Amplify is a wooden box originally designed to be used as a replacement box for the Fender Mini Tone-Master Amp. The goal for this project was to design a modular box that would hold similar items (different amplifiers or even other circuits that fit within it) by providing the users with a customizable front and side panel to match their specific needs.

Instructable's Link: `https://www.instructables.com/id/Amplifier-Box/`

[1] source: `https://www.instructables.com/id/Amplifier-Box/`

B.3 Sample Questions for the Semi-Structured Interview

These are sample questions that were asked during the interviews. Additional questions were asked based on the interviewee's responses.

1. Can you tell us more about your strategy for associating documentation data to the tags?
2. What do you think about where the tags should be placed? What is your preference? Does it vary based on context?
3. How did you feel about the retrieving process? Was it easy for you to access the information in comparison to other types of documentation that you are used to?
4. What are your thoughts on the overall experience? Do you think you got a better understanding of the project?
5. Do you think this form of documentation worked for you? Are you satisfied with the result?

B.4 Post-study Questionnaire

1. This new form of documentation helped me question the way that the object had been created, and it helped me to think of alternative ways to build the object.

   - ☐ Definitely agree
   - ☐ Agree with reservation
   - ☐ Only to be used if a definite answer is not possible
   - ☐ Disagree with reservation
   - ☐ Definitely disagree

2. This new form of documentation helped me reflect on how I create my current or past projects, and it helped me think of how I might improve my techniques.

   - ☐ Definitely agree
   - ☐ Agree with reservation
   - ☐ Only to be used if a definite answer is not possible
   - ☐ Disagree with reservation
   - ☐ Definitely disagree

3. This new form of documentation helped me reflect on how I create documentation for my projects, and it helped me think of how I might improve my documentation techniques.

   - ☐ Definitely agree
   - ☐ Agree with reservation
   - ☐ Only to be used if a definite answer is not possible
   - ☐ Disagree with reservation
   - ☐ Definitely disagree

4. I re-appraised my experience in using this new form of documentation so I can learn from it and improve for my next time building a project and documenting the building process.

   - ☐ Definitely agree
   - ☐ Agree with reservation
   - ☐ Only to be used if a definite answer is not possible
   - ☐ Disagree with reservation
   - ☐ Definitely disagree

5. After using this tool to explore the documentation of the object, I have a different understanding of the project.
   - ◻ Definitely agree
   - ◻ Agree with reservation
   - ◻ Only to be used if a definite answer is not possible
   - ◻ Disagree with reservation
   - ◻ Definitely disagree
6. This tool has challenged some of my old practices of documentation.
   - ◻ Definitely agree
   - ◻ Agree with reservation
   - ◻ Only to be used if a definite answer is not possible
   - ◻ Disagree with reservation
   - ◻ Definitely disagree
7. As a result of using this tool, I have changed my normal way of approaching a new project.
   - ◻ Definitely agree
   - ◻ Agree with reservation
   - ◻ Only to be used if a definite answer is not possible
   - ◻ Disagree with reservation
   - ◻ Definitely disagree
8. During my use of this tool, I discovered faults in what I had previously believed to be the correct way of approaching a project.
   - ◻ Definitely agree
   - ◻ Agree with reservation
   - ◻ Only to be used if a definite answer is not possible
   - ◻ Disagree with reservation
   - ◻ Definitely disagree

Appendix C

Photos from the Prototype: Documented

Figure C-1: Documented full setup.

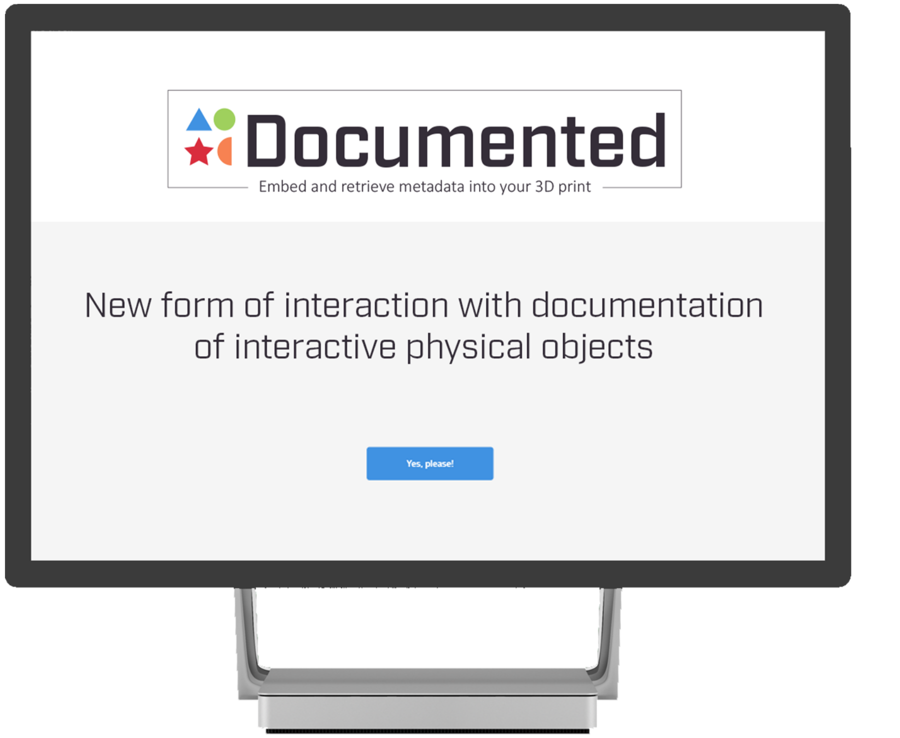


Figure C-2: Documented's startup page.

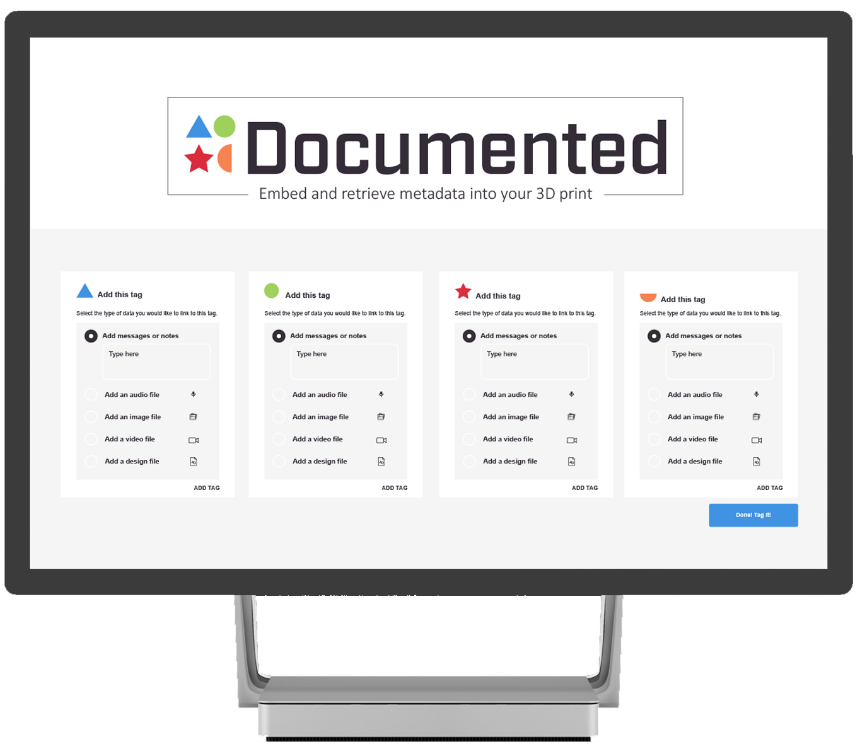


Figure C-3: Documented's data attachment page.

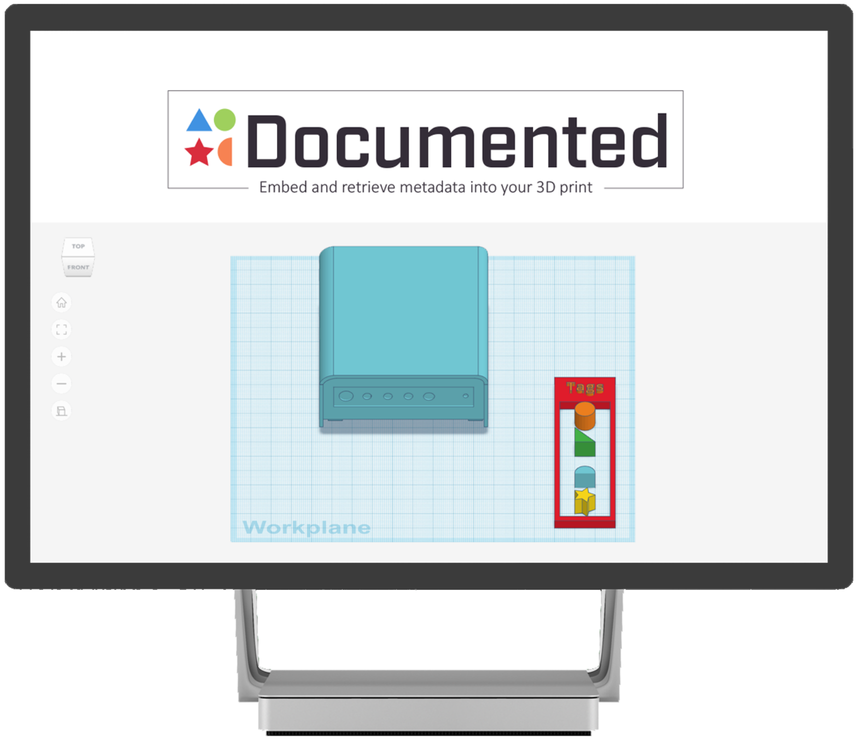


Figure C-4: Documented's embedding tag page.

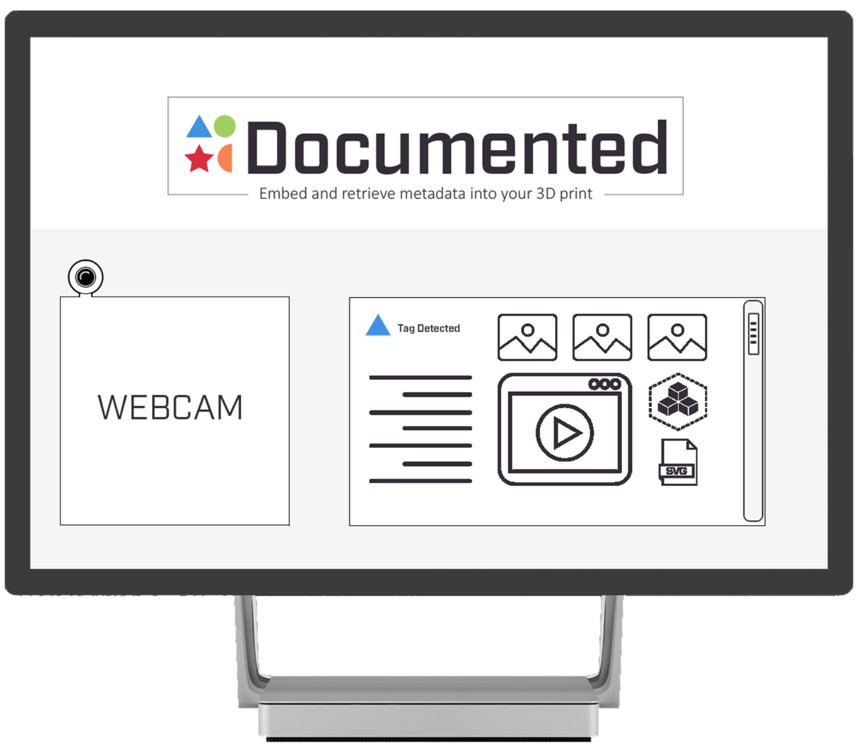


Figure C-5: Documented's retrieving data page.

THIS PAGE INTENTIONALLY LEFT BLANK

Appendix D

Additional Media Files

A Video titled *Documented* can be found at `openresearch.ocadu.ca` by searching for *Omid Ettehadi* and clicking on the thesis titles: *"Documented: Embedding and Retrieving Information from 3D Printed Objects"*. This video demonstrates the three steps of the built prototype in this research.

THIS PAGE INTENTIONALLY LEFT BLANK

Bibliography

[1] The field guide to human-centered design: Design kit.

[2] Bannon, L. Reimagining HCI: toward a more human-centered perspective. 50–57.

[3] Becky Stern. Silver RFID ring. Library Catalog: www.instructables.com.

[4] Burke, J. J. *Makerspaces: A Practical Guide for Librarians*. Rowman & Littlefield.

[5] Desjardins, A., and Tihanyi, T. ListeningCups: A case of data tactility and data stories. In *Proceedings of the 2019 on Designing Interactive Systems Conference*, DIS '19, Association for Computing Machinery, pp. 147–160.

[6] Dewey, J. *How We Think*. Courier Corporation.

[7] Dougherty, D. *Free to Make: How the Maker Movement is Changing Our Schools, Our Jobs, and Our Minds*. North Atlantic Books, 2016.

[8] Ferguson, E. S. *Engineering and the Mind's Eye*. MIT Press.

[9] Foundation, I. D. What is human-computer interaction (HCI)?

[10] Halverson, E. R., and Sheridan, K. The maker movement in education. 495–504.

[11] Ishii, H., and Ullmer, B. Tangible bits: Towards seamless interfaces between people, bits and atoms. In *Proceedings of the ACM SIGCHI Conference on Human Factors in Computing Systems*, CHI '97, ACM, pp. 234–241. event-place: Atlanta, Georgia, USA.

[12] Kleveno, C. Make a secret light up LED ring.

[13] Koleva, B., Benford, S., Ng, K., and Rodden, T. A framework for tangible user interfaces.

[14] Kuznetsov, S., and Paulos, E. Rise of the expert amateur: DIY projects, communities, and cultures. In *Proceedings of the 6th Nordic Conference on Human-Computer Interaction: Extending Boundaries*, NordiCHI '10, ACM, pp. 295–304. event-place: Reykjavik, Iceland.

[15] Lee, M.-H., Son, O., and Nam, T.-J. Patina-inspired personalization: Personalizing products with traces of daily use. In *Proceedings of the 2016 ACM Conference on Designing Interactive Systems*, DIS '16, Association for Computing Machinery, pp. 251–263.

[16] Liptak, A. The company behind maker faire and make magazine has abruptly shut down. Library Catalog: www.theverge.com.

[17] Litvin, N. Artifact analysis.

[18] Martin, L. The promise of the maker movement for education.

[19] Moon, J. A. *Reflection in Learning and Professional Development: Theory and Practice*. Routledge.

[20] O'Malley, C., and Fraser, D. S. Literature review in learning with tangible technologies.

[21] Price, I., Matzdorf, F., Smith, L., and Agahi, H. The impact of facilities on student choice of university. 212–222. Publisher: MCB UP Ltd.

[22] Rich, T. Encoding data into physical objects with digitally fabricated textures. Library Catalog: www.media.mit.edu.

[23] Roedl, D., Bardzell, S., and Bardzell, J. Sustainable making? balancing optimism and criticism in HCI discourse. 1–27.

[24] Rosner, D., and Bean, J. Learning from IKEA hacking: i'm not one to decoupage a tabletop and call it a day. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '09, Association for Computing Machinery, pp. 419–422.

[25] Rosner, D. K., and Ryokai, K. Spyn: Augmenting knitting to support storytelling and reflection. In *Proceedings of the 10th International Conference on Ubiquitous Computing*, UbiComp '08, ACM, pp. 340–349. event-place: Seoul, Korea.

[26] Savage, A. Adam savage's one day builds: Overengineered bottle opener!

[27] Sharples, M., McAndrew, P., Weller, M., Ferguson, R., FitzGerald, E., Hirst, T., and Gaved, M. Open university: Innovating pedagogy 2013. Accepted: 2014-02-05T12:22:24Z.

[28] Tanenbaum, J. G., Williams, A. M., Desjardins, A., and Tanenbaum, K. Democratizing technology: pleasure, utility and expressiveness in DIY and maker practice. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '13, Association for Computing Machinery, pp. 2603–2612.

[29] Torrey, C., McDonald, D. W., Schilit, B. N., and Bly, S. How-to pages: Informal systems of expertise sharing. In *ECSCW 2007*, L. J. Bannon, I. Wagner, C. Gutwin, R. H. R. Harper, and K. Schmidt, Eds., Springer, pp. 391–410.

[30] Tseng, T. Making make-throughs : Supporting young makers sharing design process.

[31] Tseng, T. Spin: A photography turntable system for creating animated documentation. In *Proceedings of the 14th International Conference on Interaction Design and Children*, IDC '15, ACM, pp. 422–425. event-place: Boston, Massachusetts.

[32] Tseng, T., and Resnick, M. Product versus process: representing and appropriating DIY projects online. In *Proceedings of the 2014 conference on Designing interactive systems*, DIS '14, Association for Computing Machinery, pp. 425–428.

[33] Tseng, T., and Tsai, G. Process products: Capturing design iteration with digital fabrication. In *Proceedings of the Ninth International Conference on Tangible, Embedded, and Embodied Interaction*, TEI '15, ACM, pp. 631–636. event-place: Stanford, California, USA.

[34] Turner, T., and Wilson, D. G. Reflections on documentation: A discussion with thought leaders from reggio emilia. 5–13.

[35] Wakkary, R., Schilling, M., Dalton, M., Hauser, S., Desjardins, A., Zhang, X., and Lin, H. Tutorial authorship and hybrid designers: The joy (and frustration) of DIY tutorials.

[36] Wien, C. A. Learning to document in reggio-inspired education.