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

RWTH AACHEN UNIVERSITY

Tackling Challenges in Designing and Making Smart Jewelry

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

by
Parth Wadhwa

Thesis advisor:
Prof. Dr. Jan Borchers

Second examiner:
Prof. Dr. Ulrik Schroeder

Registration date: 19/01/2021
Submission date: 22/06/2021

Zentrales Prüfungsamt/Central Examination Office

Eidesstattliche Versicherung
Statutory Declaration in Lieu of an Oath

___________________________ ___________________________

Name, Vorname/Last Name, First Name

Matrikelnummer (freiwillige Angabe)
Matriculation No. (optional)

Ich versichere hiermit an Eides Statt, dass ich die vorliegende Arbeit/Bachelorarbeit/ Masterarbeit* mit dem Titel
I hereby declare in lieu of an oath that I have completed the present paper/Bachelor thesis/Master thesis* entitled

____

____

____

selbstständig und ohne unzulässige fremde Hilfe (insbes. akademisches Ghostwriting) erbracht habe. Ich habe keine anderen als die angegebenen Quellen und Hilfsmittel benutzt. Für den Fall, dass die Arbeit zusätzlich auf einem Datenträger eingereicht wird, erkläre ich, dass die schriftliche und die elektronische Form vollständig übereinstimmen. Die Arbeit hat in gleicher oder ähnlicher Form noch keiner Prüfungsbehörde vorgelegen.
independently and without illegitimate assistance from third parties (such as academic ghostwriters). I have used no other than the specified sources and aids. In case that the thesis is additionally submitted in an electronic format, I declare that the written and electronic versions are fully identical. The thesis has not been submitted to any examination body in this, or similar, form.

___________________________ ___________________________

Ort, Datum/City, Date

Unterschrift/Signature

*Nichtzutreffendes bitte streichen

*Please delete as appropriate

Belehrung:
Official Notification:

§ 156 StGB: Falsche Versicherung an Eides Statt
Wer vor einer zur Abnahme einer Versicherung an Eides Statt zuständigen Behörde eine solche Versicherung falsch abgibt oder unter Berufung auf eine solche Versicherung falsch aussagt, wird mit Freiheitsstrafe bis zu drei Jahren oder mit Geldstrafe bestraft.
Para. 156 StGB (German Criminal Code): False Statutory Declarations
Whoever before a public authority competent to administer statutory declarations falsely makes such a declaration or falsely testifies while referring to such a declaration shall be liable to imprisonment not exceeding three years or a fine.
§ 161 StGB: Fahrlässiger Falscheid; fahrlässige falsche Versicherung an Eides Statt
(1) Wenn eine der in den §§ 154 bis 156 bezeichneten Handlungen aus Fahrlässigkeit begangen worden ist, so tritt Freiheitsstrafe bis zu einem Jahr oder Geldstrafe ein.
(2) Straflosigkeit tritt ein, wenn der Täter die falsche Angabe rechtzeitig berichtigt. Die Vorschriften des § 158 Abs. 2 und 3 gelten entsprechend.
Para. 161 StGB (German Criminal Code): False Statutory Declarations Due to Negligence
(1) If a person commits one of the offences listed in sections 154 through 156 negligently the penalty shall be imprisonment not exceeding one year or a fine.
(2) The offender shall be exempt from liability if he or she corrects their false testimony in time. The provisions of section 158 (2) and (3) shall apply accordingly.

Die vorstehende Belehrung habe ich zur Kenntnis genommen:
I have read and understood the above official notification:

___________________________ ___________________________

Ort, Datum/City, Date

Unterschrift/Signature

Contents

Abstract xv

Überblick xvii

Acknowledgements xix

Conventions xxi

1 Introduction 1

1.1 Emergence of smart jewelry 1

1.2 Smart jewelry 2

1.3 Aim of the thesis 3

1.4 Outline 3

2 Related work 5

2.1 Research Studies 6

2.1.1 Understanding importance of user requirements 6

2.1.2 Market analysis of smart jewelry products . . . 9
2.2 Prototyping Tool Kits . . . 11
2.2.1 CodaChrome . . . 12
2.2.2 Snowflake . . . 13
2.3 Commercial Products . . . 15
2.3.1 Rings . . . 15
2.3.2 Bracelets . . . 17
2.3.3 Others . . . 20
2.4 Artifacts . . . 21
2.4.1 The light refracting jewelry - *Sparklry* 21
2.4.2 Expressing emotions - *BuddyBeads* . . 22
2.4.3 Toy-based sentimental jewelry . . . 24
2.4.4 The olfactory artifact - *Essence* . . . 25
2.4.5 The sound locket - *Memento* . . . 27
2.4.6 Augmented reality necklace . . . 28
2.5 Previous work . . . 30

3 Overview of software tools **33**

3.1 Origin of CAD . . . 33
3.2 CATIA . . . 34
3.3 Illustrator . . . 35
3.4 Photoshop . . . 35

3.5 Rhino 35
3.6 Blender 36
3.7 ZBrush 36
3.8 KeyShot 37
3.9 Meshmixer 37

4 User Study 39

4.1 Motivation and Research question 40
4.2 Preliminary study 41
4.3 Interview study 43
4.3.1 User group 43
4.3.2 Participants background 43
4.3.3 Interview design 44
Meeting platform 44
Data protection details 44
Questionnaire details 45
Interview procedure 46
4.3.4 Data Analysis 46
4.3.5 Results and Discussion 48
Course details 48
Challenges for students 50
Outsourcing 51

Workflow 52
Materials, tools, and techniques 55
Software 57
Potential solutions 63
Smart Jewelry 67
Suggestions for goldsmiths 71
4.4 Survey study 73
4.4.1 User group 73
4.4.2 Participants background 73
4.4.3 Survey Design 75
Survey platform 75
Data protection details 75
Questionnaire details 75
Survey procedure 77
4.4.4 Results 78
Outsourcing 78
Tools 79
Software 81
Smart jewelry 99
4.4.5 Discussion 106

5 Summary and future work **111**

5.1 Summary and contributions 111
5.2 Future work 114

A Interview Questions **117**

B Codes **123**

C Survey Form **125**

Bibliography **133**

Index **139**

List of Figures

2.1 Catalogue of user requirement ranking 8

2.2 Most popular jewelry type for smart jewelry product 9

2.3 Number of functionalities of smart jewelry . 10

2.4 Different types of communication provided by smart jewelry 10

2.5 The prediction of market shift 11

2.6 The *CodaChrome* system 13

2.7 *Snowflake* 14

2.8 Commercial rings 15

2.9 Commercial bracelets 18

2.10 Commercial earring : Earring Backing. 21

2.11 *Sparklry* 22

2.12 *BuddyBeads* 23

2.13 Sentimental Fish Necklace *Pesciolino Robot* . . 24

2.14 The *Essence* Necklace 26

2.15 Memento 27

2.16 The Augmented Reality (AR) Necklace . . . 29

4.1 Workflow for jewelry fabrication 42

4.2 Code Cloud 48

4.3 Students' opinion on 3D printer statements . 80

4.4 Hobbyists' opinion on 3D printer statements 82

4.5 Software tools used by students 85

4.6 Software tools used by hobbyists 87

4.7 Students' opinion on software benefits 89

4.8 Hobbyists' opinion on software benefits . . . 90

4.9 students' opinion on software challenges . . 93

4.10 Hobbyists' opinion on software challenges . 95

4.11 Students' opinion on potential solution . . . 97

4.12 Hobbyists' opinion on potential solution . . . 98

4.13 Students' opinion on smart jewelry 101

4.14 Hobbyists' opinion on smart jewelry 102

4.15 Students' opinion on smart jewelry challenges 104

4.16 Hobbyists' opinion on smart jewelry challenges 105

List of Tables

2.1 Tabular representation of the categorical classification of user requirement made in the study by Fortmann et al. [2015]. 7

2.2 Summary of highlighted features in commercial products for Rings. 17

2.3 Summary of highlighted features in commercial products for Bracelets. 19

2.4 Summary of highlighted features in commercial products for others. 20

Abstract

Pacing with technological advancements, the jewelry industry has made progress in the last few decades. It started with the advent of smart wearable, which are devices worn close to the skin. These devices are an aid for the detection, analysis, and transmission of biological and physical information. As the popularity of smart wearable grew, the curiosity for creating smart jewelry increased amongst goldsmiths and designers. These experiments transformed traditional jewelry into a jewelry piece with additional functionalities such as water hydration tracking. This added another purpose for wearing jewelry, along with the expression of emotions.

Several problems are faced during the creation of smart jewelry. One such problem is the small size of jewelry that constraints the addition of components, which help enhance the jewelry's functionality. As a result of this, there is a trade-off between the size of the jewelry and its functionality. This trade-off also affects the aesthetic design of jewelry. Furthermore, the processes are vaguely defined and documented due to their experimental phase, and application-specific design tools are absent. Apart from this, the fabrication of smart jewelry requires knowledge of technology as well as jewelry making.

Thus, this thesis aims to uncover and unravel such challenges in depth. For this purpose, we would be interviewing academic experts and surveying beginners in jewelry design and making.

Überblick

Im Gleichschritt mit dem technologischen Fortschritt hat die Schmuckindustrie in den letzten Jahrzehnten Fortschritte gemacht. Es begann mit dem Aufkommen von Smart Wearables, das sind Geräte, die nahe der Haut getragen werden. Diese Geräte sind ein Hilfsmittel für die Erkennung, Analyse und Übertragung von biologischen und physikalischen Informationen. Mit der wachsenden Popularität von Smart Wearables wuchs auch die Neugierde von Goldschmieden und Designern, intelligenten Schmuck zu kreieren. Diese Experimente verwandelten traditionellen Schmuck in ein Schmuckstück mit zusätzlichen Funktionen, wie z. B. der Verfolgung der Wasserzufuhr. Dies fügte einen weiteren Zweck für das Tragen von Schmuck hinzu, zusammen mit dem Ausdruck von Emotionen.

Bei der Entwicklung von intelligentem Schmuck gibt es mehrere Probleme. Eines dieser Probleme ist die geringe Größe des Schmucks, die das Hinzufügen von Komponenten, die die Funktionalität des Schmucks verbessern, einschränkt. Daraus ergibt sich ein Kompromiss zwischen der Größe des Schmucks und seiner Funktionalität. Dieser Kompromiss wirkt sich auch auf das ästhetische Design des Schmucks aus. Außerdem sind die Prozesse aufgrund ihrer experimentellen Phase nur vage definiert und dokumentiert, und es fehlen anwendungsspezifische Designwerkzeuge. Abgesehen davon erfordert die Herstellung von Smart Jewelry sowohl technisches als auch schmucktechnisches Wissen.

Daher zielt diese Arbeit darauf ab, diese Herausforderungen in der Tiefe aufzudecken und zu enträtseln. Zu diesem Zweck werden wir akademische Experten interviewen und Anfänger im Bereich Schmuckdesign und -herstellung befragen.

Acknowledgements

First and foremost, I would like to thank Prof. Dr. Jan Borchers for allowing me to carry out my research work at Media Computing Group, Computer Science Department at RWTH Aachen University.

I would like to thank Prof. Dr. Ulrik Schroeder for his interest and support during this thesis.

I would like to thank Anke Brocker for her valuable time, guidance, support, and patience for the successful completion of this thesis. I also thank her for her constant encouragement and careful monitoring.

I am also grateful to all the thesis study participants. The completion of my thesis would not have been possible without their support and enthusiasm.

I would like to thank Yojana, Adit, Chrishanti, Mubashir, Praveen, Priyanka, Shahnawaz, Soliha, and Wahab for their constant advises and interest in my work.

I would also like to thank my colleagues at Media Computing Group for their support.

Lastly, I would like to thank my family for their support, encouragement, and wisdom throughout the thesis.

Conventions

Throughout this thesis we use the following conventions.

Text conventions

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

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

Definition: *Excursus*

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

`myClass`

The whole thesis is written in Canadian English.

Download links are set off in coloured boxes.

File: myFile[a]

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

Chapter 1

Introduction

Our lives revolve around technology, from sitting at home and shopping for groceries to meeting people. Our life has been surrounded by technology, and we have come to a point where we cannot survive without it. Commercial companies take advantage of this factor and transform their products so that they help ease functionalities for us. Companies like Apple and Google take this to another step and create products such as smartwatches that help us monitor our health in a given time frame. These technological trends are now combining into the fashion industry.

1.1 Emergence of smart jewelry

The term smart jewelry first emerged in 2012 in a company's innovation workshop. Here one of the technology company shared their idea and concept of smart jewelry (Salmela and Vimm [2018]). This was the starting point for researchers to innovate smart jewelry. This eventually led to brainstorming potential ideas in the field of smart jewelry. A common platform was also created, with the help of a workshop specific to smart jewelry, for discussion ideas amongst various interested parties.

From hereon, the domain of smart jewelry has had a bumpy ride. Although it has been accepted in the industry and other researchers who have been part of the workshop, the outreach to jewelry and goldsmiths has not been extensive. These challenges could be mismatched expectations of the pieces, poor accuracy of the prototype of the piece, unattractive appearance, to name a few. This indicates that the domain is in its initial phase where attention amongst researchers is present, but several challenges and difficulties exist.

1.2 Smart jewelry

Jewelry plays an individual role in fashion. It defines security, elegance, emotion, and beauty. A long known history of jewelry exists in all traditions. Women initially used to wear jewelry as a symbol of social status and feminism.

Definition: *Jewelry*

JEWELRY:
Jewelry can be defined as an object with sentimental values associated with it.

Remembering and embracing this tradition till date, the jewelry field is taking a step to adapt to the current technology-driven culture with the help of ”smart jewelry”. It is considered to be a sub-domain of smart wearable. Before defining smart jewelry, it is essential to define smart wearable.

Definition: *Smart wearable*

SMART WEARABLE:
Smart wearables are devices that are worn on the body and comprise of certain computing abilities. This is just not related to watches or clothes but extends up to implants and prosthetics too. They are mainly used for analysis, detection, or transmission of information

As there is no agreed-upon definition of smart jewelry, our perspective of looking and defining smart jewelry is as follows:

SMART JEWELRY:
Smart jewelry can be defined as a jewelry piece that provides additional functionalities without losing the aesthetic value of the jewelry piece. These functionalities thereby add to the reason for wearing the jewelry piece. It can either be in the form of digital functionality or something that could give the wearer another medium of expressing their emotions.

Definition:
Smart jewelry

1.3 Aim of the thesis

We start by looking at the essential tools required for crafting smart jewelry and then move towards smart jewelry. Different designers use different approaches to craft jewelry. Some make use of software tools to craft jewelry, while others prefer crafting without it. Little is known why people do not use software and what benefits one can get by using them. This is the basic thing that needs to be looked at if someone thinks of crafting smart jewelry. Therefore, this thesis aims to find the difficulties one can encounter while crafting jewelry and some potential solution to make one's experience of crafting jewelry easier. Additionally, since software tools are essential in the smart jewelry-making process, we also try to find challenges and potential solutions for crafting smart jewelry focusing on software tools in this thesis.

1.4 Outline

The following chapter (Chapter 2) talks in detail about the previous work that has been carried out in the smart jewelry domain. In Chapter 3 we will look in detail at the theoretical background of different software tools that help in crafting smart jewelry. We then come to the main chapter of the thesis, Chapter 4. Here we start with describing our motivation and research question. This is followed by a detailed explanation of our methodology, the results, and the discussions associated with our two studies. Finally, Chapter 5 summarizes the finding from our study and opens discussions on possible future work concerning this thesis.

Chapter 2

Related work

As the smart jewelry field paved its way into academics and the market, several researchers have crafted prototypes, artifacts, and commercial products. This chapter provides an overview of the current status of the smart jewelry field in academic, commercial, and other known infrastructures.

We will start by discussing the different research studies that revolve around gathering insights about smart jewelry from a user's perspective (Section 2.1). Following this, as the interest in making smart jewelry grew, a number of prototyping tool kits were prepared (Section 2.2). We also surveyed the commercial (Section 2.3) and the non-commercial industry (Section 2.4) concerning the current status of smart jewelry. Finally, we end this section by looking at the previous work done (Section 2.5), which provided the inspiration for the current thesis.

Since each of the authors have their perspective and understanding of smart jewelry, with each research work, we mention the author(s) understanding of these terms with the help of definition boxes.

2.1 Research Studies

In any market, the user requirement analysis plays a vital role in the development of a product. Similarly, in the domain of smart jewelry, user requirement analysis plays a key role in crafting products or prototypes. In this section, we look at two such studies that provide a synopsis of user perspective along with market analysis.

2.1.1 Understanding importance of user requirements

Definition: *Digital jewelry*

DIGITAL JEWELRY:
It is a piece of jewellery that offers one or more useful digital features. These features are integrated decently, i.e. in a way that observers would not recognize the jewel as being more than just a fashionable accessory. Hence, the authors see the jewel and not the technology as the base.

In the era of modernization, every day, new technologies are introduced. With time, this technology is either drifted apart or booms the market. Prior to launching a product in the market, researchers analyze the market space and gain an understanding of user requirements and design suitable for the product. As a consequence of this analysis, researchers craft a product. However, Fortmann et al. [2015] highlights that in this process, researchers overlook two essential factors in their study; first, the generalizability of the user requirement and second, the hierarchical ranking of these requirements. Hence, the absence of this stratification disables researchers to focus on key elements first.

To inspect the importance of requirements and their stratification, Fortmann et al. [2015] conducted an online survey with the user group restricted to adults (18 - 45 years old) because of their enthusiasm for fashionable jewelry. The focus of the survey was to rank certain requirements based on users' perspectives. These requirements were converted into 16 phrases based on outcomes from inter-

Category	Phrases with codes
Form factor	**FF1 :** It looks good. **FF2 :** It is small. **FF3 :** It is lightweight. **FF4 :** It is solid. **FF5 :** It is comfortable to wear.
Functionality	**FU6 :** Its battery lasts for at least 24 hours. **FU7 :** It offers several functions
Body location	**BL8 :** It can be worn on a finger. **BL9 :** It can be worn on the wrist.
Customisability	**CU10 :** I can change its appearance. **CU11 :** I can configure how the information is presented.
Interaction and Display design	**ID12 :** The functionality is integrated unobtrusively and it can be operated unobtrusively. **ID13 :** I can operate it quickly and with few effort. **ID14 :** Without further knowledge, people near by cannot understand the meaning of the displayed information.
Context Awareness	**CA15 :** The display adapts to my environment. **CA16 :** The display adapts to my situation.

Table 2.1: Tabular representation of the categorical classification of user requirement made in the study by Fortmann et al. [2015].

views conducted previously (Fortmann et al. [2014a], Fortmann et al. [2014b], Meyer et al. [20150]). For generalizability of these phrases, they were categorized into six categories namely *Form factor* (appearance), *Functionality*, *Body location*, *Customisability*, *Interaction and Display design*, and *Context Awareness*. The phrases, along with their unique codes used in each of these categories, are illustrated in Table 2.1. Apart from these, questions focusing on other user requirements (that could be missing from the previous questions), the users' opinion on these requirements, and their demographic details were also examined.

For the study, the authors asked the participants to allocate 100 points to each of the 16 phrases based on their priority. Since each of these phases belonged to a category, an aggre-

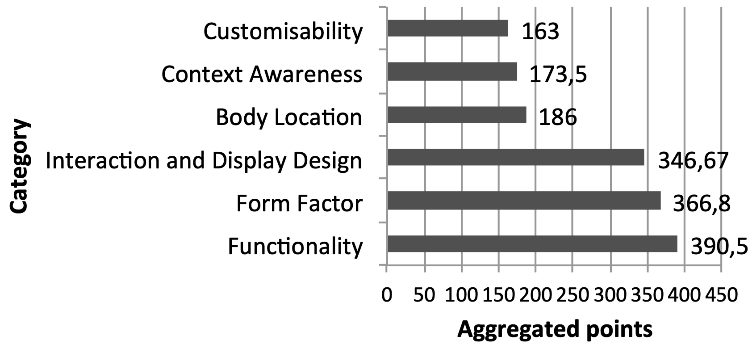

Figure 2.1: Analysis of the categorical classification of user requirements from the study conducted by Fortmann et al. [2015].

gate score was establish for each category (Figure 2.1). As a consequence of this, the authors inferred that *Functionality*, *Form factor*, and *Interaction and Display design* remain a priority for most users compared to *Customisability*, *Context Awareness*, and *Body location*. With respect to *Functionality*, a long-lasting battery (**FU6**) was spotlighted by the participants; for *Form factor*, visual appearance (**FF1**); and for *Interaction and Display design*, ease-of-use (**ID13**) were popular choices.

Leveraging gender diversity in the study, the authors also compared the differences in their requirements. For example, males ranked a good appearance of the wearable as a priority, and on the other hand, females ranked ease of accessibility as a preference. Additional comments were also made for interesting developments such as finger gestures or pressure-related gestures for the wearable. Hence, with the help of this analysis, researchers can now focus on certain prioritized requirement aspects during their jewelry crafting and designing phase.

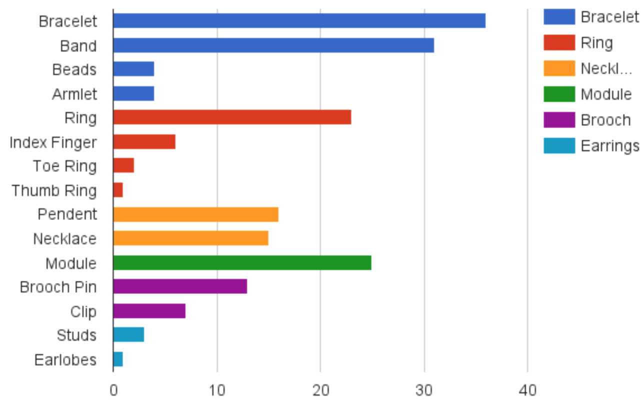

Figure 2.2: Statistical analysis of the most popular jewelry present in the current smart jewelry market according to study by Silina and Haddadi [2015].

2.1.2 Market analysis of smart jewelry products

Computational jewelry:
They are adornment artifacts that function both as jewelry and as a computational device

Definition: *Computational jewelry*

According to an analysis done by Duke Woolley and Romeo [2014], a number of smart jewelry products in the market were dominated by health and fitness functionalities. As a result of this, the authors hypothesized that the market's growth would increase by adapting smart jewelry in the lifestyle, glamour, and communication industry. Inspired by this analysis, Silina and Haddadi [2015] surveyed the smart jewelry market and scrutinized many products.

For their study, Silina and Haddadi [2015] were successfully able to collect 187 jewelry-like products. These products belonged to a range of developmental stages. Upon classification of these products, the authors found that bracelets are the most predominant jewelry (≈40%), followed by Bands (≈32%), and Modules (≈25%) that exists currently in the market (Figure 2.2). Interestingly, the designers for this jewelry were either coming from an aca-

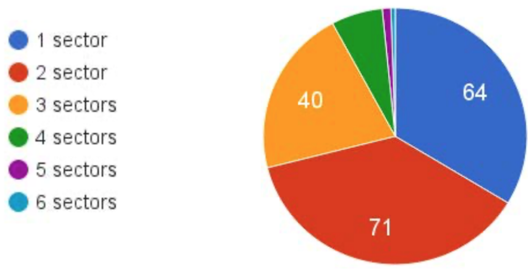

Figure 2.3: Summary of the vast functionalities (based on sectors) of smart jewelry-based product according to survey conducted by Silina and Haddadi [2015].

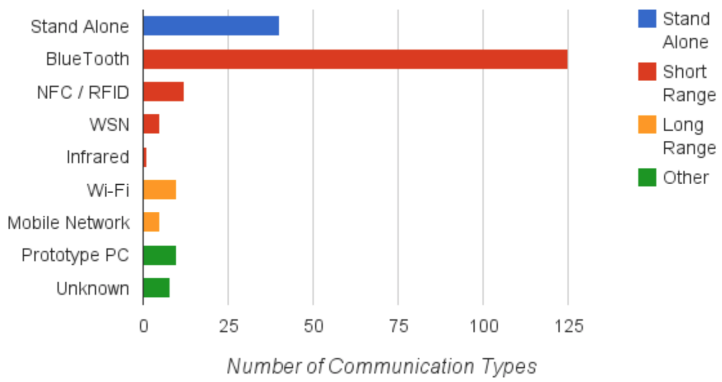

Figure 2.4: The figure denotes the different types of communication and data transfer strategies used by smart jewelry products according to survey conducted by Silina and Haddadi [2015].

demic background or from a designing one.

Market sector is a term used by the author to signify the field in which the jewelry was applied, for example, in glamour, health sector, communication, security, etc. Looking at the market sector side of these products, the authors noticed that more than half of these products (64%) connected with a single sector compared to the products being part of more than two sectors (Figure 2.3). With respect to the products that belonged to two sectors, they mostly part

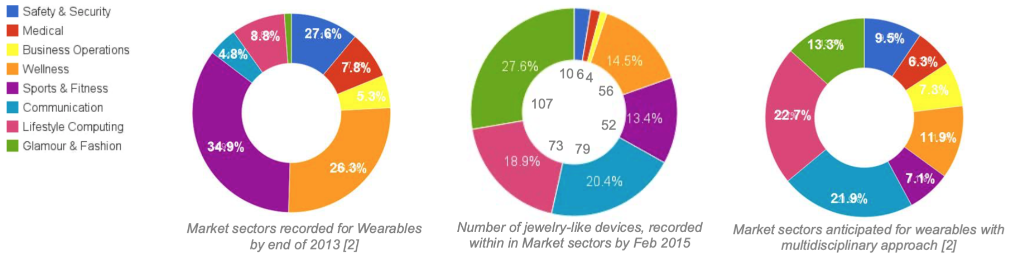

Figure 2.5: The prediction of the market shift by Duke Woolley and Romeo [2014] and Silina and Haddadi [2015].

of the *Health and Fitness* and *Communication and Lifestyle* sector.

Additionally, the smart jewelry products were not unisexual and were majorly crafted for women. Exploring the technical aspects, the authors denote that 69% of the jewelry-like devices make use of Bluetooth functionality for data transfer and communication compared to others strategies (Figure 2.4). On taking a deeper look into these Bluetooth-enabled products, the authors found that these were the products crafted by jewellers without any collaboration with engineers. Lastly, the authors point out that replaceable batteries were used in most products (≈52%).

In conclusion of this study, Silina and Haddadi [2015] demonstrated that even though the market was dominated by fitness functionalities, a gradual shift toward the glamour industry was observed (Figure 2.5). The authors feel disappointed that such growth was not seen in the healthcare sector and hope to see developments in this sector in the future.

2.2 Prototyping Tool Kits

Smart jewelry includes an interplay between jewelry and "smart" electronic components. Usually, people crafting these products only belong to one of these domains, which hinders crafting smart jewelry. For such situations, a number of researchers work on creating prototyping tool kits that enable one to overcome this barrier. Thus, the prototyping tool kit is a DIY (Do It Yourself) kit that allows users the freedom to customize the jewelry and provides the power to select its features. In this section, we look at two prototyping tools: *CodaChrome* and *Snowflake*.

2.2.1 CodaChrome

Definition:
Electronic jewelry

ELECTRONIC JEWELRY:
It is a product that does contain not only static properties of jewelry but also certain dynamic properties.

Making the process of fabricating smart jewelry easier for non-coders, Dekoli and Mikhak [2004] create a visual programming environment called *CodaChrome* system. Their main aim was to encourage children into making smart jewelry or "electronic jewelry" as they call it.

The system consists of hardware and software components. The hardware side is made up of basic modules, the microcontroller and the LED module, and other modules such as sensors, actuators, data storage can also be easily integrated. On the other hand, the software allows users to control the colour patterns and time sequence of the LED (Figure 2.6[1]). For fusing into an already existing jewelry piece, a circuit board connecting the hardware components can be added on top of the piece. Hence, they can be easily fused into any user-made jewelry. Also, the software can be controlled using a simple drag-and-drop method. Combined together, this flexible tool enables users to amplify and tweak the behavioural outcomes of their jewelry.

For assessing the ease of use, Dekoli and Mikhak [2004] conducted a two day workshop for children and adults. In this hands-on workshop, the process of creating a piece of smart jewelry, starting from a paper model to a finished

[1] `http://gig.media.mit.edu/projects/codachrome/hardware.htm`

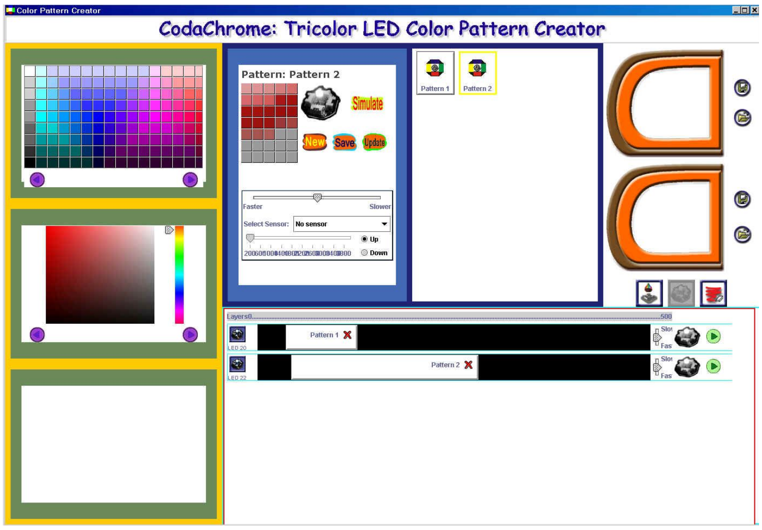

Figure 2.6: The *CodaChrome* system by Dekoli and Mikhak [2004]. The figure provides a glance of the software interface of the system.

model, using the *CodaChrome* system was explored. Although this process was complex for school-going children, the authors reported positive feedback with respect to the students' interest in crafting smart jewelry with the help of *CodaChrome* system.

2.2.2 Snowflake

SMART WEARABLE:
It starts with an aesthetically appealing jewelry design and forces the technology to subtly blend in or disappear (Miner et al. [2001])

Definition:
Smart wearable

Revealing the importance of aesthetics in smart jewelry design, Insel et al. [2018] crafted a prototypical tool kit called *Snowflake*. Here the authors experimented and studied the acceptance of the fusion between aesthetics and smart functionality of jewelry. The authors achieved this by following an iterative design approach where a loop of creativity followed by interactivity and user testing was done repeti-

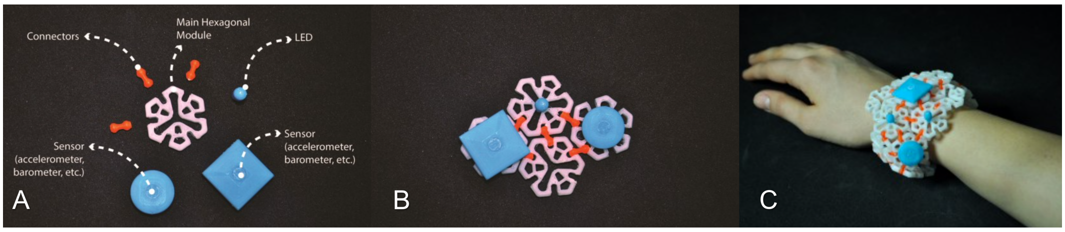

Figure 2.7: *Snowflake* bracelet by Insel et al. [2018]. The figure shows the transition of the bracelet from individual components (A) to connected components (B) and finally the prototype bracelet (C).

tively until the satisfying results were available.

The *Snowflake* tool kit constitutes of a hexagonal module that is connected with other modules with help of connectors (Figure 2.7). These connectors are available in two types: conductive connectors and non-conductive connectors. The addition of connectors into this prototype expands the usability and allows freedom of movement for *Snowflake*.

The conductive connectors help in data acquisition by transmitting the input and output data, while the non-conductive connectors are used for aesthetic purposes. Furthermore, a number of different hardware components such as heat sensors or motion sensors can be added on top of this tool kit using the provided microprocessor, sensor, and actuator modules. *Snowflake* also has the potential to connect to a computer interface with the help of wireless transmission.

On the whole, by providing such individual components (in the form of different modules) to the user, the authors provide a freedom of choice to create their desired jewelry piece. Thus, The authors feel confident about the *Snowflake* prototype and indicate that it could be one step closer to achieving an alliance between aesthetics and smart jewelry.

Figure 2.8: Commercially available ring products. (A) Luxe Smart Ring (B) Sesame Ring.

2.3 Commercial Products

Being a novel field, this domain was untouched by a number of large-scale commercial industries. It was not until 2001 when one of these big companies, IBM, stepped into this field and saw a future perspective in it (Silina and Haddadi [2015], Miner et al. [2001]). In this section, we briefly look at the features of some of these commercially available products. A major source of information for these products was gathered from Abrar [2020].

For understanding purposes, we group the products into three sections: Rings, Bracelets, and Others. In each of these sections, products are further described based on their features. The health features denote health-related functionalities such as activity monitoring; communication features denote features that help in the interaction between smartphone and the jewelry like notifications; others include additional unique features. A note on the customisability of these products is also made.

2.3.1 Rings

Ringly's **Luxe Smart Ring**[2] has a gold plated base and a gemstone on the top (Figure 2.8). With its vast functionality such as mobile alerts, activity tracking, etc., the product

[2] https://ringly.com/products/smart-ring

also can customize tactile and light effects based on notifications. It has a battery life of 24 to 48 hours based on use. Furthermore, it has the ability to connect to more than 200 applications.

Omate's **Ungaro Smart Ring**[3] is a personalized ring that can be tailored for an individual's choice of gemstone. However, its functionality is limited to communication only and that also to restricted contacts.

Oura Ring[4] is a durable titanium ring that helps in the analysis of an individual's daily activity. This product sends personalized reports of sleep and activity through its connection with a smartphone, enabling individuals to monitor their habits.

Nimb Ring[5] is personal safety and emergency product available in the United States. This ring has the functionality to contact and send messages to close friends and family in case of emergencies. This product has a unique subscription model and a dedicated service. It has a battery life of two weeks.

NFC Ring[6] is an NFC-based ring that helps share data between people just with a fist bump. It can also be used for security-related functionalities such as bank payments, locking and unlocking devices, etc.

Cnick Ring[7] is a product similar to an access card. This product allows individuals to unlock and control smartphones and their related applications. Moreover, it allows sharing of personal information with other people with just a click.

Sesame Ring[8] is a metro-pass 3D printed ring supported by the Massachusetts Bay Transportation Authority (Fig-

[3] https://www.omate.com/
[4] https://ouraring.com/life-with-oura
[5] https://www.kickstarter.com/projects/1629204423/nimb-a-smart-ring-that-keeps-you-safe-and-sound
[6] https://nfcring.com/
[7] https://www.cnick.io/
[8] http://www.ringtheory.com/

Product name	Highlighted features
Luxe Smart Ring	**Health :** Activity tracking **Communication :** Call and text notifications
Ungaro Smart Ring	**Communication :** Vibration alerts for calls and texts
NFC Ring	**Communication :** Information sharing **Others :** Payments, lock/unlock doors and devices
Nimb Ring	**Communication :** Call and text notifications **Others :** Panic button
Oura Ring	**Health :** Sleep tracking, Activity tracking, Illness monitor
Cnick Ring	**Communication :** Share information **Others :** Access Card, Manage smartphone (unlock smartphone, turn on flashlight)
Sesame Ring	**Others :** Metro pass alternative
Nod Ring	**Others :** Control application with gestures

Table 2.2: Summary of highlighted features in commercial products for Rings.

ure 2.8). This product helps individuals with contactless payments and metro tickets. The smart jewelry product is restricted to the United States. Lastly, it is a passive device that requires no battery for functioning.

Nod Ring[9] is a gesture-controlling ring that can help control several applications from thermostats to television to presentations in the office just with the help of gestures. It can connect to a number of devices and operating systems such as Mac, iOS, Windows, Philips Hue, GoPro camera, LG TV, and the list goes on. It connects to these devices with the help of its Bluetooth feature. It has a rechargeable watch battery.

An overview of these products can be seen in Table 2.2.

2.3.2 Bracelets

Bellabeat's **Leaf Urban**[10] is a fashionable product that is made up of wood and stainless steel (Figure 2.9). Although it is created as a pendant, it is wearable in a number of

[9] https://www.wearables.com/products/nod-ring
[10] https://bellabeat.com/product/leaf-urban/

Figure 2.9: Commercially available bracelet products. (A) Leaf Urban (B) Wellness and Activity Bracelet.

forms, such as a clip or a bracelet along with a necklace. This smart product has several features like water resistance, sleep tracking, menstrual cycle tracking, and inactivity alerts, to name a few. Additionally, the battery used to power this product is a six month replaceable battery.

Fitbit's **Flex 2**[11] has a removable tracker that can be remodeled into a pendant or a bangle. This waterproof product has the ability to track your activity along with the type of activity due to its SmartTrack sensor. The power consumption capacity of this product is less due to its LED lights, and hence, the battery life is up to five days.

Misfit Shine[12] is another waterproof bracelet that is available with a stainless steel frame. This frame is used to transform the product into a necklace if needed. Its features include sleep monitoring and sports tracking. Visually, it has a LED disc that enables one to monitor the activity progress and time. Finally, its replaceable coin battery lasts up to six months.

Ringly's **Luxe Smart Bracelet**[13] is analogous to the Luxe Smart Ring created by Ringly apart from the designing

[11] https://www.fitbit.com/in/flex2
[12] https://www.misfit.com/
[13] https://ringly.com/products/smart-bracelet

strategy.

Michael Kors' **Access Bracelet**[14] is a silicone-made bracelet that enables activity tracking functionality. Apart from the rest of the "smart" functionalities, this product enables smartphone functionalities such as taking pictures, playing music and presenting presentations. Like others, this product also has a replaceable battery.

Mira's **Wellness and Activity Bracelet**[15] is a flexible and attractive bracelet available in a range of sizes (Figure 2.9). The tracker is detachable and can be an add-on with another clothing or jewelry piece. Its functionalities include distance tracking, calorie monitoring, and so on. It can also be connected with your smartphone, thereby providing customized notifications for motivation.

Product name	**Highlighted features**
Leaf Urban	**Customisability :** Necklace, Bracelet, Clip **Health :** Sleep tracking, Activity tracking, Stress Sensibility, Menstrual cycle tracking
Fitbit Flex 2	**Customisability :** Bracelet, Bangle, Pendant **Health :** Sleep tracking, Activity tracking, Sport tracking **Communication :** Call and text notifications
Misfit Shine	**Health :** Sleep tracking, Activity tracking, sports tracking
Luxe Smart Bracelet	**Health :** Activity tracking **Communication :** Call and text notifications
Access Bracelet	**Health :** Sleep tracking, Activity tracking **Communication :** Call and text notifications **Others :** Taking selfies or playing music remotely
Wellness and Activity Bracelet	**Customisability :** Bracelet, Clip **Health :** Activity tracking
Gemio Band	**Communication :** Send signal to friends **Others :** Light effects that respond to music and movement

Table 2.3: Summary of highlighted features in commercial products for Bracelets.

[14] https://www.michaelkors.com/

[15] https://us.amazon.com/Mira-Wellness-and-Activity-Bracelet/dp/B014M8YOR0

Gemio Band[16] is an LED-driven bracelet that responds based on music or movement. Furthermore, it provides a number of appearance options that can be easily customized and matched with one's clothing style.

An overview of these products can be seen in Table 2.3.

2.3.3 Others

Joule's **Earring Backing**[17] is not yet available in the market, but it available for pre-order (Figure 2.10). It has a detachable tracker, which can be worn in combination with any non-smart earring piece. The earring offers heart rate monitoring and activity tracking features. The product does not affect an individual's fashion style as it stays hidden behind the ear.

Smart Cufflink[18] has an in-build RFID NFC microchip that allows it to communicate with devices. With the help of this product, individuals can unlock car doors, smartphone screens, and share files on the air.

An overview of these products can be seen in Table 2.4.

Product name	**Highlighted features**
Earring Backing	**Jewelry type :** Earring **Health :** Activity tracking, health monitoring
Smart Cufflink	**Jewelry type :** Cufflink **Communication :** Share information **Others :** Access Card, Manage smartphone (unlock smartphone)

Table 2.4: Summary of highlighted features in commercial products for others.

[16] https://gogemio.com/pages/lightlifem
[17] https://shopjoule.com/
[18] https://www.amazon.com/Smart-Cufflink/dp/B077RJNSPP

Figure 2.10: Commercial earring : Earring Backing.

2.4 Artifacts

Apart from commercially available products, researchers from Human-Computer-Interaction (HCI) and design backgrounds tried to develop novel ideas for smart jewelry. Such products are known as artifacts. We now take a deeper look into what makes these artifacts unique.

2.4.1 The light refracting jewelry - *Sparklry*

INTERACTIVE JEWELRY:
It is an embedding of multiple LEDs that are dynamically controlled by computers into clothes or accessories to support novel expressions or daily activities.

Definition:
Interactive jewelry

Rather than focusing on adding additional health-related or other functionality, Oki and Tsukada [2017] created a simple but elegant design of smart jewelry. Using the classic combination of light and gem, the authors created *Sparklry*.

The authors design *Sparklry* by passing a smart LED light

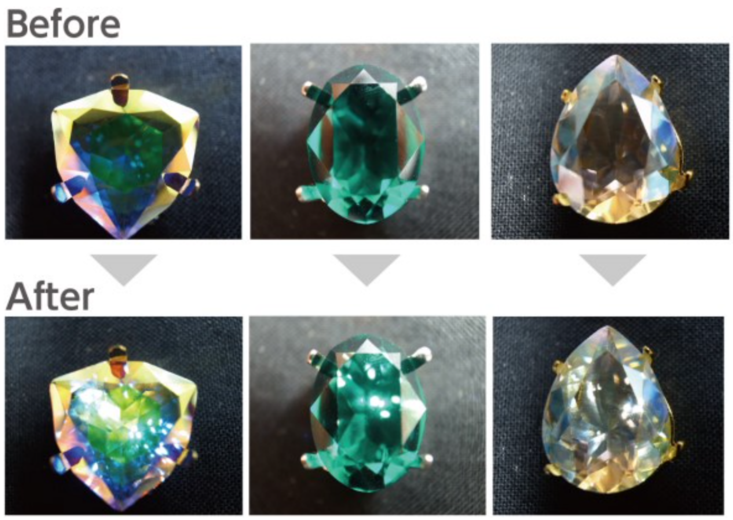

Figure 2.11: Examples of *Sparklry* by Oki and Tsukada [2017].

through a patterned slit. The light from this slit is then passed into the jewelry, thereby making attractive patterns into it (Figure 2.11). The smart LED is controlled by Arduino at the back-end, and with the help of this, different patterns can be visualized in the jewelry piece.

Undoubtedly, Oki and Tsukada [2017] take advantage of the geometry of the gem for designing stylish jewelry. This smart move elevates the visual appearance of the jewelry piece.

2.4.2 Expressing emotions - *BuddyBeads*

Definition: *Techno-jewelry*

TECHNO-JEWELRY:
It is a jewelry piece that facilitates non-verbal communication.

One of the under-rated types of communication is the one of emotions. Kikin-Gil [2006] gave an application of smart jewelry focusing on the importance of emotional communication. The author created a jewelry piece called *Bud-*

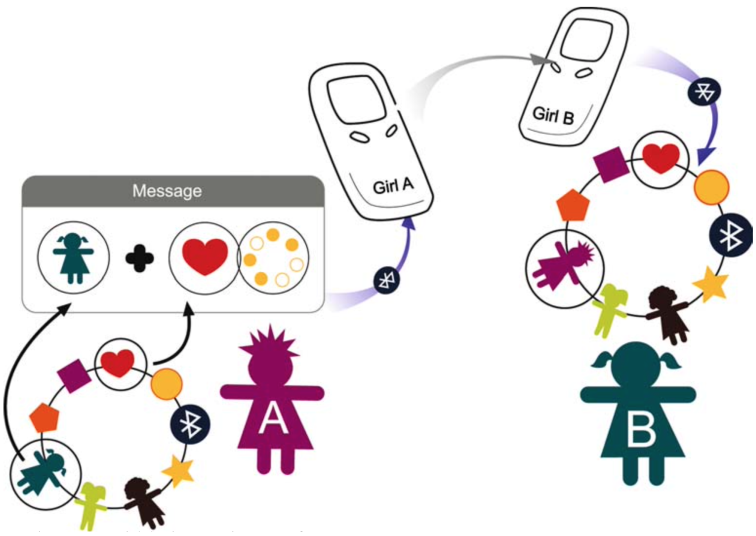

Figure 2.12: *BuddyBeads* project by Kikin-Gil [2006]. This figure depicts the working of a *BuddyBeads* jewelry piece.

dyBeads that helps users to communicate with their group members through codes and signals. Additionally, through this piece, the users can focus on both their social and behavioural needs.

The *BuddyBeads* project could be expanded to any jewelry piece. The author demonstrated the use of this project with the help of a bracelet. A pre-defined bead message, linking to an emotion, is unanimously decided by the group members. To interact within the group, one member would press the bead and the corresponding bead on other members' bracelet would receive the message. This message could be perceived with the help of different senses such as sight, touch, and hearing (Figure 2.12). This combination of senses creates excitement between users, thereby making this product fascinating.

To test the *BuddyBeads* project, Kikin-Gil [2006] collected few participants who were willing to try and provide feedback on the tool. According to the study, the author denoted that adding an encryption layer on the messages (with the help of code language) was found to be likable by the users.

Figure 2.13: *Pesciolino Robot* piece made by Ju [2016] denoting the fabrication of wearable jewelry with help of children toys.

2.4.3 Toy-based sentimental jewelry

Definition: *Functional jewelry*

FUNCTIONAL JEWELRY:
They are personal adornments with computing abilities that are designed to be worn.

Ju [2016] fascinates us with yet another smart jewelry application using household objects. The author makes use of simple children's toys and transforms them into smart jewelry. Such a concept thereby preserves and enhances the sentimental value of the jewelry piece. Furthermore, the author emphasizes the use of functional, expressive, and aesthetic (FEA) mesh to produce any smart wearable.

With help of this concept, Ju [2016] fabricated three wearable: *Pesciolino Robot*, *Funny Penguin Twinkling Light*, and *Cavallino Filoguidato*. *Pesciolino Robot* is a fish-in-a-necklace (Figure 2.13). When the pendant comes in contact with liquid, its tail is set in a swimming motion. *Funny Penguin Twinkling Light* is a visually attractive piece with the piece being designed to sync light with music. Lastly, *Cavallino Filoguidato* enables the user to stay in close contact with horses with the help of certain tactile and audio settings.

Although the pieces mentioned above do not denote any smart interactive functionality, Ju [2016] remains confident that such type of jewelry pieces demonstrate a different type of interaction. Furthermore, the author also mentioned that such a jewelry piece would influence a person's perception and body language.

2.4.4 The olfactory artifact - *Essence*

FASHIONABLE WEARABLE:
They are devices that can make use of human senses for functionality purposes.

Definition: *Fashionable wearable*

Sense of smell is one of the important senses in the human body due to its ability to control emotions and memories. Making use of this interesting modality of smell, Amores and Maes [2017] designed the *Essence* necklace. It is an easy-to-use, smartphone-controlled technology that emits fragrance at a pre-defined time. Keeping up with the trend, the authors designed a fashionable and lightweight necklace that an individual could wear in day-to-day life.

The working of *Essence* is based on the interplay between the micro-controller and the piezoelectric transducer (Figure 2.14). As the micro-controller activates the transducer, it induces ultrasounds in the fragrance containing-tube, thereby breaking the liquid in it to vapour. Using this mechanism, the scent is released into the air.

For this study, the authors asked four participants to inspect the usage of this artifact in real-life situations for three days. At the end of the study, each participant was asked to fill surveys and questionnaires along with an interview as part of the feedback. Additionally, the study focuses on a limited number of scents based on those inducing calmness and alertness.

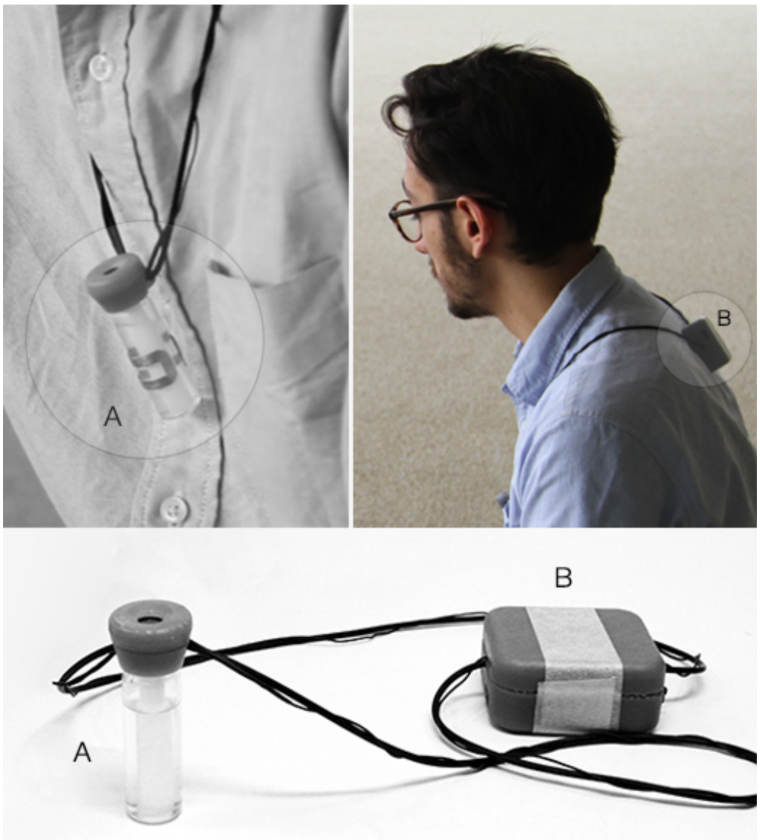

Figure 2.14: The *Essence* necklace by Amores and Maes [2017]. (A) Piezo-electric transducer attached to the fragrance containing-tube. (B) Micro-controller along with the battery enclosed in a case.

As a future perspective, authors analyzed this artifact to a vast range of neurological applications ranging from their effects on memory to their effects on one's social relations among people. Apart from this, the authors also understood the impact fragrance could have on health. Thus, with the help of this experiment, the authors were able to successfully proved that *Essence* was comfortable and robust to use.

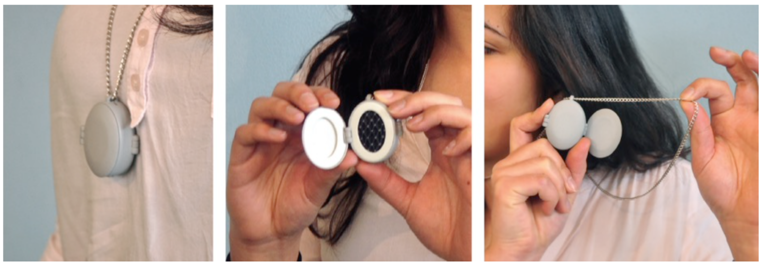

Figure 2.15: Memento sound locket by Niemantsverdriet and Versteeg [2016]. The figure shows the front and back lids of locket.

2.4.5 The sound locket - *Memento*

INTERACTIVE JEWELRY:
It involves the addition of microelectronics to traditional jewelry to extend its interactivity and enrich its function.

Definition:
Interactive jewelry

Acknowledging the importance of traditional jewelry as a memory cue, Niemantsverdriet and Versteeg [2016] crafted a sound locket called *Memento*. Traditionally, a piece of jewelry was purchased and given to our loved ones as a token of memory or remembrance for a particular moment. Likewise, *Memento* is an artifact designed to recollect a particular memory based on sound.

For the study, Niemantsverdriet and Versteeg [2016] asked their participants to record sound fragments that they would like to keep as "locked memories" in a jewelry piece. With the help of these audio clips, *Memento* was created. Concerning its modelling, *Memento* has two lids; the front lid records an audio message for approximately ten seconds while the back lid helps the user listen to the recorded messages (Figure 2.15). Noteworthy is that these audio messages are stored in the chain virtually, and one could adjust this chain accordingly to hear the messages.

Unfortunately, due to the time constraints of the study, Niemantsverdriet and Versteeg [2016] found that none of the users heard the stored audio from this locket. On the positive side, the authors were convinced about this jewelry piece with respect to its privacy. For future perspectives, the authors would like to create studies for a larger group and on a larger time scale.

2.4.6 Augmented reality necklace

Definition:
Enhanced wearable

ENHANCED WEARABLE:
It involves embedding functionality and digital information in such a way that it does not affect the jewelry item itself.

While creating smart jewelry, researchers focus on the addition of "smart" factor rather than focusing on the user's needs. This is a typical top-to-bottom approach for the creation of smart jewelry. Interestingly, Rantala et al. [2018] take the bottom-to-top approach, where they first inquire about the user's needs and then create an artifact based on the user's need.

During their study, the authors collected feedback about smart jewelry with the help of focus groups and survey forms. Based on this feedback, they created a prototypical necklace artifact that had an augmented reality (AR) reader. This AR reader enabled one to scan the jewelry via a smartphone camera to view its contents (Figure 2.16). Since the necklace was analogous to a friendship book, friends could easily share and store digital contents as a memory for their friendship. According to the authors, this aspect of AR preserved both the aesthetic value of the jewelry as well as introduces the so-called "smart" factor into it, thereby making it smart jewelry.

Rantala et al. [2018] conducted a final survey on the artifact to understand the security perspective of the necklace. This survey was focused on finding two outcomes: the first being the type of data to be shared and the second being the comfort level of sharing data with known and anonymous users.

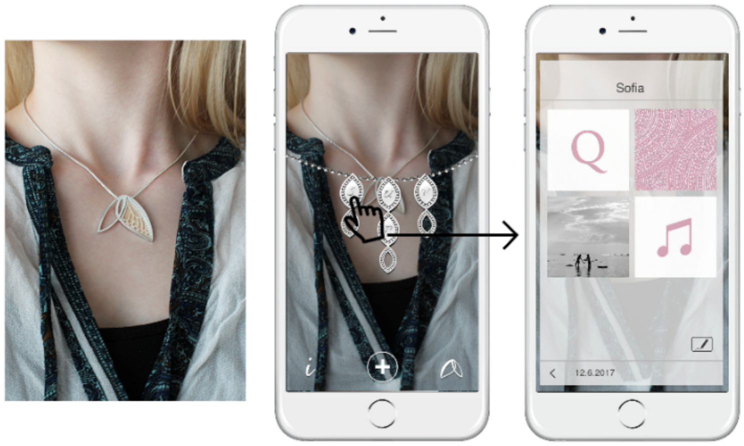

Figure 2.16: The Augmented Reality (AR) necklace by Rantala et al. [2018]. The figure illustrates the mobile AR application which overlays a digital view on the necklace. In this digital view, one could select the 'bead' for which one would like to view the content.

Concerning the type of data to be shared, most of the users (55%) were biased towards sharing personal data for medical-related emergencies. In contrast, others (≈38%) preferred not to share personal data due to privacy concerns. Regarding the comfortability of sharing data, as expected, the users preferred it to be limited to a group of people (42%) rather than it being open for all.

Furthermore, since the user group was distributed on a wide range of age groups, the authors were also curious to know the usability of such digital necklaces among younger and older generations. With such modernization, the younger generation was happy to incorporate such necklaces in daily life. Likewise, the older generation was also willing to wear the necklace in day-to-day life, provided the aesthetic and creativity of jewelry being preserved like the given artifact. Hence, Rantala et al. [2018] successfully proved the importance of preserving and focusing equally on the aesthetic and creative aspect of smart jewelry along with the smart aspect, rather than just focusing on one.

2.5 Previous work

Definition:
Smart jewelry

SMART JEWELRY:
It would be the combination of both the aesthetics and uniqueness of jewelry and the functionality and technology of wearable.

Feser [2019] in his master's thesis walks us through the different steps involved in the production and modeling of jewelry. His thesis covers an overview of hardware and software components required for jewelry, along with an analysis of the designing phases of jewelry. Furthermore, the author also investigated the development stage of smart jewelry with the help of goldsmiths.

The author introduced us to various hardware ranging from data transmission components like sensors to basic components such as energy sources and mainboards. A key point from his analysis was that the dimensional limitation of hardware components holds back their integration into traditional jewelry pieces. This raises concerns about creating jewelry-compatible hardware, and companies do not prefer the production of these customized components. Altogether, this adds a two-layer complexity towards the integration of undersized hardware to jewelry components.

Besides hardware, the author also sheds light on software components involved in crafting jewelry. In this section, the author provides a detailed study of various jewelry-making CAD software such as 3Design, MatrixGold, etc. Together with CAD software, the author mentions administrative software, also called jewelry management software like Bejeweled Designer Manager. As a result of the study, the author enlightens us with two basic problems in the integration of software into smart jewelry production, the first being the financial investment. Since not all software tools are open source, an additional cost factor is to be considered to use these tools. The second is the ease of using these software tools. Even though each software provides tutorial videos, the time associated with learning the software remains debatable.

Upon detailed analysis of individual components involved in jewelry making, Feser [2019] now glanced into the interoperability of these individual components into jewelry creation. The author does this by interviewing goldsmiths due to their talent in designing jewelry pieces. According to the user group of this study, the author outlines that the jewelry-making process was a ”one-man show” and the jewellers, in spite of their interest in creating smart jewelry, could not invest their time and money in such pieces. The main cause for this was the non-acceptance of the smart jewelry domain. Through the study, the author was also able to point out that language barriers and interest conflicts amongst co-workers were some of the reasons for such an independent jeweller approach.

Another problem raised by this study was the lack of concordance between the language CAD software used and those used by jewellers. The author believed that this was because these software programs were adopted from different domains into this field, and the significance of language translation to this field was forgotten. On the contrary, certain software explicitly designed for jewellers exists, but they lack the documentation of use, leaving the users in a helpless condition.

Along with goldsmiths, the author uncovers a group of users that no one considered yet, the hobbyist. These are groups of people who craft jewelry as a hobby and sell their products on marketplaces such as Amazon and eBay. Moreover, the author also points out that even though the jewellers are interested in experimenting with smart jewelry, the awareness among users for this smart jewelry is currently non-existent. As a consequence, the user cannot digest the fact of smart jewelry at this time phase making their experimentation even more challenging.

Chapter 3

Overview of software tools

Computers have always been an integral part of our development, and the impact of their incorporation in our daily life cannot be left unnoticed. This impact has tempted individuals to fuse computational technology into their work domains to ease the process. The jewelry industry is no different. The use of computers has successfully enabled designers to decrease the time and effort required for crafting jewelry, thereby allowing them to work easily and efficiently.

3.1 Origin of CAD

The journey of designing using computational technology began in 1969 by Ivan Sutherland at the Massachusetts Institute of Technology (MIT) with the invention of the sketchpad (Sutherland [1963]). In the following years, as research progressed, precision and flexibility for modelling curves and surfaces increased, giving rise to Non-uniform rational B-spline (NURBS) (Piegl and Tiller [1995]). This formed the basis of Computer-Aided Design and Manufacturing (CAD/CAM). CAD/CAM is defined by Mikell and Emory [1984] as the use of computer systems to assist in creating, modifying, analyzing, or optimizing a design. While CAD technology reduces the designing time, CAM technology transforms the virtual models (made with the help of CAD) into physical ones with machines.

Understanding the importance of this technology, CAD was soon made available to IBM personal computers by Autodesk. This paved the way for the development of various programs like SolidWorks, Solid Edge, and Parasolids. Finally, in 1991, these CAD/CAM technologies were introduced in the jewelry industry (Bernabei et al. [2015]). Thanks to this introduction, advancement in design quality and better communication amongst designers was achieved.

In this section we will look at some of the software tools that assist in the process of creating of jewelry. We will talk about CATIA in Section 3.2, Adobe Illustrator in Section 3.3, Adobe Photoshop in Section 3.4, Rhino in Section 3.5, Blender in Section 3.6, ZBrush in Section 3.7, KeyShot in Section 3.8, and lastly Meshmixer in Section 3.9.

3.2 CATIA

CATIA[1] was first released in 1977 by Dassault Systems for designing and developing their fighter jet (Patel [2021]). It provides a number of applications such as assembly modelling, part modelling, surface modelling, rendering, etc. Due to its collaborative sharing platform, this software is chosen by designers for use. Over the period of time, CATIA has been adapted for jewelry designing. Certain designers still use CATIA for designing jewelry pieces (Wannarumon [2011], T.C. [2014]). For using the software, a subscription licence has to be purchased.

[1] https://www.3ds.com/products-services/catia/

3.3 Illustrator

Illustrator[2] was initially released in 1987 by Adobe Creative Cloud. This tool is a 2D CAD software and was designed for drawing precision lines using vectors. Its one-click pattern replication and collaborative editing add to its value. In the context of jewelry, these tools help render and design jewelry pieces that are later converted into 3D models. There is a high demand for this software due to its wider user base that helps in finding solutions to problems easily. This software offers a trial period of one week.

3.4 Photoshop

Photoshop[3] was developed and published by Adobe Creative Cloud in 1988. This is a 2D design software that makes use of raster and pixels to create images (Troutner [2017]). Its visual effects remain a key point for attracting designers, and due to the ease of its use, it is a perfect choice for newcomers in designing. It also allows designers to paint and render designs similar to those observed in traditional methods. In the jewelry domain, Photoshop is used for post-production rendering combined with other CAD software and Keyshot. Like Illustrator, this software has a wider user base and offers a trial period of one week for use.

3.5 Rhino

Rhino[4] is a 3D CAD software developed by Robert McNeel and Associates. It is developed based on NURBS that helps in overcoming the limitation of AutoCAD software. This tool helps in viewing a conceptual design in

[2] `https://www.adobe.com/products/illustrator.html`
[3] `https://www.adobe.com/products/photoshop.html`
[4] `https://www.rhino3d.com/`

3D, thereby enabling one to modify and rebuild parts wherever required. For adapting to jewelry processes, Rhino has jewelry-specific plugins such as Grasshopper 3D that make the program more efficient. Thus, this software does not necessarily make jewelry pieces but aids in reducing the time complexity required for the same. The customization flexibility offered by the software allows users to work with ease. It assists in a number of processes such as precision modelling, organic character modelling, rendering, among others (Meyer [1970]). Like Adobe software, this software has a larger user base and hence finding certain solutions in case of problems could be found easily. It can also be used as a 3D sculpturing and texturing tool with the help of plugins such as Clayoo and T-Spline. A 90-day free trial period for the software is available.

3.6 Blender

Blender[5] is a collaborative open-source, freely accessible computer graphic CAD software written in Python. This software provides a path for creating 3D pipelines with processing such as simulation, rendering, sculpting, etc. Since it has not been tweaked for jewelry processes, designers use this software for general purposes. It has a larger community base of jewelry designers available to help newcomers.

3.7 ZBrush

ZBrush[6] is a 3D sculpture software developed by Pixologic inc. With the help of simple pulling and pushing features, ZBrush stands out to be a perfect digital sculpting tool (Latour [2021]). Hence, complex structures and detailed structures can be easily drawn effortlessly. This tool excels in designing organic shapes. The advantage of this software is that it enhances the realism of imaginary designs. With the

[5] https://www.blender.org/
[6] https://pixologic.com/

help of ZBrush, processes such as organic character modelling, sculpting, 3D carving, and rending are fast-tracked. It has a large user base. It is available on a subscription basis, but a certain version of this software is free to use for non-commercial purposes.

3.8 KeyShot

KeyShot[7] is a 3D rendering software used for creating photographic and realistic designs. It is a stand-alone program. Although it works on rendering techniques, it does not require any high-end graphic card on users' devices. Its unique rendering technology supports its fast and easy-to-use qualities, thereby taking a step close to being user-friendly. For jewellers, this software enables them to display their designs in an aesthetically pleasing way, thereby attracting potential customers. KeyShot software also provides a free trial for 15 days.

3.9 Meshmixer

Meshmixer[8] is a state-of-the-art software initially created by Ryan Schmitt in 2009 and later sold to Adobe in 2011 (Stevenson [2020]). This software specializes in the creation of 3D meshes that helps in creating 3D printing models. Key features of Meshmixer include mesh mixing, mesh smoothing, and free-form deformations. The software is available for free and requires no registration for use.

[7] https://www.keyshot.com/
[8] https://www.meshmixer.com/

Chapter 4

User Study

A user study is a crucial aspect in designing a product and hence has been a part of several workflows made by designers and researchers worldwide (Hasdoğan [1996]). They indeed aid researchers in understanding users' expectations, understanding, and perspective of the product. Such insights thus ensure the sustainability, reliability and growth of a product in the future. Apart from providing positive aspects, such studies also offer a negative aspect such as challenges and pitfalls of the product. Overcoming these challenges would be a plausible solution to provide better service of the product in the future.

Likewise, we use user study to gain a deeper understanding of the field of smart jewelry and the day-to-day problems that researchers or designers encounter while fabricating such jewelry pieces. In this chapter, we provide exhaustive information about the user study we conducted to achieve this. We start the chapter by providing the motivation that led to the formulation of our research question in Section 4.1. Once our research question was defined, we looked for suitable user groups that would help answer our research question. This process of selection of user groups is described in Section 4.2. Once we have identified our user group, we performed our study. This study is divided into two parts: the interview (Section 4.3) and the survey (Section 4.4).

4.1 Motivation and Research question

Feser [2019] in his study portrayed a current picture of the smart jewelry industry by interviewing goldsmiths. His main goal was to gather insights about the working style and possibilities of integration of "smartness" in traditional jewelry. For this reason, he examined goldsmiths due to their expertise in crafting traditional jewelry.

The author mentioned that the study was limited by the number of participants and their professional backgrounds. As a result, the author suggested that a broader perspective of smart jewelry could be achieved by examining and interviewing people from different professions. Furthermore, the results of his study showed that goldsmiths outsourced the work of designing a model for fabricating jewelry. This was mainly related to the learning curve associated with these software tools and the limited support communities present for helping. Keeping in mind these two outcomes from his thesis, we formulated our research question.

Research question

Research question: What are the difficulties in fabricating smart jewelry and how to overcome them?

This research question tries to cover the following points:

- To find **novel processes and techniques** involved in fabricating smart jewelry or traditional jewelry.
- To point out the **various tool used** in making jewelry.
- To enumerate the **problems encountered while crafting smart jewelry** along with **finding potential future solutions** to resolve these issues.
- To understand the **benefits of using software tools**.
- To understand the **difficulties encountered while using software tools**.
- To find out **potential reasons for not using software tools** in the jewelry crafting process.

- To find out ways that can **enable the students to fabricate smart jewelry** themselves.
- To find **potential solutions to overcome the difficulties faced by goldsmiths** while using CAD software.

4.2 Preliminary study

As mentioned in the motivation section (Section 4.1), we looked over the hurdles presented in our predecessor's thesis and try to get a broader perspective of smart jewelry. Since he could only interview goldsmiths, we inspected other jewelry-making groups as part of this thesis.

We started our thesis by taking a deeper look into the process of crafting jewelry. For this purpose, we made use of open source and freely accessible websites such as YouTube, Google, SkillShare[1], Instructables[2], as well as certain hobbyists websites such as Jewellers academy[3]. We collected information about the current crafting process and how different people have their unique approaches to this process.

Jewelry crafting process

After collecting the information about the crafting process, we had a fundamental understating of how the jewelry crafting process works. The process for crafting jewelry starts with an idea from the customer. For portraying this idea into jewelry, the idea is either drawn in CAD software or on paper. The resultant model is shown to customers to gather their views of the model. Once approved, this model is fabricated using metal or wax. The design could be fabricated directly using metal as a starting point or be carved in wax first and then cast in metal. The metal piece is then finished using hand. At the end of this manual finishing process, the jewel is fitted into the metal. At last, the piece is packaged and delivered to the customer. This workflow can be summarized in Figure 4.1

[1] `https://www.skillshare.com/browse/jewelry-making`
[2] `https://www.instructables.com/class/Jewelry-Class/`
[3] `https://www.jewellersacademy.com/jewellery-making`

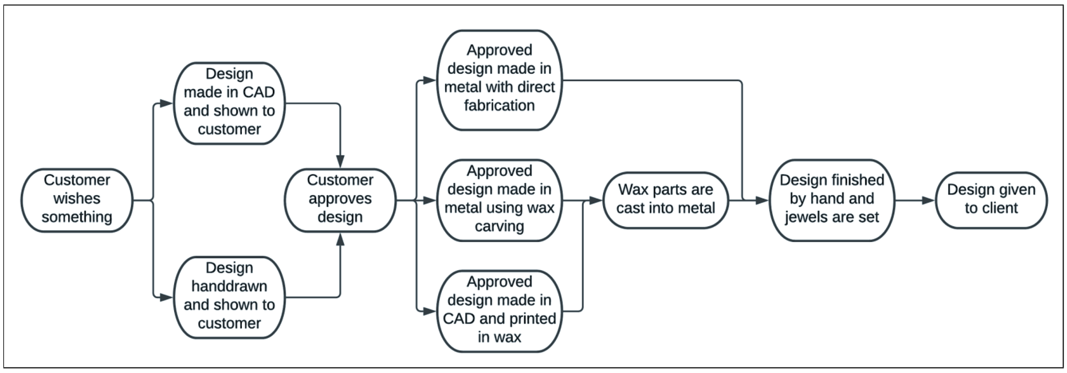

Figure 4.1: Workflow for fabricating a jewelry starting from an idea.

Search for user group

Once we understood the basic steps involved in crafting jewelry, we tried to formulate and isolate our required user group for this study. Since the commercial industry crafted products that focused on the health and safety domain, we did not prioritize them.

Following the lead from Feser [2019], we looked at cosplayers and their methodology of crafting jewelry. We gathered information from a number of cos-play specific sites such as Kamui Cosplay[4], Cosplay Tutorial[5], Cosplay Supplies[6], and PunishedProps Academy[7] along with general sources such as Instructables[8], YouTube, and Facebook groups. During this analysis, we found that the jewelry made by cosplayers was focused more on aesthetic looks rather than the material used or process followed. This raised questions about their fit into this study. Therefore, we took a different approach to tackle our research question.

To find answers to our research question, we conducted two studies; the first was an interview with university professors, and the second was a survey with students and hobbyists. The details of these two studies are covered in Section 4.3 and Section 4.4 respectively.

[4] https://www.kamuicosplay.com/startingwithcosplay/
[5] http://www.cosplaytutorial.com/
[6] https://www.cosplaysupplies.com/tutorials.php
[7] https://www.punishedprops.com/
[8] https://www.instructables.com/

4.3 Interview study

4.3.1 User group

As seen from Section 2.1.2, the market analysis suggested that the creators of smart jewelry were either belonging to engineering or academic backgrounds. This gave us the idea to approach academic experts such as professors, who have been teaching and are well versed with modern-day's jewelry crafting practices.

Based on their experience with traditional jewelry, the academic experts seemed to be the closest fit who could design and build a smart jewelry piece. Thus, we interviewed experts to get insights into novel jewelry-making techniques and processes. We also wanted to know the exact problems that can be encountered while crafting smart jewelry and the potential solutions to overcome these problems.

4.3.2 Participants background

We invited experts from around the globe via e-mail, and they were contacted based on their expertise in jewelry design. The relevant professors were found from university websites, LinkedIn, and references from other contacted teaching professionals.

From all the invitations sent, we heard back from several professors. Some of these professors had no expertise in smart jewelry and hence did not find the topic relevant for an interview. Some professors did not have expertise in working with smart jewelry but knew colleagues and friends who belonged to this domain. They were kind enough to provide us with contact information for these experts. Nine academicians accepted the invitation, out of which eight accepted the invitation call, and one could not attend due to a busy schedule but replied to questions over e-mail.

For anonymization, we call the participants P1 - P9, respectively. Out of the nine participants, seven were female, and two were male. The participants had an educational background from various domains such as fashion designing, object designing, metalsmithing, architecture and jewelry designing. The participants had experience of 4 - 30 years working with jewelry. The participants were situated in three different countries; four participants were located in Germany, two participants were located in Italy, and three participants were located in the United States of America. From the selected participants, four participants had some experience in crafting smart jewelry. One of the participants was also a freelancer working with CAD jewelry companies.

4.3.3 Interview design

Meeting platform

With the ongoing COVID-19 pandemic, there were difficulties in meeting users personally. As a result of this, we shifted to a virtual model of meeting with the help of Zoom meeting[9]. Using this situation to our benefit, we were able to contact participants from all around the globe. All the interviews were conducted in English.

Data protection details

To ensure the anonymization and usability of information given by the participants, a consent form was provided before the interview. In this consent form, information about the research question and prior knowledge about the interview course was provided.

[9] `https://zoom.us/`

Questionnaire details

The interview took place in a semi-structured manner. Some of the questions were defined based on previous work and related work. We followed the recommendation provided by Lazar et al. [2017]. These questions covered 6 broad sections:

1. **Participant demographics** - This included the background information about the participant. The questions focused on how they were introduced to the field of jewelry, their current projects, and their experience in teaching and crafting smart jewelry.
2. **Product-making process** - This included questions on workflow, tools and materials used, outsourcing practices, and the techniques practiced in-house.
3. **Teaching content** - This included the content, the method, and the depth of the content covered while teaching the courses.
4. **Software** - This included questions on software used, advantages of using a software, reasons not to use software, and challenges while using certain software. It also included questions on certain improvement ideas and users' opinions on them.
5. **Smart jewelry** - This included participants' understanding of smart jewelry, their previous experiences working on smart jewelry, problems that can be encountered while making smart jewelry, and suggestion on how to make the process of crafting jewelry/smart jewelry efficient.
6. **Suggestions** - This included question on suggestions for goldsmiths that could help them solve the problems encountered while using CAD.

The interview questions can be found in Appendix A. Ultimately, the questionnaire gained insights about the jewelry-making workflow, the content taught in universities, the advantages and problems of using software, the smart jewelry fabrication process, and the suggestions for goldsmiths.

Interview procedure

At the beginning of the interview, participants were informed about the study's purpose and the research question. They were assured about the anonymization of the data collected. Participants were part of this study voluntarily, and no compensation, cost or risk was involved in the study. Lastly, there were no strict time restrictions for the study, and hence, the participants could take breaks during the study if required.

During the interview, participants were encouraged to discuss topics that were part of the smart jewelry domain but were not part of the interview questions. All misconceptions and misunderstandings in the questions asked were solved with counter questioning by participants. Nevertheless, all the interviews followed a semi-structured interview method (Lazar et al. [2017]) and discussions revolving around the research question were highly encouraged.

The interviews lasted for a period of approximately 40 to 105 minutes. All the interviews were recorded over the Zoom platform for documentation purposes, and specific notes were jotted down. Furthermore, these interviews were manually transcribed by me.

At the end of the interview, the participants were thanked for their time and contribution to this thesis. Following this, their feedback on the topic as well as the questionnaire was collected.

4.3.4 Data Analysis

After conducting the interviews using the techniques mentioned in Section 4.3.3, we move towards analyzing this data. For this purpose, we first transcribe these interviews using a qualitative data analysis software called MAXQDA[10] (version 20.4.0.). It is a state-of-the-art analysis tool providing interactive coding and powerful visualizations.

The analysis of the interview was performed using a well-known approach, the grounded theory approach (Strauss and Corbin [1998], Glaser and Strauss [1967], Charmaz [2006]). For our thesis, we use the grounded theory approach in a two step iterative manner; that is, we iterate through the collected data multiple times to understand our hypothesis. As mentioned at the start of this chapter, our hypothesis is to find out the difficulties in the fabrication of smart jewelry and point out their potential solutions. Hence, we use three coding steps to find novel results from the data: open coding, axial coding, and selective coding.

We worked parallelly in conducting, transcribing, and coding the transcribed interview. We started by following an open-coding step wherein relevant pieces of information were extracted and categorized in codes. The codes were labelled based on the topic or subject highlighted in the statements, and these labels were kept consistent between different transcripts. Upon completing this step, we moved towards axial coding (Glaser and Strauss [1967]), during which we aggregated all the codes together and found meaningful connections between them. These connections would be based on the context of data represented or the causal condition reflecting the data. Such connections helped us in grouping specific codes into categories. Lastly, we performed the selective coding step. This was a crucial step for us to formulate general categories significant to our study hypothesis. We also removed certain categories that were not relevant to the hypothesis and were not found in more than half of the transcripts. As a result of this iterative process, we were left with 612 codes present in seven main categories. The detailed information on these codes can be found in Appendix B.

To get an overall picture of the usage of the coding sys-

[10] https://www.maxqda.com/

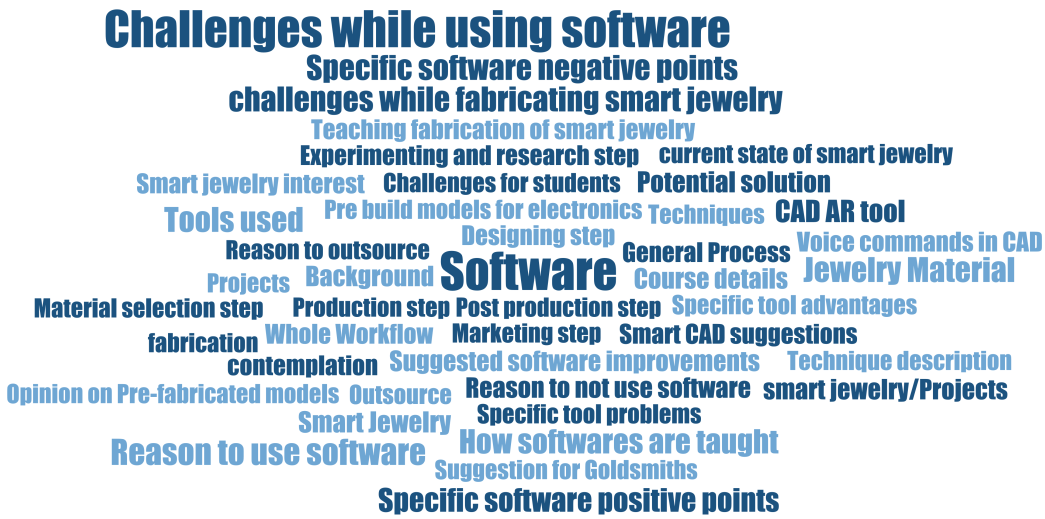

Figure 4.2: Code Cloud of the codes finalized after analyzing the data. The size of the word positively correlates with their occurrence in the data.

tem in our transcripts, we created a code cloud representing the most frequent code appearing in the transcripts (Figure 4.2).

4.3.5 Results and Discussion

In Section 4.3.4, we described in detail our coding procedure, which we followed to analyze our data. In the following section, we will point out the results we achieved after analyzing the data with the help of these codes.

Course details

The foundation of learning smart jewelry or jewelry design, in general, begins at university, and academicians or departmental professors decide the module structure for such courses. During the interview, we spent some time discussing what aspects of jewelry design the participants find relevant to be included in their course work.

Participant 1 mentioned that during the three year course, the students are exposed to several techniques, right from the basics of goldsmithing to advanced 3D software. They are taught how to use traditional tools along with technology and have the flexibility to *"experiment new approaches"* with the help of many different materials (*from plastic and wood to recycling materials*). Furthermore, the course also provides training using 3D tools and software, thereby preparing students for industry. Similarly, Participant 2 mentioned several 3D software such as SolidWorks, Photoshop, Illustrator, InDesign, and Rhino, and Participant 7 talked about other software such as ZBrush that is part of their curriculum. On the contrary, Participant 9 highlighted that the course did not focus on CAD software, as mentioned below.

> P9 : *..we do not put any focus on CAD as a part of the artistic/design process, although CAD classes are part of the program in basic education.*

Apart from these details, Participant 7, Participant 8, and Participant 3 mentioned the different techniques and workflows of the program. These techniques include rapid prototyping with the help of 3D printing, laser cutting, 3D scanning, CNC milling, novel methods like electroplating and electroforming on 3d printed parts, and others.

Rather than referring to specific course details, Participant 4 enlightened us with the central ideology for the course. We spoke about the importance of the course, which is to communicate one's idea and reflect it into the jewelry piece.

> P4 : *..So you have the jewelry, but how do you communicate the story behind the jewelry, or how do you communicate something important for you to make the jewelry so when the person has the jewelry and sees the images, they get a complete image, and the last thing we teach or that is part of the course is how to present your work or how to present it in a context whether it is a gallery or a series or a commercial, so*

you understand what you do in the context in which you place it.

Teaching both traditional methods as well as novel methods

Altogether this discussion of course details with participants provided us with information regarding the depth and level of material taught at the university level. On the one hand, participants mentioned the traditional approach of jewelry design by teaching details about design language and competency. On the other hand, modernization in the study program took place with novel methods, techniques, and workflows.

Challenges for students

Along the process of learning, several situations make students hesitant towards learning. This is something that is commonly seen by designer students, also known as independent designers. On addressing how students face challenges during jewelry designing, participants had some opinions. Participant 1 and Participant 5 remarked that students find it difficult to approach companies for assistance in their designing process because of two reasons; the first being *"one-in-a-kind"* jewelry and the second being the production of just a single piece of the jewelry.

> P1 : *...but as you are an independent designer, sometimes its hard to approach technologies that are used may be from factories because if you want to do one of a kind jewelry, you need to find a factory that is happy to help you, you are not asking them to produce but to experiment one of a kind piece, that is something hard as an independent designer...*

> P5 : *You also have to find a company that will print your products on a small scale, especially if you are just going to produce one as either a prototype, an independent artist, or a student...*

Participant 6 discussed the issue concerning the course curriculum rather than the designing workflow. Participant 6 told us that students coming into this field tend to be scared about using software and other technologies.

> P6 : *I see that at the beginning of the course they are scared about it as it is a big world and unknown to people studying jewelry...I feel that the students in this field are scared about new technology and these kinds of different things they are not used to.*

Since the focus of commercial companies is on the mass production of products, they have a majority of tools and techniques required for each of the independent steps in jewelry designing. These tools are expensive and not affordable to some independent designers, especially students. This leads them to ask companies for support during their workflow when they need to use these tools. However, given the time and money spend on using these tools just for a single product, it becomes difficult for companies to lend such services to designers, thereby leaving independent designers in a helpless state.

Students struggle to find a company to 3D print their design

Outsourcing

Outsourcing is a standard business practice where a group of people does a particular job on someone else's behalf. Such practice is also seen in jewelry designing, where due to the limitation of in-house tools and techniques, jewellers opt for an outsourcing approach. With the curiosity to know if an academician undertakes such practices, we raised this issue in our interview. Participants 1 and 3 denoted that they outsource certain workflow steps such as model making using 3D software or casting. Other participants also reported that they outsource certain processes. On further cross-examining the reason for outsourcing, Participant 1 stated that not enough time on learning and mastering the process was present, and Participant 1 found it better to give the work to experts. Participant 7 found that such an outsourcing approach boosted the working proficiency, thereby making multi-tasking possible.

> P7 : *The reason why I love the digital process in my workflow is that I can push out, I could work on other things wait for things to come back such as 3D prints while waiting on those I'm able to multi-task so it's you know I think the benefit of this is that and the goal of this is the more that I can digitally push out and wait for things to come back, the more efficient my workflow and my process is.*

Furthermore, Participant 4 and Participant 5 feel the need to outsource their work due to limitations in the available resources, along with the cost required for maintaining and using such tools.

> P5 : *The reason I keep outsourcing my work instead of owning a printer myself outside of the educational purpose, so schools as purpose to teach students but for myself as a jeweller that's what I have been waiting for but they are huge. I do not have a studio big enough even to house one as they can be as long as a car, but then they also are tens of thousands of dollars, if not close to 100,000 dollars.*

Outsourcing enables parallelization

As seen from Feser [2019] thesis, goldsmiths outsource certain processes during their designing phase. Similar behaviour is observed in academicians who outsource certain parts of their designing phase either due to handling expensive parts of jewelry or because such an approach helps them work in parallel on other tasks. Hence, as a result of outsourcing, they can work efficiently.

Workflow

With many essential steps involved in crafting jewelry, it becomes essential to follow these steps sequentially. This resultant workflow thus enables one to reach a finished product starting from an idea. To enquire whether the workflow remains general between different academicians, we questioned our participants and asked them about their jewelry-making workflows. All the participants emphasized that there is no pre-defined workflow followed, but rather a combination of research and experimentation takes place while designing. They also mentioned that the experimentation is just not limited to the workflow level, but it could also be at the process level. For example, with the same workflow but different starting material, different ideas or perspectives of the same jewelry piece can be represented. On the whole, the choice of a workflow is dependent on the final product that has to be made.

Each workflow first starts with research revolving around the idea for which the piece is created. The idea could be inspired either from be political, or historical or emotional field. This is followed by a designing step, as participants pointed out. In this step, the designing idea of the jewelry piece is either drawn using 3D software like Illustrator or on paper. Participants mentioned that it is at this step that the selection of certain initial tools along with the selection of relevant software for designing the jewelry piece takes place. Both Participant 4 and Participant 7 outlined that this designing step helps designers recognize the material used to craft the piece.

> P7 : *I can begin to kind of lay down something on paper roughly to do the napkin sketch, to figure out what materials I am going to prototype in and look at something in you know it is just like looks like feels like a type of modelling that's not the final presentation.*

Once the academicians have identified the piece and the material to be used, the production of this piece begins. In this step, participants pointed out using several techniques such as laser cutting, casting, metal plating over 3D printed models, and moulding in particular. Once they have made the product, the post-production step begins. Here, the participants spoke about the piece's hand-finishing, packaging, assembling, and painting. If this piece were to be sold in a marketplace, marketing of this piece would be done. Participant 1 mentioned the use of a mixture of media components for doing so.

> P1 : *Parallel to that, I work with photography, I mix media to communicate the final product as well.*

During each of these steps, the participants perform experimentation and research as pointed above. We found varying views of this experimentation amongst participants. Participant 1 reported that the experimentation occurred in the material selection step.

> P1 : *I experiment with metal or with any material that I want to use in the workshop. I do parallel material experiments, and at the same time, I try to work on the concept and find the inspiration where my work wants to start.*

Participant 4 commented that along with experimenting on material, experimentation on the body of the piece also takes place. The desired thickness of a ring could be one such experimentation. Furthermore, Participant 6 pinpointed that such a workflow is also used to create prototypes and these prototypes serve the purpose of verifying usability.

> P6 : *After this, you make a prototype and at that moment you are verifying the aesthetics, the wearability, and the mechanism so it has to work on your body.*

On a detailed discussion with Participant 4, we found out about four different approaches one could take to craft jewelry.

1. One can start with an idea or concept, select the appropriate material and then follow an experimental design approach.
2. One can start with sketches of the piece and then decide on appropriate materials and techniques required to craft the piece.

3. One can start with an idea and form digital drawings. From this point on, they can take the necessary route to craft the product.

4. One could start with an idea portrayed in a manual sketch. This sketch is then converted into a digital model with the help of software. Following this path, the jewelry can be crafted using rapid prototyping tools or manually.

As a result of the discussion with the participants, we can conclude that two types of jewelry crafting workflows remain prominent. One being a pre-defined step-by-step guide. This involves designing, material selection, production, post-production, and marketing steps, respectively. The second being on-the-flow workflow, where once the idea or design has finalized, experiments with the different approaches are undertaken to reach the finalized product. Irrespective of which approach one takes to craft jewelry, an iterative process in these steps lead to refinement in the technique and the final piece of jewelry.

A more flexible jewelry crafting workflow

Materials, tools, and techniques

Along with the discussion on workflow, we also discussed and enquired the participants about the materials, tools, and techniques used in the above-mentioned process. All the participants made use of precious metals such as silver and gold. Apart from these other materials such as plastic, wood, plexiglass, titanium, paper, textile, Nylon12, Japanese alloys, recycled material, elastomers, and cellulose were used. Some of the participants also made use of certain unique and interesting materials. Participant 1 makes use of Corian, which is a solid surface material, while a student of Participant 4 made use of surgical masks.

Materials used

Looking at the difference in the techniques used during crafting processing, we found the use of electroplating and electroforming on 3D printed pieces, inter-locking casting, sand casting, directly 3D printing in metal, and lost wax casting as prominent techniques used by the participants.

Techniques used

Participants mentioned using laser cutting, 3D printing, casting tools, 3D scanning devices, stereolithographic cameras, soldering machines and torches, and computer numeric control (CNC) machines from the tool's point of view. Almost all the participants mentioned that they used 3D printers for one or more processes, and hence we questioned them about the pros and cons of these printers. Participant 1 and Participant 5 remarked that 3D printers assist in the visualization of the jewelry piece. Participant 5 added that this computation process also helps speed up the process.

Tools used

> P5 : *I really enjoy using 3D printing during the preview step, that is, to understand how the piece will be...With 3D printing, there are so many alternative materials that if I make one file, I can print it in all those materials and see what feels right or what works well. Is it light enough? is not strong enough?...*

Moving towards the cons, Participant 1 mentioned that a controlled environment is required for maintaining the resin required for 3D printing. *If the resin is too hard, it would not be used for casting* Participant 1 quoted. In Participant 5's views, 3D printers are expensive, huge, and not accessible at times. Additionally, Participant 5 adds that such tools have a restricted environment, which blocks designers' flexibility.

> P5 : *The process can be very different with computer-aided design, we have to work around not only in what type of 3D printing you would have access to create the product but also thinking about what materials are available...I think the hardest part is to access printers with high resolution.*

Material selected based on the ideology depiction

Undoubtedly, a large number of materials seem to be used presently for crafting jewelry pieces. These materials depend on the idea the designer wants to portray through the jewelry. Hence, the current state of jewelry making encourages designers to think out of the box and use any material available that would depict their ideology in the best way possible. Furthermore, 3D printing remains an essential tool for crafting jewelry due to its benefits compared to its challenges.

Software

As demonstrated in Chapter 3, software tools are one of the factors that contribute to the evolution of the smart jewelry domain. Because the introduction of these software tools was to ease the burden on designers, we wanted to know if they were used practically after collecting all the theoretical background about software. With this objective in mind, we questioned our participants about the software they use, the software they teach, the purpose of using these software tools, their pros and cons, and the challenges academicians face while using them.

Participants told us that they use several software tools such as Photoshop, InDesign, Illustrator, Rhino, Meshmixer, Fusion, KeyShot, CATIA, Grasshopper, AutoCAD, ZBrush, SolidWorks, Blender, and Geomagic. This list was exhaustive, and we just mentioned a few of them here. Participant 8 mentioned the use of Clayoo for the jewelry-making process.

> P8 : *...so clayoo is a hybrid plug-in that utilizes subdivision, and it also utilizes sculpting tools. So you can create surfaces that use sculpting like push-pull sort of toolsets, but it can take that sculpted surface and convert it into subdivision surfaces.*

Participant 7 explicitly stated that these software tools are an advancement in jewelry and have eased the process so that it would be difficult to get back to the traditional way of designing.

> P7 : *...I think I would not go back to a very traditional analog if I were not forced to.*

Additionally, the participants pointed out the uses of these software tools in their process. Software such as Illustrator, InDesign, and Photoshop was used for image manipulation, KeyShot was used for rendering, Rhino was used for modelling, and ZBrush was used for polygonal modelling. Illustrator was also used for laser cutting purposes.

Ways for students to learn software

Looking at the inexhaustive list of software used by participants, we discussed which software is taught at the university. Participants 1, 5, and 7 remarked that software such as Photoshop, Illustrator, and InDesign are the primary software taught to university students as they make a good starting point in software. On the other hand, Participant 2 feels that SolidWorks is easier to learn. Furthermore, participants mentioned that many other things play a role in software usabilities, such as the time spent learning them and the self-motivation required to learn them. Participant 5 also added the importance of making students think in the software's language.

Along with this, tutorials and workshops to learn and practice this software were recommended by Participants 3, 6, and 7. All the participants felt that when introducing beginners to using software, it is essential to help and assist them when in need and encourage the documentation of the processes to refer and learn. Also, Participant 7 and Participant 8 strongly felt that CAD software should be a part of every jewelry-designing curriculum.

Software-specific advantages and disadvantages

Moreover, participants were asked about the advantages and disadvantages of the software mentioned above. Rhino was found to be good for crafting free-form objects, it is user-friendly, and it remains consistent with each update. The presence of a large community for Rhino helps participants when stuck. It adds to its advantages. Also, its cheap and affordable license helps individuals to buy this on their own. Some participants mentioned that using Rhino's crafting of free-form objects adds to its disadvantage as it is restricted to these objects only. Participant

5 points out that the commands used in this software are not user-friendly, and hence one has to remember a different vocabulary to work with Rhino. Lastly, Participant 7 pointed out a vast difference in Rhino's user interface between different operating systems such as macOS and Windows.

When we spoke with the participants about SolidWorks, they mentioned that this is used when working with straight lines, primary geometric forms and figures. Like Rhino, participants mentioned that with each update, the interface remains the same and consistent, thus causing less to no user interface-related issues. Other software such as Illustrator, Grasshopper, Photoshop, and Meshmixer were also part of the discussion. Illustrator was found to be suitable for converting the drawing into vector lines. Grasshopper was free to use but had a steeper learning curve and required a higher skill set. When talking about the user interfaces, participants were unhappy with how the user interface for Meshmixer was designed and the non-intuitive nature of the interface of Photoshop.

Feature requests

Considering these advantages and disadvantages of software, participants gave their opinion on what could be possible feature requests that they would want to make to these communities. Participant 1 suggested a feature improvement with SolidWorks such that it could be compatible with drawing organic shapes. In contrast, Participant 4 suggested the addition of a feature that could enable the users to fix the 3D scanned files in Rhino.

Reasons for using software

The discussion then shifted to understanding the importance of using or not using software in certain steps of the jewelry-making process. Most of the participants agreed that with the help of software, clear communication of ideas was achieved by viewing drawings of the jewelry piece.

> P1 : *...This is because drawing is not enough for me to understand if things can work; of course, then I use a lot of illustrator program to design...*

Apart from visualization, these tools help analyze the requirements such as shape, size, or material type for the jewelry piece.

> P1 : *If I work on earrings to understand the shape and the size, I might experiment a lot with computers and print them to understand the ratios with the body...*

> P5 : *With 3D printing, there are so many alternative materials that if I make one file, I can print it in all those materials and see what feels right or what works well. Is it light enough? is not strong enough?*

Moreover, the efficiency that the use of 3D software tools adds to the jewelry process is commendable, stated the participants. This includes the ability to copy a given design multiple times with just a click, the ability to adjust digital models faster compared to analog, and the ability to preserve models and data over time.

> P4: *There is an area in Germany that is known for hand carving out of ivory balls in balls in balls. And you would say that is typical for a 3D technology, you can print moving things in one print but a human hand, it might take months.*

With the ongoing pandemic and work-from-home scenarios, participants discovered the use of 3D software as a collaboration tool for communicating between team members.

> P6: *In my experience, where I worked with a team on wearable smart technology, I used CAD modelling in order to understand what I was doing and what my ideas are in collaboration with others.*

Lastly, these tools were found to be a great way to reduce the material wasted in creating different designs. Thus, it aids researchers in finalizing the material in which they would want their jewelry piece to be crafted.

> P6: *So in the past, I had to make a lot of different models with metals, and it would waste a lot of time and material, whereas with using CAD software, I could make a little adjustment on a part, and it would be beneficial...*

Reasons for not using software

Even though CAD software helped participants ease their work, there is always a new technique or method evolving in these software tools; Participant 7 mentioned that learning these software products remains forever.

> P7: *You know I always hear this like this phrase asked "how long did it take you to make that" and he goes you know 60 years...*

Furthermore, these software programs have a steeper learning curve and require the need to learn "software-specific" languages were some of the outcomes from the discussion.

> P8: *So the downside to this all-potent CAD solution is ultimate, at least at this phase of the game is the mammoth level of technique that is required. Moreover, that mammoth level of technique in many ways is then becoming exclusive to a specific form language or a specific aesthetic.*

Participant 2 and Participant 4 pointed out that 3D software skills limit the design. On top of that, Participant 6 mentioned that when working with software, haptic feedback is absent, which is generally present while crafting jewelry by hand.

Challenges while using software

Since our participants were actively using software in their jewelry-making process, we enquired about the different challenges while using these software tools. Participant 1 mentioned that these software tools are inaccurate and do not follow the WYSIWYG (What you see is what you get) system. Along with this, Participant 5 pointed out that for the whole jewelry-making workflow, different software needs to be used, and with each software, a new language needs to be learned. Participant 3 and Participant 7 added that during the transition between these software tools, neither does the user interface nor does the tool names remain consistent, thereby adding to the learning curve for software. As a matter of fact, the step involving the use of software turns out to be the most time-consuming in the workflow.

> P3: *The buttons or the navigations in the programs are not the same, and then you have to get used to this, and it is different for all the programs, and all the shortcuts are different as well and you have to memorize a lot of stuff.*

Participant 4 reminded us that even though we see the potential benefits of using software, it comes at the expense of learning the language of the software, and this learning is what causes a hindrance in the process. Thus, a designer has to "think in terms of the software" to use the software.

> P4: *You have to spend a lot of time trying to trick the system to make it do what you want, and I think that is either reflection of my poor rhino skills or that cannot be the idea that you have to outsmart the program rather than using the program how it is intended to.*

Furthermore, Participant 3 mentioned that the user interface is difficult to understand for beginners and Participant 4 also mentioned that debugging the error using software is challenging and time-consuming.

> P4: *So it tends to be a more frustrating kinda problem, It's difficult to deal with it because with analog*

> *tools like cars when you open the hood and you see the motor you can fix it and the more you have to be a programmer or the more you have to understand the complexity of the program and you are just the user and if there is a problem, it's more difficult to deal with the problem.*

In conclusion of this long discussion of software with participants, we understand that there remains a trade-off between the ease of use and functionality of these software tools. The more features or functions a particular software offers, the higher and steeper is the learning curve for this software. Furthermore, the professors emphasized that learning these software tools should be done step-wise for beginners, aiding and assisting them when in need. This helps build the foundation for using the software in the future. Post the retrospective analysis of the usability of these software tools, it was clear that the benefit of learning and using these software tools in crafting jewelry far outweigh its challenges.

There exists a trade-off between the ease of use and functionality a software tool offers

Potential solutions

From the discussion with participants, we found out that certain solutions can make it easier to craft jewelry. Before and during the interview, specific suggestions regarding these solutions were highlighted and debated. Not all of these solutions required the creation of new technology; instead, they could also be an addition to an already existing technology. One such solution was the addition of digital components to the already present jewelry component library. Since some software already supported pre-existing models for traditional jewelry components, we first questioned our participants about their opinions on using these existing models for jewelry.

When the participants were asked whether they used such a model for their design, all the participants agreed that they do not use it. Furthermore, when questioned on the reason for not using these models, they told us that they

Addition of digital components to the jewelry component library like to have complete ownership and authenticity of the designs.

> P3: *I would like more, If I make my models myself. It is more authentic, and although it is digital then, it is then my model. I cannot take anything from the internet.*

Since we know their opinion on pre-built models, we were interested in knowing whether they would use pre-built models for electronic components. These models would have additional digital objects as pre-built jewelry components and would make fabricating smart jewelry easier. All the participants agreed that having such pre-built models for electronic components would be great for an industrial purpose where efficiency is at a higher priority. Participant 5 added that such models could also be helpful for beginners as they would help them get started in the field. On an individual basis, almost all of the participants disagreed on using such a feature as it would *"kill their creativity"*. In contrast, one participant was excited to use such a model.

Voice commands as input for CAD

Another potential solution we discussed during the interview was using voice commands as an additional input for the software. Here we received mixed answers where some participants were hesitant to shift towards the idea, and the remaining participants appreciated the idea. Participant 2 belonged to the first category. Although Participant 2 liked the idea, the participant was unsure if it would suit the designing process. Participant 2 also added that this would increase the complexity of working with CAD tools.

> P2: *I think it would be more difficult. Working with the symbols in the layout and working with shortcuts is easier with respect to voice. Maybe this is just subjective. I never felt comfortable using my voice with my computer.*

Participant 4 also belonged to the first group and told us that it might be fascinating to try and found it unusual to talk with the jewelry-making tools.

> P4: *I would be fascinated to try it definitely, but it is interesting because it does go into that context that I would communicate with this tool in the way I would never communicate in my other life, you know because I am not going to talk to my wax and have it do something so I think I would find it quite fascinating and interesting..*

Participants 3, 5, 7, and 8 were extremely excited about the idea and were happy to try it out. They also had certain interesting opinions, such as Participant 5 pointed out that such an approach could benefit when one has to use both mouse and keyword for performing certain tasks, and Participant 8 stated that this could be helpful in transitions between views and applications. Participant 5 also added that this tool could be of great help to people with disabilities.

Smart CAD suggester

Inspired by machine learning applications, we came with another potential solution, the smart CAD suggester. We asked our participants about their thoughts on using such a tool that would give suggestions to designers for possible next steps in their designing process. Like the other suggestions previously, the participants did not find this idea interesting as they thought it would in some way *"kill their creativity"*. Participant 4 personally did not like the idea and believed that sometimes mistakes in the designing process could lead to great jewelry pieces. Participants 6 and 8 both liked the idea. Participant 8 suggested that the model could also have a design improvement function, such as detecting mistakes. Interestingly, Participant 8 also pointed out that suggestion of incorrect or unnecessary steps could be one of the downfalls faced with this tool.

CAD AR tool

As digitization has progressed in the jewelry field, jewellers have started using software to design their products. The interaction they experience while using these software tools is quite different from the interactions experienced while using analog tools. Thus, we thought of a possible solution to help reduce this difference by suggesting a CAD AR tool. This would be a tool enabling augmented reality (AR) functionalities with the help of smart glasses and hand gestures.

As opposed to the previous answers, Most of the participants were really happy about this suggestion and found it intuitive. Participant 1 added that it would be easier to learn in such a manner, and Participant 5 added that it could bring the digital and analog worlds closer.

> P5: *I think, and for a lot of students, that might help bridge the gap between digital which exists on the screen and your hands are controlling the keyboard and the mouse is your tool versus skills that often come with your handling skills and working with the material in reality..*

Participant 6 mentioned that such a tool could help in providing more insights using visualization, thereby saving material and reducing costs. Participant 8 pointed out that it could be an excellent tool for sculpting purposes, and since the whole body would be involved, it might be physically exhausting to use.

Other solutions

As mentioned earlier, looking at the suggestion we made previously, other participants also offered their ideas. Participants 3, 5, and 7 mentioned that there could be a possibility to standardize the user interface between different jewelry designing software in the future, thereby making navigation and transition from one software to another easier. Participant 8 told us that in the future, it would be good to have a single software that would handle the complete designing process, including 3D printing.

CAD AR tool can bridge the gap between digital and analog worlds

At the end of this exhaustive discussion of opinions on our suggested solutions, it is clear that there is a distinction between two groups of people present in the jewelry field. One group is traditional and is hesitant towards modern techniques, while the other group is enthusiastic and is free to shift from traditional methods to modern ones. Despite these differences, all the participants agreed that there exists a gap between the analog and digital worlds, and this could be bridged with the idea of the CAD AR tool.

Smart Jewelry

Contemplation of smart jewelry

Smart jewelry has been a term that has been extensively used, but a standard definition for this term does not exist yet. Each designer has their perspective of smart jewelry. Hence, to gain insights on how the meaning of smart jewelry differs from person to person, we asked our participants about their contemplation of smart jewelry.

Participant 1 mentioned that smart jewelry is *"anything that would have technology in it and would react with the body"*. Even though Participant 1 was interested in making smart jewelry, the participant saw smart jewelry only as a design piece and not as a jewelry piece because it does not have any emotional connection.

According to Participant 2, smart jewelry is *"something that has a secondary purpose, for example, a screwdriver on top of a ring"*. Like Participant 1, Participant 2 also pointed out that these types of jewelry do not have an emotional side. Hence, Participant 2 would be interested in exploring smart jewelry's emotional or artistic side rather than the healthcare functionality.

In Participant 3's opinion, smart jewelry is *"something that is added on the body to check the state of the body"*. On the other hand, Participant 4 contemplated smart jewelry as *a packaging of a product that helps to bring something onto the body*. Thus, Participant 4 strongly believed that smart jewelry contains jewelry as only an additional thing added on top of technology for it to be packaged. When asked about their interest in smart jewelry, both Participants 3 and 4 were interested in crafting smart jewelry. According to Participant 4, this type of jewelry could provide an additional way to express emotions with the help of jewelry.

Unlike others, Participants 5 and 6 explained their meaning of smart jewelry with the help of projects. Participant 5 explained about *"a necklace that one could use in case of emergencies and with a single push it could send out a message or signal to one's contacts"* as an example of smart jewelry. Moreover, Participant 6 discussed a project work where *"a* *bracelet was used to change the perception of temperature with the help of waves"* as an example of smart jewelry. Along with this, Participant 5 added that current smart jewelry is not aesthetic.

Interestingly, the view of smart jewelry for Participants 7 and 8 was aligned with Participant 4. They thought smart jewelry is just some technology that is packaged in the form of jewelry. According to Participant 9, *"jewelry has always been smart as it has been an essential factor within the society"*. Furthermore, Participant 9 mentioned that *"traditional jewelry can overcome globalization and withstand digitization"* and found smart jewelry to be unattractive due to its questionable sense of modernity.

Fabrication of smart jewelry

Now that we understood participants' understanding of smart jewelry, we directed the discussion to the fabrication part of smart jewelry. Here we asked them for important pointers one should look at during this process and the fabrication process in general.

Initially, Participant 2 took us through a quick overview of the process by making the piece's body in software, followed by printing and casting this body, and later adding the electronic components. Contrary to this, Participant 4 suggested a different approach by creating a prototype first and subsequently improving it to get to the finished smart jewelry piece. Altogether, Participants 1, 2, and 4 mentioned that a higher focus on the jewelry aesthetic should be present during the crafting process.

> P2: *I think it would be even more interesting if you would focus on modern design for modern things. Because most people who are attracted to classic and typical jewelry are not interested in their "smart" functionalities...*

Contrary to this, Participant 7 mentioned that even though one focuses on jewelry more, the focus on the technology part should not be lost and hence suggests an equal focus on both parts be present to craft smart jewelry. Furthermore, due to the involvement of different expertise (such as jewelry makers, designers, computer scientists, and electrical engineers) in this process, Participants 1, 4, and 6 believe involving people from different backgrounds and working as a team would be the key to making a successful smart jewelry piece. Along with these points, Participant 4 added that good knowledge about programming could be beneficial. Participants 6 and 8 pointed out research and experimentation steps as critical steps in the process. These two factors remain a crucial step in the process as several problems encountered during the process can be predicted and solved prior mentioned Participant 8.

Enabling students to fabricate smart jewelry

From the dialogue with the participants, we found that several key details were essential while crafting smart jewelry. This made us inquisitive about how these details could be translated during the course to the students. Hence, we asked them on what they think could be a possible way to incorporate smart jewelry into the curriculum.

During crafting smart jewelry, there is an overlap and interplay between the different domains. Due to this reason, Participant 1 suggests that students should be encouraged to craft smart jewelry in groups or teams. Contradicting ideas were denoted between Participants 5 and 6 and Participant 2. Participants 5 and 6 mentioned that a specific course for smart jewelry could exist. In contrast, Participant 2 mentioned that a lecture or module on digital aspects of smart jewelry would be sufficient rather than a whole course. Participant 7 felt that jewelry designing students could be slowly introduced to electronic components, thereby eliciting their interest in crafting smart jewelry. Participants 2 and 4 referred to improvements in the basic block of smart jewelry, the software. They mentioned that students could be encouraged to learn programming and experimentation so that later they are comfortable transitioning their ideas in the field of smart jewelry.

Challenges faced while fabricating smart jewelry

After looking at the suggestions for students and pointers for smart jewelry, we asked the participants what challenges one could face while fabricating smart jewelry. Participants 1, 4, 6, and 7 mentioned that research and experimentation are vital elements for crafting smart jewelry, and these two things could be difficult at times due to several reasons. Firstly, not everyone could be open to experimentation and learning new things, thereby limiting smart jewelry crafting. Secondly, researching and applying new learning for crafting could be exhaustive both physically and mentally. Lastly, experimentation could be time-consuming as several things need to be considered for this, and if one thing is missed, the experiment is bound to fail. Thus, a very high amount of enthusiasm is required to experiment with the technology until it is functional.

Participants 3, 4, 5, and 7 debated the technology size required for crafted smart jewelry. They mentioned that there could be difficulty with designing jewelry based on the small electronic components required to be added on top of the jewelry. Furthermore, electronic wiring could be a possible hurdle in making the jewelry piece aesthetic. Along with this, Participant 4 added that limited to no knowledge about programming is also a hurdle as programming is needed to make a jewelry piece ”smart”.

> P4: *As soon as you get into the abstract programming or you write an algorithm, and that is not gonna be everybody's cup of tea, but especially if you want to work with smart jewelry as a poetic, artistic medium, then you either have to do programming or you either have to work with someone who does that and that goes beyond CAD..*

Participants 5 and 7 mentioned additional factors that need to be thought of for making the jewelry smart. For example, when using jewelry made from metals, metal oxidation could occur due to the electronic currents present in the smart jewelry. Also, smart jewelry is not waterproof, and damage to electronic components could occur if water enters the jewelry piece. Another factor could be child protection due to the current flow in such types of smart jewelry pieces.

Participant 5 discussed that the current jewelry pieces are available in a range of sizes, and during the period of using the jewelry, there could be a possibility that the users' body shape and size change. This could add to the limitations of crafting smart jewelry as the size of jewelry needs to be scaled with the size electronic component. As a result of this, the complexity of dealing with too small components reoccurred.

Participants 6 and 7 highlight that there is a need to understand the technology first before crafting smart jewelry. There are several things such as the battery, electronic component's size, comfort of the jewelry, material, weight of the jewelry, and how can it be in constant contact with skin that needs to be considered for successfully crafting a smart jewelry piece. Thus, a significant drawback of this approach for jewelry designers is that it could require exponential time and constant learning to gain this information.

Smart jewelry definition is ambiguous

Generally speaking, the definition of smart jewelry is ambiguous where some people consider it to be a piece of jewelry capable of smart functionalities while others consider it to be a technology using jewelry as a casing. Even though such an uncertain contemplation exists, the idea of smart jewelry among individuals remains the same; the combination of technology and jewelry. Hence, to successfully create a product with this combination, one would require expertise from both the technology side and the jewelry side, thereby involving teamwork in the process. Another takeaway from the above conversation is that research and experimentation remain the critical points for crafting smart jewelry products, and the ability to do so would require dedication and self-motivation.

Research, experimentation, and teamwork are key to craft smart jewelry

Suggestions for goldsmiths

Till this point of the interview, we successfully gained all the knowledge related to crafting smart jewelry beginning from the process till the challenges faced in the process. We also asked our participants for suggestions they could give to students that could help them craft smart jewelry. However, we never looked at the perspective from which goldsmiths could craft smart jewelry easily. Thus, to cover this area in this study, we concluded our interview by first informing our participants about the challenges goldsmiths faced while using software and then asking them suggestions they would like to give to goldsmiths to overcome these challenges.

Since goldsmiths did not have time to leave their professional lives and study in an institute full-time, participants provided suggestions leveraging virtual institutes. Participant 1 mentioned that provided that the goldsmiths are dedicated to learning, many online courses could be a good starting point for introducing them into the field of software. Participant 6 suggested that they could look for YouTube videos and tutorials to learn, experiment and play with software as in the end, the comfortability of using the software would be a great benefit from crafting smart jewelry.

> P6: *I just go on YouTube or web and search for tutorials. I mainly search for advice's and feedback for the software. Apart from this, I think it is important to spend time on the software and to play with it if you want to learn a software and do not have a specific professor teaching you.*

Moreover, Participant 7 encouraged the goldsmiths to attend software workshops as it could be an opportunity for them to blend into a community of beginners and experts.

Learning software requires motivation and dedication

In the end, a number of suggestions were highlighted above for goldsmiths to learn the software tools. Combined with this, the methods described by professors to teach software could help goldsmiths to work with software. Thus, we can conclude that there is potential for goldsmiths to learn software provided they have the dedication and motivation to do so.

4.4 Survey study

4.4.1 User group

Since we had time left after analyzing the interviews, we decided to take advantage of this extra time. Considering the results obtained from teaching professionals as a baseline, we quantitatively analyzed this data with the help of jewelry-design students and hobbyists. As a consequence of this, we aimed at comparing the results between professors (from interviews (Section 4.3)) and the two user groups; the first being the student, who are beginners in the jewelry domain and the second being the hobbyists who have worked professionally in the field of jewelry for some years. Thereby, we aimed at getting the overall picture of the research topic by looking into a vast range of participants.

4.4.2 Participants background

How students were contacted

Due to the pandemic situation, universities were shut down, and lectures took place via online sources such as Zoom. This made it difficult to physically contact jewelry-design students and forced us to find alternative options for obtaining users for this study. Our first point of contact to university students were the professors, who had taken part in our interview study. Hence, we asked professors for help and thanks to their support and enthusiasm, they forwarded the survey details among their students and other academicians whom they thought were suitable for this study.

Students' background

For the survey with university students, we gathered ten participants who volunteered to help us with our study. Of these 10 participants, eight belonged to the age group 20 - 25 years, while two belonged to 26 - 30 years. Concerning their gender demographics, six participants were females, while four participants were male. All the participants were pursuing a bachelor's course in jewelry designing but were present in different semesters. One participant was studying between the 1^{st} and 2^{nd} semester, four participants were studying between the 3^{rd} and 4^{th} semester, one participant was studying between 5^{th} and 6^{th} semester and the remaining four participants studied in the 6^{th} and above semesters. Like the teaching professionals, the survey was completed by participants situated in Italy (Six participants) and the United States of America (Four participants). Moving towards their experience in making jewelry, one participant had an experience less than a year, four participants had an experience of 1 - 2 years, three participants had an experience of 2 - 3 years, and two participants had an experience of greater than 3 years. Moreover, we also looked at the participant's expertise in using 3D software tools. We found out that one participant had used 3D software tools for less than a year, three participants had used them for 1 - 2 years, one participant has used them for 2 - 3 years, and five participants had used them for greater than 3 years.

How hobbyists were contacted

For getting in touch with hobbyists, we leveraged the social media platforms such as LinkedIn and Facebook. For example, we searched for "jewelry designers" to find potential participants on LinkedIn. On the other hand, for Facebook, rather than searching for individuals, we searched for jewelry designing and hobbyist groups intending to reach out to a larger number of people.

Hobbyists' background

Given the time limitation for the survey, we were able to collect five participants out of which two participants belonged to the age group of 21 - 25 years, two participants belonged to the age group of 26 - 30 years, and one participant belonged to the age group 31 - 40 years. From the participants collected, three were male, and two were female. Since the survey was online, we could reach people across the border. Hence, our participant group was situated in India (Two participants), the United States of America (One participant), the United Kingdom (One participant), and Italy (One participant). Upon examining the experience in making jewelry in this participant group, we found that one participant had an experience less than a year, one participant had an experience of 1 - 2 years, two participants had an experience of 2 - 3 years, and one participant had an experience of greater than 3 years. Lastly, upon evaluating their expertise in using 3D software tools, we found that two participants had an experience of less than a year in using 3D software tools, two participants had an experience of 2 - 3 years, and one participant had greater than 3 years of experience.

4.4.3 Survey Design

Survey platform

For this survey, we made use of an online survey tool available from Google, Google Forms[11]. The survey questions were in the English language.

Data protection details

The form did not contain any questions that could reveal the identity of the participant. For contacting the students, we emailed the professors with the survey details, and they forwarded this email to their students. This contacting of students via professors added an additional layer of anonymity. Hobbyists were contacted as mentioned in Section 4.4.2. Additionally, there was a lottery system present with the survey. Participation in the lottery was voluntary as the participants would be asked for their email-ids for the same.

Questionnaire details

The questions in the survey were defined based on the results of the interview conducted by us. The questionnaire included both open-ended as well as closed-ended questions (Olson and Kellogg [2014], Krosnick and Fabrigar [2012], O'Muircheartaigh et al. [2000]). Two different questionnaires were prepared for students and hobbyists. The content of both these surveys remained the same, with

[11] https://www.google.com/forms/about/

the exception of one demographic section. These questions covered five broad sections:

1. **Participant demographics** - This included the background information about the participant like age and gender, their experience in making jewelry, and their experience in using 3D software tools. We also included questions related to the curriculum, that is, the course name, course location, and course semester details, for students. Questions like age, gender, experience in making jewelry, experience using 3D software tools, and course semester were single-choice questions. Whereas questions regarding course location and course name were open-ended questions.

2. **Outsourcing** - This included question to understand their outsourcing experiences. The participants were asked single-choice Yes-No questions about outsourcing model designing, 3D printing, and laser cutting. They were also asked to rate on a unipolar 5-point scale about the difficulty to find a company for 3D printing, the intimidating nature of outsourcing, and their comfortability towards new technology. Lastly, we asked the participants to rate three advantages of outsourcing using a bipolar 7-point rating scale based on their agreement.

3. **Tools** - This included single-choice Yes-No question regarding the usage of a laser cutter, a 3D scanner, and a 3D printer. Furthermore, a conditional questioning for 3D printers existed, wherein if they used a 3D printer, they would be asked to rate three questions based on their experience using a bipolar 7-point rating scale.

4. **Software** - This included questions revolving around ten different software tools, the benefits and challenges one faces while using software tools, and the potential improvement ideas. We first asked them to rate their comfort towards using software using a unipolar 5-point scale. This was followed by a single-choice Yes-No question where participants were asked about using ten different software tools. Then, depending on the choice of software

tools selected previously, participants were asked to rate (using a bipolar 7-point rating scale) the difficulty of learning these software tools and working with them. Finally, questions regarding benefits (Seven questions), challenges (14 questions), and potential improvement ideas (Five questions) were rated using a bipolar 7-point rating scale.

5. **Smart jewelry** - This included open-ended questions like their understanding of smart jewelry and several closed-ended questions like their perception about smart jewelry and challenges faced while crafting smart jewelry. To get their perception about smart jewelry and to find out the challenges faced during crafting, participants were asked to rate six questions each using a bipolar 7-point rating scale.

Overall, the questionnaire consists of 93 questions. The questions in the survey can be found in Appendix C.

Survey procedure

Collecting the results from the interview (Section 4.3), we were intrigued to known if similar results would be observed for students and hobbyists. As a result of this, we conducted this survey. Furthermore, to increase the number of responses for our survey, we provided an additional monetary incentive in the form of a lottery (20 Euros) to the participants. The participant in the survey and the lottery system was voluntary.

The survey would take between 10 - 15 minutes to finish. This was discovered in a pilot study done by five colleagues. The selection of questions was based on priority. The most popular statements and findings from the interview formed the basis for the formulation of the survey questions.

4.4.4 Results

In this section, we report the results found from the survey after analyzing and pre-processing the data. The following section is divided into four main categories mentioned in Section 4.4.3 (excluding demographics), and in each section, we discuss the results obtained for both students and hobbyists. Considering the limited number of participants involved in this study, we provide an overview of the bipolar 7-point rating scale questions based on three conditions: participants supporting the statement as positive, participants contradicting the statements as negative, and participants undecided about the statement as neutral.

Outsourcing

Assembling the information from our predecessor's study and our interviews, we found that on one side, goldsmiths outsourced 3D software-related work while professors outsourced tool-related work. As a result, we asked our participants about several modelling and tool-related works they had outsourced. This included: laser cutting, 3D printing, and model designing in software. Furthermore, from the interview study, it was pointed out that the students struggled to find a company that would 3D print their product, and they could find it intimidating to approach someone else to do their work. Also, the professors in the interviews highlighted that outsourcing helped in the parallelizing the task, thereby making it more efficient and time-saving. Thus, using these results, we formulated our questions for this section.

Outsourcing from students' perspective

When we asked the students whether they outsourced any task, eight of them denied them, while two of them said they outsourced. For these two students, we asked more details about their outsourcing tasks. First, we asked them whether they outsourced any tasks from model designing, laser cutting, and 3D printing. One of them had outsourced model designing in software; both had outsourced 3D printing, and none had outsourced laser cutting. Following this we asked them to rate[12] the difficultly of finding a company to 3D print their products. The students rated it two on average (One of the students rated it to be 1, whereas the other rated it to be 3). The next question was addressed to the comfortability nature, where we asked the participants to rate between one to five on the intimidating factor on approaching someone to do their work. The average rating found for this was three on a unipolar 5-point scale (One of the students rated it 2 while the other rated it 4). On average, the scariness felt by students towards new technology can be rated as 2.5 on a unipolar 5-point scale (One of the students rated it 2 while the other rated it 3). Finally, to validate certain pointers that we assembled from the interview, we asked the students, who had outsourced, to rate the agreement to these pointers (using a bipolar 7-point rating scale). Both of the students acknowledged that outsourcing helps to parallelize tasks (Both students agreed), and be more efficient (Both students agreed). However, the students were unsure whether outsourcing saves time (One student agreed, one slightly disagreed).

Outsourcing from hobbyists' perspective

We asked the same questions as above to the hobbyists. Four of the hobbyists mentioned that they do not outsource any task, whereas one of them mentioned they outsourced certain tasks. When asked about the specific outsourcing tasks, the hobbyist had outsourced model designing in software and 3D printing. The hobbyist rated the difficulty to find a company to 3D print products as two on a unipolar 5-point scale. For the intimidating nature of approaching someone to do their work, the hobbyist rate it to be three. The hobbyist gave a rating of three for feeling scared about new technology. Lastly, when asked on agreement to the pointers, the hobbyist agreed that outsourcing helps in task parallelization, in being efficient, and in saving time.

Tools

From our interview study, we gather that there were certain tools that professors had frequently used. These tools include laser cutting, 3D scanning, and 3D printing. To get in-

[12] A unipolar 5-point rating scale where 1 is "not at all" and 5 is "very"

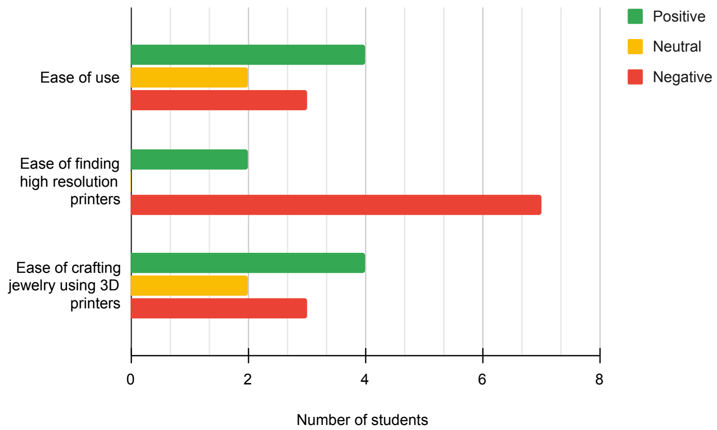

Figure 4.3: The figure denotes the opinions students gave on 3D printer statements (Positive sums up the count of extremely easy, easy, and somewhat easy. Negative sums up the count of extremely difficult, difficult, and Somewhat difficult. Neutral represents neither easy nor difficult). Detailed statements can be found in Appendix C.

sights if these tools were used by other user groups, too, we asked our participants about the usage of these tools. Furthermore, from the interviews, it was also highlighted that certain problems were associated with 3D printers, such as getting access to a printer with high resolution. Thus, we asked them about their opinion on this statement, along with the ease of use of 3D printers.

Tools from students' perspective

When we asked the students about using certain tools, seven of the students had used a laser cutter, four had used a 3D scanner, and nine of the students had used a 3D printer. For the nine participants who used 3D printers, we enquired more about their opinion on using 3D printers (Figure 4.3). When we asked the students to rate the ease of using 3D printers, we found that majority of students find using them to be easy (Three students found it extremely easy, one found it somewhat easy, two found it neither easy nor difficult, and three found it somewhat difficult). We also found that most of the students find it difficult to access high-resolution printers (Two of the students mentioned it is easy, four mentioned it is somewhat difficult, and three mentioned that it was difficult). Finally, we also discovered that most of the students find it easy to make jewelry using 3D printers (Three of the students found it easy, one found it somewhat easy, two found it neither easy nor difficult, and three found it to be somewhat difficult).

Tools from hobbyists' perspective

Concerning the hobbyists, two hobbyists have used a laser cutter, one has used a 3D scanner, and three had used a 3D printer. As above, we asked the 3 hobbyists in-depth about 3D printers (Figure 4.4). When asked about the difficulty of using 3D printers, we found that most of the hobbyists find it easy to use (Two hobbyists found it somewhat easy, and one found it neither easy nor difficult). Next, we asked them to rate the difficulty of getting access to high-resolution 3D printers. We found that for majority of the hobbyists, it was easy to access high-resolution 3D printers (Two of the hobbyists found it somewhat easy while one found it difficult). In the end, they were asked to rate their difficulty in crafting jewelry using 3D printers. Here, we found that most hobbyists find 3D printers easy to use for crafting jewelry (One hobbyist mentioned it was easy, and two hobbyists mentioned it was somewhat easy).

Software

As software tools remain an essential part of crafting smart jewelry, it becomes necessary to question our participants about software tools. From our discussion with professors, it was concluded that students were scared of using software tools. Since we had the opportunity to contact independent designers with the help of this survey, we raised this question and asked their opinion on it. Along with this, we asked our participants about their usage, learning curve, and working experience on ten different software tools. These software tools include Rhino, Meshmixer, Blender, Illustrator, KeyShot, InDesign, Photoshop, CATIA, Grasshopper, and ZBrush. They were the most popular software tools mentioned by professors during the interviews. Furthermore, several key pointers regarding the benefits, challenges, and improvements for software were collected from the interviews and opinions of students and

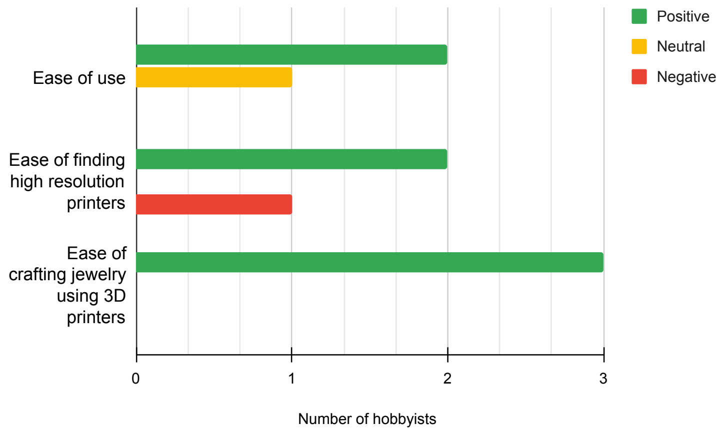

Figure 4.4: The figure denotes the opinions hobbyists gave on 3D printer statements (Positive sums up the count of extremely easy, easy, and somewhat easy. Negative sums up the count of extremely difficult, difficult, and Somewhat difficult. Neutral represents neither easy nor difficult). Detailed statements can be found in Appendix C.

hobbyists on these pointers were requested.

Software tools from students' perspective

At the beginning of this section, students were asked to rate (between one to five) the scariness they felt for using software tools. It was found that students felt an average of 1.8 on a unipolar 5-point scale (Four of the students rated 1, four rated it 2, and two rated it 3). This was followed by questions related to the ten software tools (Figure 4.5). CATIA remained an exception in this as none of the students had used it in the past.

When asked about Rhino, all the participants mentioned that they had worked with it. Upon analysis, we found that students were undecided on its ease of learning and found it easy to work with.

- Learn - One student said it to be extremely easy, two said it was easy, two said it was somewhat easy, three said it was somewhat difficult, one said it was difficult, and one said it was extremely difficult

- Work - Four students said it to be easy, two said it was somewhat easy, one said it was neither easy nor difficult, two said it was somewhat difficult, and one said it was difficult

For Meshmixer, four of the students had worked with it previously. From these four students, most of them found Meshmixer easy to learn, and they were undecided on its ease of use.

- Learn - One student said it to be easy, one said it was somewhat easy, one found it neither easy nor difficult, and one said it somewhat difficult
- Work - One student said it to be easy, one said it somewhat easy, one said it somewhat difficult, and one said it difficult

In the same way, three of the students had worked with Blender previously. These students found the software difficult to learn and difficult to work with.

- Learn - Two students said it to be somewhat difficult, one said it was difficult
- Work - One student said it to be neither easy nor difficult, one said it was somewhat difficult, and one said it extremely difficult

For Illustrator, nine of the students had worked with it previously. The students found this software easy to learn and easy to work with.

- Learn - Two students said it to be extremely easy, one said it was easy, three said it was somewhat easy, one said it was neither easy nor difficult, one said it was somewhat difficult, and one said it was difficult
- Work - One student said it to be is extremely easy, five said it was easy, one said it was somewhat easy, one said it was somewhat difficult, one said it was difficult, and one said it was extremely difficult

For KeyShot, four of the students mentioned that they had worked with KeyShot earlier. These students found KeyShot easy to learn and easy to use.

- Learn - One student said that it was extremely easy, two said it was easy, and one said it was neither either nor difficult
- Work - One student said that it was extremely easy, two said it easy, and one said it neither easy nor difficult

Similarly, seven of the students had used InDesign previously. Most of the students found software neither easy nor difficult to learn and easy to work with.

- Learn - One student said it easy, one said it somewhat easy, three said it neither easy nor difficult, and two said it was somewhat difficult
- Work - One student said it extremely easy, two said it was easy, two said it was somewhat easy, one said it was neither easy nor difficult, and one said it was somewhat difficult

Regarding Photoshop, nine of the students had worked previously with Photoshop. These students found Photoshop difficult to learn and easy to work with.

- Learn - Two students said it was extremely easy, one said it was easy, two said it was neither easy nor difficult, three said it was somewhat difficult, and one said it was difficult
- Work - One student said it was extremely easy, three said it was easy, one said it was somewhat easy, two said it was neither easy nor difficult, and two said it was somewhat difficult

We found that only one of the students had worked with grasshopper previously. The student mentioned that it was

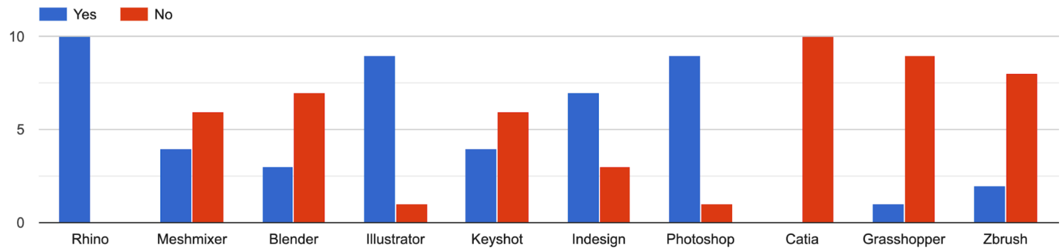

Figure 4.5: The figure denotes the count of different software tools used by students.

extremely difficult to learn and work with it. Lastly, we asked about ZBrush. We found out that two of the students had worked with ZBrush in the past. The ease of learning was found to be indecisive, and the ease of use was found to be easy.

- Learn - One student said it was somewhat easy while the other said it was somewhat difficult
- Work - One student said it was easy and the other said it was somewhat easy

Software tools from hobbyists' perspective

Analogous to the students, we asked the hobbyists to rate how much they feel scared about using software tools. To this, we found that hobbyists, on average, rated it 2.6 on a unipolar 5-point scale (One rated it 1, two rated it 2, and two rated it 4). Furthermore, we asked the hobbyists their opinion on the ten different software tools (Figure 4.6). Out of these ten tools, none of the hobbyists had used CATIA and InDesign in their past.

For Rhino, four of the hobbyists mentioned that they had worked with it. From the results of the hobbyists were inconclusive for its ease of learning and ease of use.

- Learn - Two hobbyists said it was somewhat easy, and two said it was somewhat difficult
- Work - One hobbyist said it was easy, one said it was

somewhat easy, and two said it was somewhat difficult

Two of the hobbyists mentioned that they had worked with Meshmixer previously. These hobbyists were undecided about its ease of learning but agreed that it was easy to work with.

- Learn - One hobbyist said was easy whereas the other said it was somewhat difficult
- Work - One hobbyist said was easy and other said it was somewhat easy

Along the same lines, when enquired about Blender, two of the hobbyists had worked with Blender previously. They were undecided on its ease of use. However, both the hobbyists agreed that Blender was somewhat easy to work with.

- Learn - One hobbyist said it was neither easy nor difficult, whereas the other said it was somewhat difficult
- Work - Both hobbyists said it was somewhat easy

For Illustrator, four of the hobbyists had worked with it previously. The hobbyists were indecisive on the ease of use of Illustrator, and most of the hobbyists found it somewhat easy to work with.

- Learn - Two hobbyists said it was somewhat easy, and the remaining two said it was neither easy nor difficult
- Work - One hobbyist said that it was easy to work with, two said it was somewhat easy, and one said it was somewhat difficult

Regarding KeyShot, one of the hobbyists mentioned that they had worked with KeyShot earlier. The hobbyist mentioned that KeyShot was easy to learn and easy to work

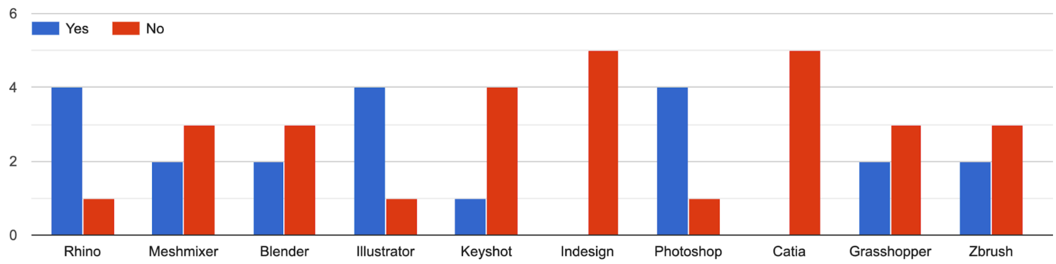

Figure 4.6: The figure denotes the count of different software tools used by hobbyists.

with. For Photoshop, three of the hobbyists mentioned that they had worked with it previously. They found Photoshop easy to learn and easy to work with.

- Learn - Two hobbyists said it was easy and one said it was somewhat easy
- Work - One hobbyist said it was extremely easy and two said it was easy

For grasshopper, two of the hobbyists mentioned that they had worked with it earlier. Both the participants mentioned that it was somewhat difficult to learn grasshopper and remained indecisive on its ease of use.

- Learn - Both said somewhat difficult
- Work - One hobbyist said that it was neither easy nor difficult and the other said it was somewhat difficult

In the end, we asked them about ZBrush. Here, we found out that two of the hobbyists had worked with ZBrush in the past. Out of these hobbyists, both the participants agreed that it was somewhat easy to learn and easy to work with.

Once we gathered all the information regarding the different software tools, we asked the participants to rate seven statements that could be potential benefits (Figure 4.7). We

Benefits of using software from students' perspective

gathered these based on our interviews with professors.. Thus, we found that most of the students believed that the following statements are benefits of using software tools:

1. Visualization using 3D software help communicate an idea better than drawing (Four students strongly agreed, one agreed, four slightly agreed, and one neither agreed nor disagreed).
2. 3D software tools help to understand the shape and size of the object before actually making it (Four students strongly agreed, four agreed, one slightly agreed, and one neither agreed nor disagreed).
3. Designing using software fastens the jewelry-making process (One student strongly agreed, four agreed, one slightly agreed, one neither agreed nor disagreed, two slightly disagreed, and one disagreed).
4. Making adjustments in the digital model is easier than physical objects (Four students strongly agreed, one agreed, four neither agreed nor disagreed, and one slightly disagreed).
5. 3D software enables faster material selection (One student strongly agreed, five agreed, two slightly agreed, one neither agreed nor disagreed, and one disagreed).
6. 3D software tools make collaboration easier (Four students strongly agreed, one agreed, one slightly agreed, three neither agreed nor disagreed, and one disagreed).
7. 3D software tools are just like any other tool on jeweller's workbench (Five students strongly agreed, two agreed, one slightly agreed, one neither agreed nor disagreed, and one slightly disagreed).

Benefits of using software from hobbyists' perspective

A similar template was provided to hobbyists, and they were asked to rate according to their opinion on the seven benefit-related statements (Figure 4.8). Most of them believed that the following are benefits of using software tools:

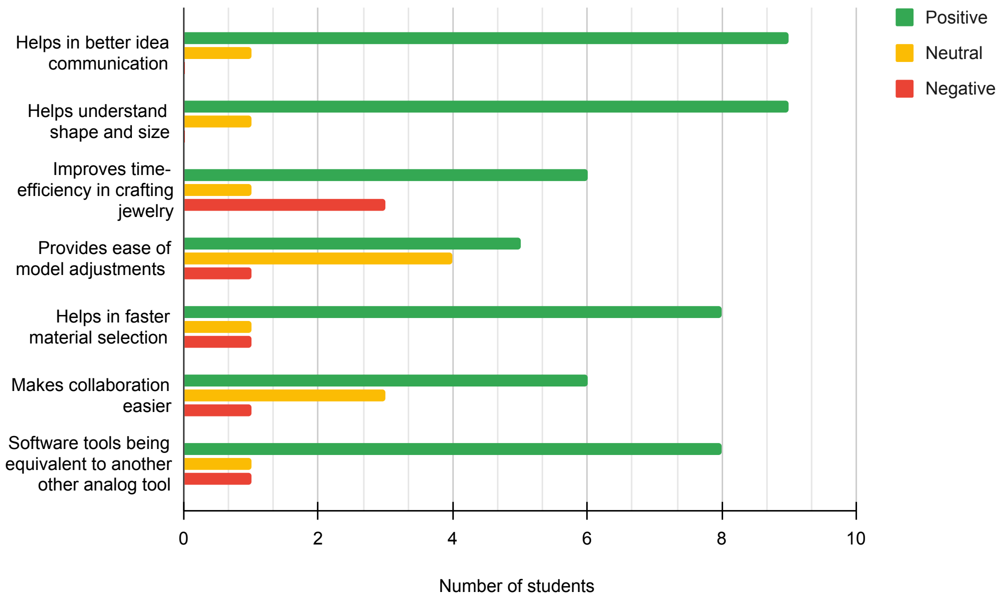

Figure 4.7: The figure denotes the opinion of students on different software benefit statements (Positive sums up the count of extremely agree, agree, and slightly agree. Negative sums up the count of extremely disagree, disagree, and slightly disagree. Neutral represents neither agree nor disagree). Detailed statements can be found in Appendix C.

1. Visualization using 3D software help communicate an idea better than drawing (Three hobbyists agreed, one slightly agreed, and one slightly disagreed).

2. 3D software tools help to understand the shape and size of the object before actually making it (One hobbyist agreed, two slightly agreed, one neither agreed nor disagreed, and one slightly disagreed).

3. Designing using software fastens the jewelry-making process (Two hobbyists agreed, one slightly agreed, and two neither agreed nor disagreed).

4. Making adjustments in the digital model is easier than physical objects (One hobbyist strongly agreed, two agreed, one slightly disagreed, and one disagreed).

5. 3D software enables faster material selection (One

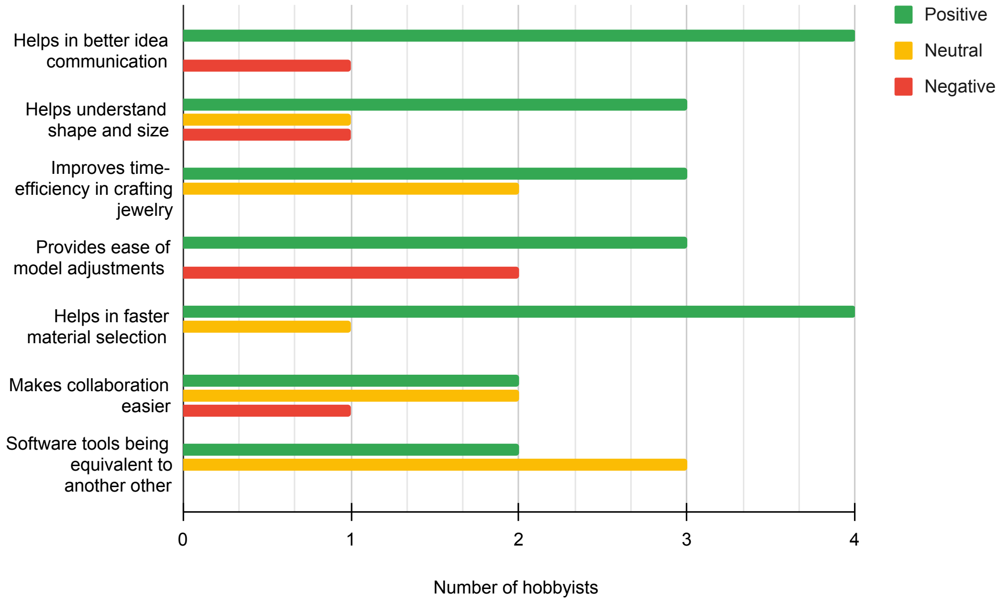

Figure 4.8: The figure denotes the opinion of hobbyists on different software benefit statements (Positive sums up the count of extremely agree, agree, and slightly agree. Negative sums up the count of extremely disagree, disagree, and slightly disagree. Neutral represents neither agree nor disagree). Detailed statements can be found in Appendix C.

hobbyist strongly agreed, three slightly agreed, and one neither agreed nor disagreed).

We also found out that the hobbyists were undecided whether 3D software tools make collaboration easier or not (One hobbyist agreed, one slightly agreed, two neither agreed nor disagreed, and one slightly disagreed). Majority of the hobbyists were also undecided on whether 3D software tools could be considered like any other tool on jeweller's workbench (One hobbyist strongly agreed, one agreed, and three neither agreed nor disagreed).

Challenges while using software from students' perspective

Apart from the software benefits, we asked our participants their opinion on the challenges faced while using software tools (Figure 4.9). Like benefits, the 14 statements were collected from the interview study. Most of them believed that the following statements are challenges they face while using software:

1. 3D software tools are time-consuming to learn (Two students strongly agreed, two agreed, four slightly agreed, one slightly disagreed, and one disagreed).
2. Many software tools need to be learnt to make a product (One student strongly agreed, one agreed, four slightly agreed, three disagreed, and one strongly disagreed).
3. 3D software skills limit the design (Two students agreed, three slightly agreed, one neither agreed nor disagreed, one slightly disagreed, one disagreed, and two strongly disagreed).
4. 3D software tools are expensive to use (Two students strongly agreed, one agreed, three slightly agreed, two neither agreed nor disagreed, and two strongly disagreed).
5. Different software are not consistent in their user interface design (Three students strongly agreed, one agreed, three slightly agreed, one neither agreed nor disagreed, and two disagreed).
6. 3D software tools are not consistent in naming their tools (Two students strongly agreed, one agreed, four slightly agreed, one neither agreed nor disagreed, and two disagreed).
7. Many things like shortcuts, tool names and their respective functions need to be remembered for every software (Two students strongly agreed, four agreed, two slightly agreed, and two slightly disagreed).
8. While using a 3D software tool, it is difficult to find the exact step where a mistake was made (One student strongly agreed, two agreed, four slightly agreed, two neither agreed nor disagreed, and one slightly disagreed).
9. Compared to analog problems, digital problems take more time to solve (Four students slightly agreed, three neither agreed nor disagreed, two slightly disagreed, and one disagreed).

10. One has to think in the software's language to design something (Two students strongly agreed, five agreed, two slightly agreed, and one slightly disagreed).

Furthermore, the students disagreed that the following statements can be considered as challenges while using software:

1. 3D software interfaces are difficult to understand (Two students strongly agreed, two slightly agreed, one neither agreed nor disagreed, one slightly disagreed, three disagreed, and one strongly disagreed).
2. Quality of product achieved using software is low (One student agreed, four neither agreed nor disagreed, one slightly disagreed, two disagreed, and two strongly disagreed).
3. Programming needs to be learned in order to use 3D software tools (Two student agreed, two slightly agreed, two disagreed, and four strongly disagreed).

We also found that the students were undecided on whether fabricating jewelry with software takes more time than without using software (One student agreed, three slightly agreed, two neither agreed nor disagreed, one slightly disagreed, and three disagreed).

Challenges while using software from hobbyists' perspective

In the same way, we asked hobbyists their opinion on the 14 challenges of using software (Figure 4.10). Majority of hobbyists believed that the following statements can be considered as challenges while using software:

1. 3D software interfaces are difficult to understand (Two hobbyists agreed, one slightly agreed, one slightly disagreed, and one disagreed).
2. 3D software tools take a lot of time to learn (One hobbyist strongly agreed, three agreed, and one slightly agreed).

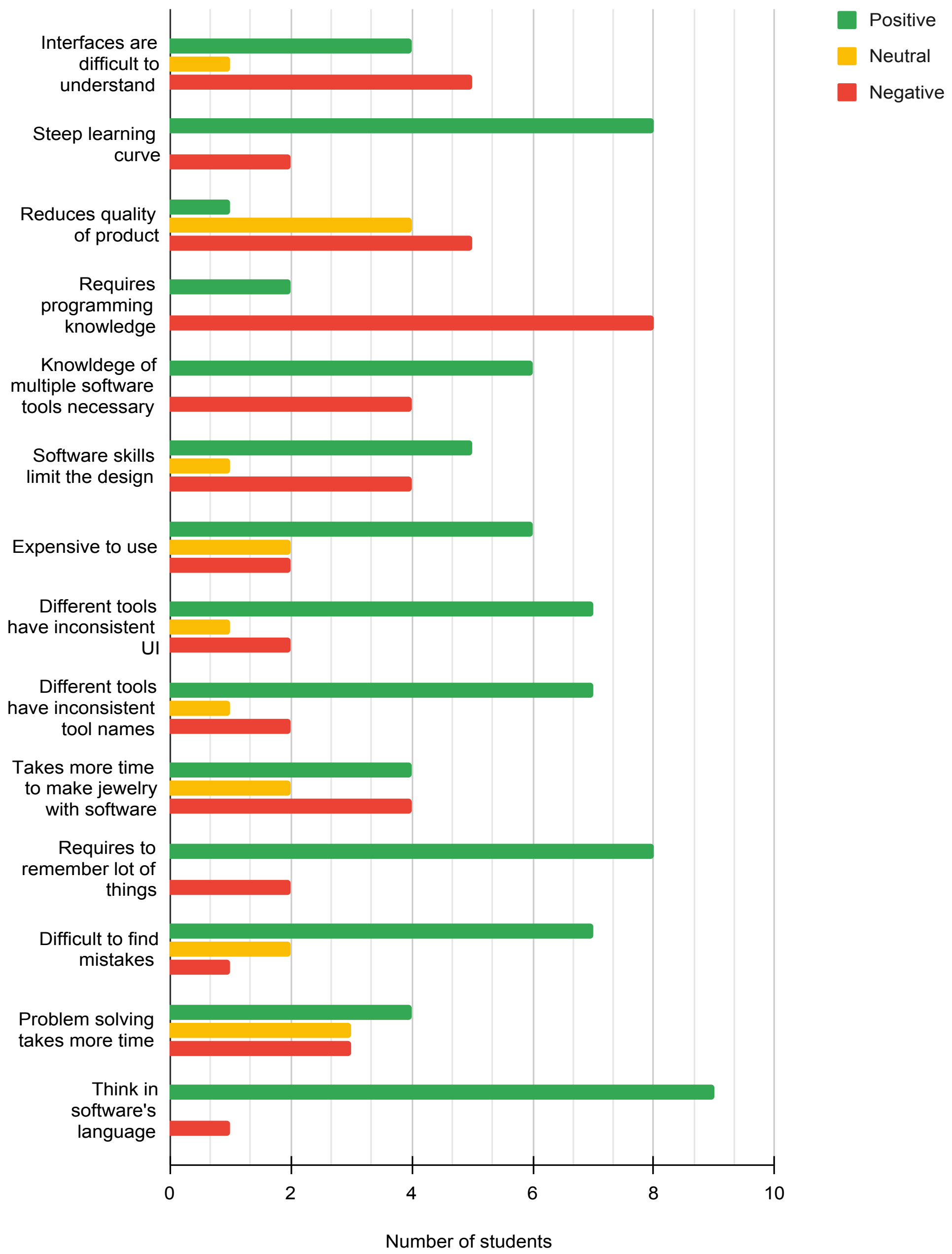

Figure 4.9: The figure denotes the opinion of students on different software challenge statements (Positive sums up the count of extremely agree, agree, and slightly agree. Negative sums up the count of extremely disagree, disagree, and slightly disagree. Neutral represents neither agree nor disagree). Detailed statements can be found in Appendix C.

3. Many software tools need to be learnt to make a product (One hobbyist strongly agreed, one agreed, two slightly agreed, and one neither agreed nor disagreed).

4. 3D software tools are expensive to use (Two hobbyists agreed, two slightly agreed, and one neither agreed nor disagreed).

5. Different software are not consistent in their user interface design (Three hobbyists agreed, one slightly agreed, and one neither agreed nor disagreed).

6. 3D software tools are not consistent in naming their tools (Two hobbyists agreed, one slightly agreed, one neither agreed nor disagreed, and one slightly disagreed).

7. Making jewelry with software takes more time than making jewelry without using software (One hobbyist agreed, two slightly agreed, and two disagreed).

8. Many things like shortcuts, tool names and their respective functions need to be remembered for every software (Two hobbyists agreed and three slightly agreed).

9. While using a 3D software tool, it is difficult to find the exact step where a mistake was made (Three hobbyists agreed, one slightly agreed, and one slightly disagreed).

10. Compared to analog problems, digital problems take more time to solve (One hobbyist agreed, three slightly agreed, and one disagreed).

11. One has to think in the software's language to design something (Two hobbyists agreed, two slightly agreed, and one neither agreed nor disagreed).

Moreover, the hobbyists disagreed that the following statements can be considered as challenges while using software:

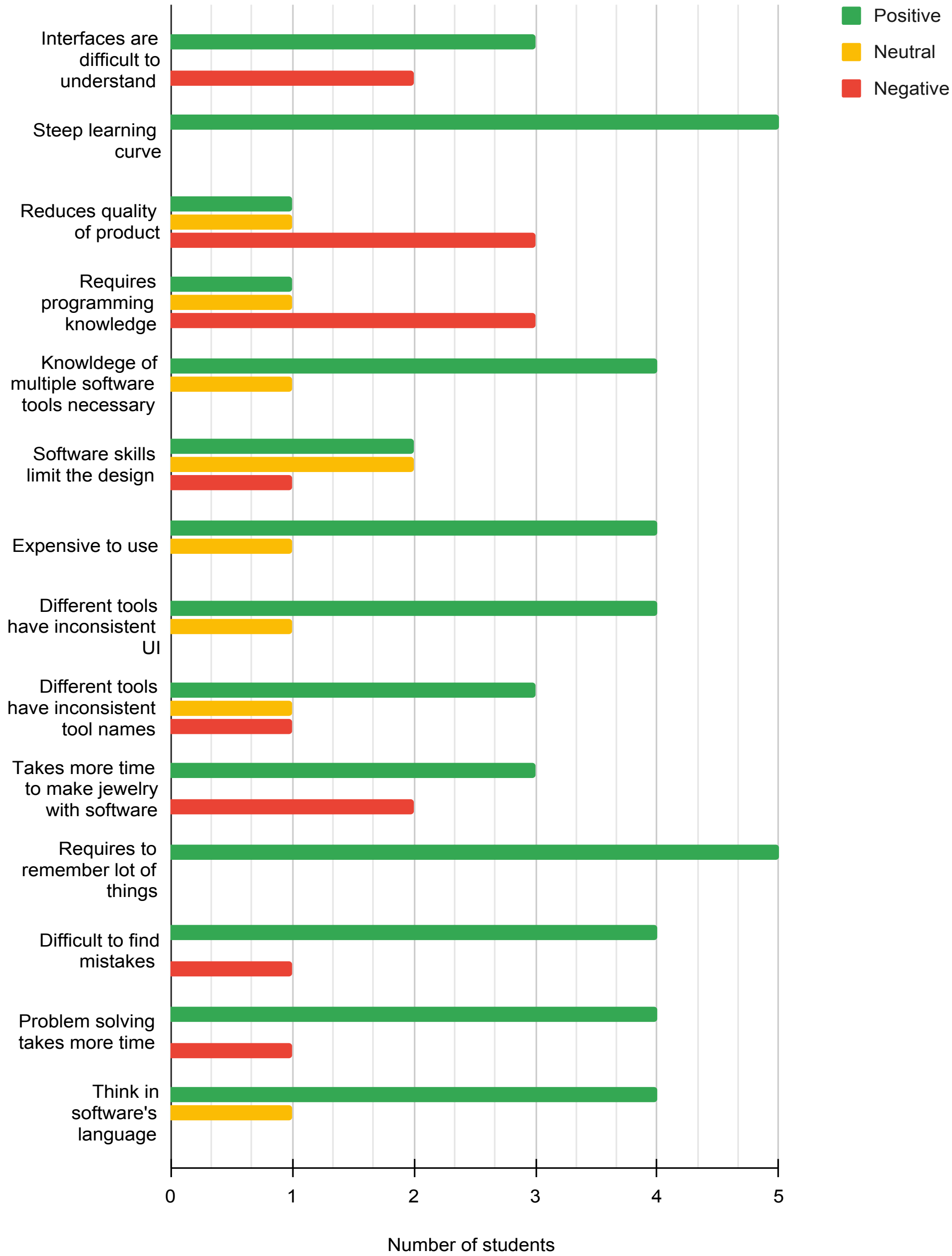

Figure 4.10: The figure denotes the opinion of hobbyists on different software challenge statements (Positive sums up the count of extremely agree, agree, and slightly agree. Negative sums up the count of extremely disagree, disagree, and slightly disagree. Neutral represents neither agree nor disagree). Detailed statements can be found in Appendix C.

1. Quality of product achieved using software is low (One of the hobbyist agreed, one neither agreed nor disagreed, two slightly disagreed, and one disagreed).

2. Programming needs to be learned in order to use 3D software tools (One hobbyist slightly agreed, one neither agreed nor disagreed, one slightly disagreed, one disagreed, and one strongly disagreed).

In addition, the hobbyists were undecided on whether the 3D software skills limit the design (Two hobbyists slightly agreed, two neither agreed nor disagreed, and one disagreed).

Potential solutions from students' perspective

Lastly, we asked our participants their thoughts on the future improvement ideas that would make working with software easy (Figure 4.11). These ideas were a collaboration of ideas collected from our side and from the interviews. Most of the students agreed that the following could be potential solutions for easing the use of software tools:

1. All software using the same language for their UI (Three students strongly agreed, three agreed, two slightly agreed, one neither agreed nor disagreed, and one slightly disagreed).

2. A single software providing all the functions required to make a product (Six students strongly agreed, two agreed, and two slightly agreed).

3. Interactive voice command feature within the software (Two students strongly agreed, two agreed, two slightly agreed, one neither agreed nor disagreed, one slightly agreed, and two disagreed).

4. A smart suggester that suggests the next possible steps while designing (Three students strongly agreed, one agreed, three slightly agreed, two disagreed, and one strongly disagreed).

5. A software tool in which glasses are worn via which the object can be seen in the real world and be manipulated by hands (Seven students strongly agreed, one agreed, and two slightly agreed).

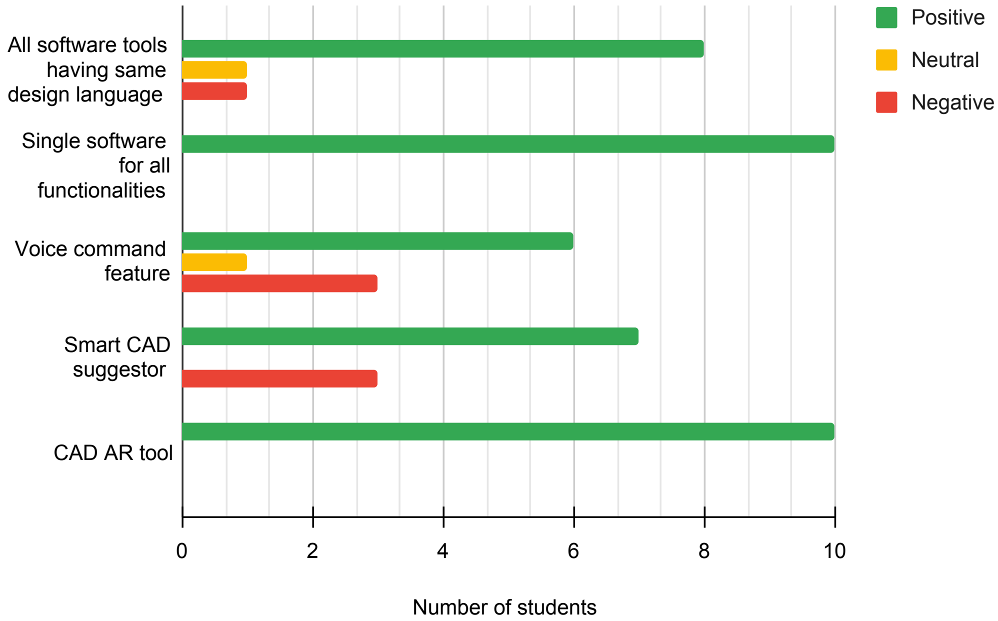

Figure 4.11: The figure denotes the opinion of students on different potential solution statements (Positive sums up the count of extremely agree, agree, and slightly agree. Negative sums up the count of extremely disagree, disagree, and slightly disagree. Neutral represents neither agree nor disagree). Detailed statements can be found in Appendix C.

Potential solutions from hobbyists' perspective

Analogous to students, hobbyists were asked to put forward their point of view on future ideas and improvements in software tools (Figure 4.12). Most of the hobbyists agreed that the following could be potential solutions for easing the use of software tools:

1. A single software providing all the functions required to make a product (Three hobbyists agreed, one slightly agreed, and one neither agreed nor disagreed).

2. Interactive voice command feature within the software (One hobbyist agreed, three slightly agreed, and one disagreed)

3. A smart suggester that suggests the next possible steps while designing (One hobbyist strongly agreed,

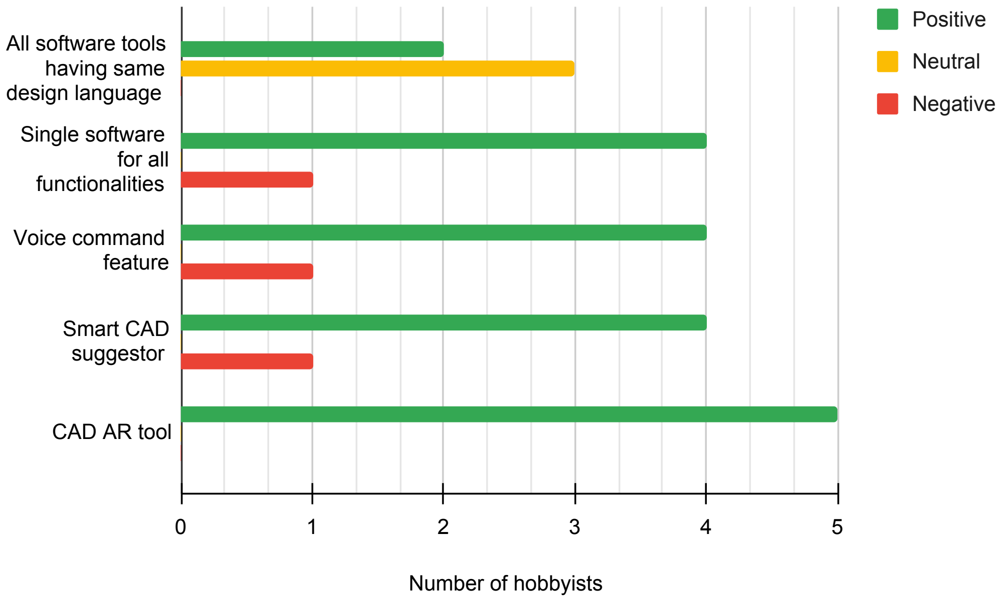

Figure 4.12: The figure denotes the opinion of hobbyists on different potential solution statements (Positive sums up the count of extremely agree, agree, and slightly agree. Negative sums up the count of extremely disagree, disagree, and slightly disagree. Neutral represents neither agree nor disagree). Detailed statements can be found in Appendix C.

one agreed, two slightly agreed, and one slightly disagreed).

4. A software tool in which glasses are worn via which the object can be seen in the real world and be manipulated by hands (One hobbyist strongly agreed, three agreed, and one slightly agreed).

The hobbyists were uncertain, whether all software tools using same design language for the UI can be a potential solution (One hobbyist strongly agreed, one agreed, and three neither agreed nor disagreed).

Smart jewelry

Moving towards the main focus of our thesis, we looked at the next section of the survey, where we asked our participants about smart jewelry. As evident from our interview study, there was no common definition for smart jewelry that existed between professors. As a result, we first asked our participants what they understood by the term ”smart jewelry”.

When asked, the students defined smart jewelry in several ways. We enlist all their definitions below and assign them S1 - S10 for anonymity. S1 defined smart jewelry as a ”technology implemented in aka jewelry”. S1 also added that ”it usually looks unattractive and lacks good quality aesthetics”. S2 did not know what smart jewelry is and mentioned that:

> S2 - I do not recognize the term Smart Jewellery; I would think that it is jewellery that can be worn comfortably easily.

S3 was uncertain about the meaning and said ”Technology with jewellery?”. On the other hand, S4 mentioned it to be a ”jewelry which might involve technologies in the production and in the final jewels (for example, accessories including a solar panel or light system)”. According to S5, smart jewelry can be defined as a ”jewelry entirely made by machines and created in CAD software”. S6 mentions smart jewelry to be ”IoT enhanced wearable objects, the simplest example is a medical information digital storage necklace”. S7 feels smart jewelry to be ”jewelry focusing on technology and user interaction” and S8 feels it to be ”aesthetic electronic devices”. Since two of the students did not know about smart jewelry, they did not define the term.

Furthermore, we asked hobbyists their definition of smart jewelry. For anonymization, we refer to these hobbyists as H1 - H5. H1 defined smart jewelry as ”jewelry digitally designed, automated jewelry manufacturing, integrated technical apps in jewelry to measure health values”. According to H2, smart jewelry can be defined as "decorative elements to be worn at the body with electronic embedded functionality". Smart jewelry is "jewelry which either has good tech integrated along with it to make life easier or is manufactured using technology which reduces/eliminates waste" said H3. H4 was uncertain about the definition and mentioned that smart jewelry might be "electronics?". Lastly, H5 said that smart jewelry is "something that you can wear as jewelry that also has additional digital functionality".

General smart jewelry pointers from students' perspective

Next we asked the participants their opinion on certain interesting pointers that we encountered during the interview study. We were able to collect six such pointers where four were focused on smart jewelry in general (Figure 4.13). In contrast, two were focused on users' interest in smart jewelry. As mentioned above, two participants did not know about smart jewelry, but since these were compulsory questions, they answered the following statements as "neither agree nor disagree".

With our analysis, we found that majority of the students agreed on the following statements:

1. Current smart jewelry focuses more on technology than the aesthetic part of the jewelry (Two students strongly agreed, one agreed, two slightly agreed, four neither agreed nor disagreed, and one slightly disagreed).

2. Current smart jewelry uses jewelry as outer-packaging to bring some technical functionality on the body (Two students strongly agreed, one agreed, two slightly agreed, three neither agreed nor disagreed, one slightly disagreed, and one strongly disagreed).

3. I would like to work on a project involving smart jewelry (Four students strongly agreed, two agreed, one slightly agreed, and three neither agreed nor disagreed).

4. I can make smart jewelry myself (Two students strongly agreed, three agreed, one slightly agreed,

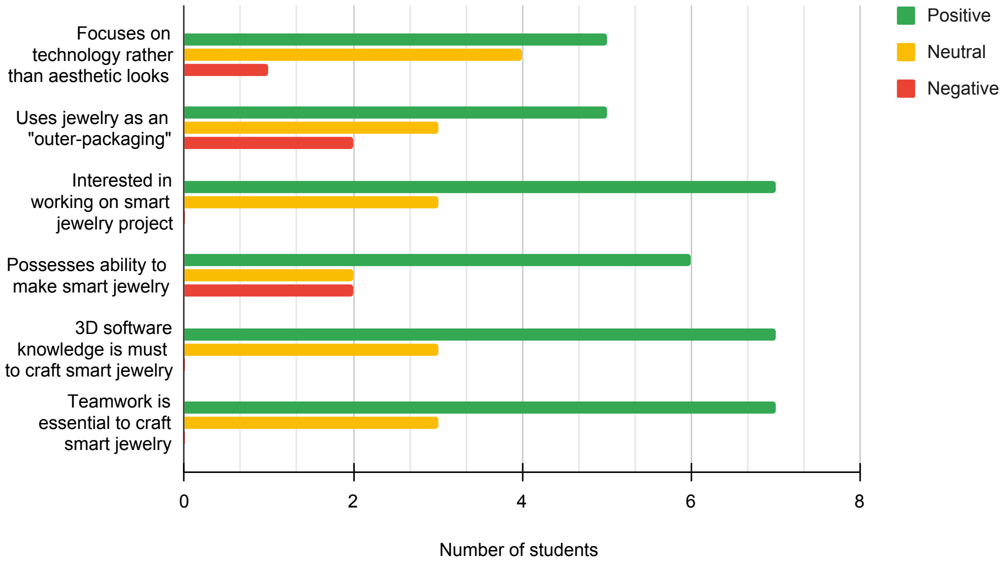

Figure 4.13: The figure denotes the opinion of students on different smart jewelry related statements (Positive sums up the count of extremely agree, agree, and slightly agree. Negative sums up the count of extremely disagree, disagree, and slightly disagree. Neutral represents neither agree nor disagree). Detailed statements can be found in Appendix C.

two neither agreed nor disagreed, one slightly disagreed, and one disagreed).

5. Knowledge of 3D software is a must to make smart jewelry (One student strongly agreed, four agreed, two slightly agreed, and three neither agreed nor disagreed).

6. To make smart jewelry, it is important that people with different expertise come together and work as a team (Four students strongly agreed, three agreed, and three neither agreed nor disagreed).

When asked the above statements to hobbyists (Figure 4.14), they agreed on the following statements:

General smart jewelry pointers from hobbyists' perspective

1. Current smart jewelry focuses more on technology than the aesthetic part of the jewelry (One hobbyist

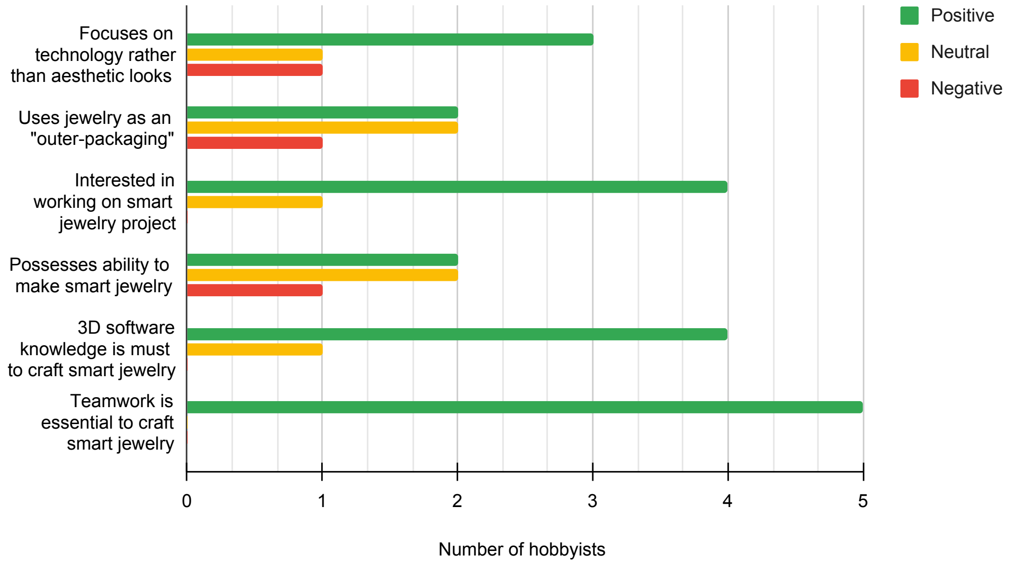

Figure 4.14: The figure denotes the opinion of hobbyists on different smart jewelry related statements (Positive sums up the count of extremely agree, agree, and slightly agree. Negative sums up the count of extremely disagree, disagree, and slightly disagree. Neutral represents neither agree nor disagree). Detailed statements can be found in Appendix C.

agreed, two slightly agreed, one neither agreed nor disagreed, and one slightly disagreed).

2. I would like to work on a project involving smart jewelry (Two hobbyists agreed, two slightly agreed, and one neither agreed nor disagreed).

3. Knowledge of 3D software is a must to make smart jewelry (One hobbyist strongly agreed, two agreed, one slightly agreed, and one neither agreed nor disagreed).

4. To make smart jewelry, it is important that people with different expertise come together and work as a team (One hobbyist strongly agreed, three agreed, and one slightly agreed).

The hobbyists were undecided on the following statements:

1. Current smart jewelry uses jewelry as outer-packaging to bring some technical functionality on the body (Two hobbyists slightly agreed, two neither agreed nor disagreed, and one slightly disagreed).

2. I can make smart jewelry myself (Two hobbyists agreed, two neither agreed nor disagreed, and one disagreed).

Challenges faced while crafting smart jewelry from students' perspective

At the end of the survey, we asked our participants to rate the challenges faced by designers while crafting smart jewelry (Figure 4.15). Like above, there were collected from our observation using the interview study. From the analysis, we found that majority of the students agreed that the following statements could be considered as challenges while making smart jewelry:

1. Process for making smart jewelry is not properly documented (Four students agreed, one slightly agreed, two neither agreed nor disagreed, two slightly disagreed, and one strongly disagreed).

2. One needs to learn programming to make smart jewelry working (One student strongly agreed, three agreed, one slightly agreed, two neither agreed nor disagreed, two slightly disagreed, and one disagreed).

3. A lot of research on electronic components needs to be done to make smart jewelry (One student strongly agreed, five agreed, two neither agreed nor disagreed, and two disagreed).

4. A lot of experimentation is required to make smart jewelry (One student strongly agreed, four agreed, two slightly agreed, two neither agreed nor disagreed, and one disagreed).

We also found that the students slightly disagreed that the following statements can be considered as challenges while making smart jewelry:

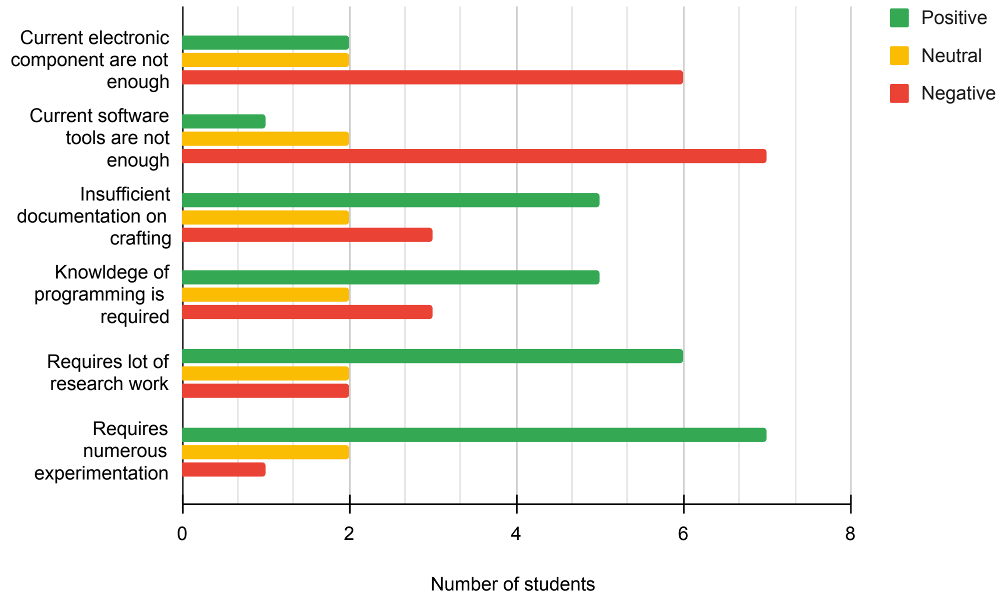

Figure 4.15: The figure denotes the opinion of students on different challenges while fabricating smart jewelry (Positive sums up the count of extremely agree, agree, and slightly agree. Negative sums up the count of extremely disagree, disagree, and slightly disagree. Neutral represents neither agree nor disagree). Detailed statements can be found in Appendix C.

1. Current electronic components are not enough to make smart jewelry (One student agreed, one slightly agreed, two neither agreed nor disagreed, two slightly disagreed, two disagreed, and two strongly disagreed).
2. Current 3D software tools are not enough to make smart jewelry (One student agreed, two neither agreed nor disagreed, two slightly disagreed, two disagreed, and three strongly disagreed).

Challenges faced while crafting smart jewelry from hobbyists' perspective

Along the same line, hobbyists were asked for their viewpoints on the challenges faced while crafting smart jewelry (Figure 4.16). Most of the hobbyists agreed that the following statements could be considered as challenges while making smart jewelry:

1. Process for making smart jewelry is not properly doc-

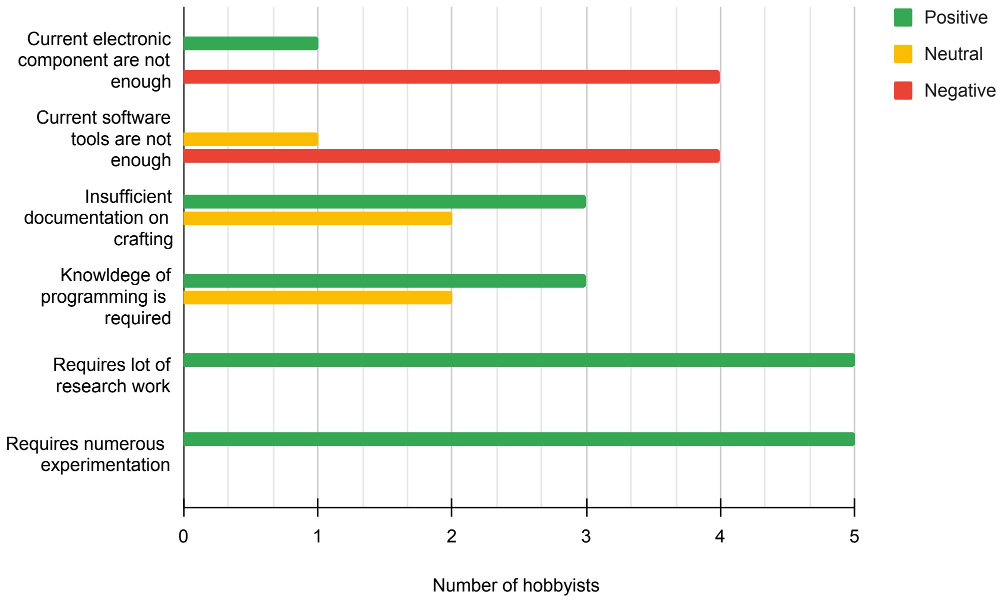

Figure 4.16: The figure denotes the opinion of hobbyists on different challenges while fabricating smart jewelry (Positive sums up the count of extremely agree, agree, and slightly agree. Negative sums up the count of extremely disagree, disagree, and slightly disagree. Neutral represents neither agree nor disagree). Detailed statements can be found in Appendix C.

umented (One hobbyist agreed, two slightly agreed, and two neither agreed nor disagreed).

2. One needs to learn programming to make the smart jewelry working (One hobbyist agreed, two slightly agreed, and two neither agreed nor disagreed).

3. A lot of research on electronic components needs to be done to make smart jewelry (Three hobbyists agreed, and two slightly agreed).

4. A lot of experimentation is required to make smart jewelry (Four hobbyists agreed, and one slightly agreed).

on the other hand, majority of the hobbyists disagreed that the following statements can be considered as challenges while making smart jewelry:

1. Current electronic components are not enough to make smart jewelry (One hobbyist slightly agreed, two slightly disagreed, and two disagreed).

2. Current 3D software tools are not enough to make smart jewelry (One hobbyist neither agreed nor disagreed, two slightly disagreed, and two disagreed).

4.4.5 Discussion

Outsourcing was the first issue that we stumbled on during our interviews with the professors. There were two main reasons for outsourcing; the first is the advantages it offers. The second is due to the designer's inability to take risks, especially while working with expensive jewelry. Unfortunately, designers have to face several hurdles while outsourcing. Professors, students and hobbyists helped us in uncovering these hurdles. They mentioned that there remains difficulty in finding a company to 3D print jewelry models for individual designers. This could be attributed to a one-in-a-kind type of jewelry, which is expensive for companies to 3D print. They also mentioned that independent designers find it intimidating to approach someone who will do their work. Nevertheless, the advantages of outsourcing overpower these hurdles. Our study concludes that outsourcing helps in the parallelization of tasks and proves to be efficient in the jewelry-making workflow. However, it remains uncertain whether it saves time and, if it does, how much time does it save.

Difficult to find a company to 3D print jewelry models

Outsourcing helps in parallelization

To make any jewelry, appropriate tools must be present with the jeweller. Keeping in mind the focus of this thesis, we collected the data regarding an essential jewelry crafting tool, 3D printers. These printers are powerful devices that help in crafting prototypes and jewelry pieces. Even though they are powerful, no information on the ease of usability or accessibility of this tool is present. Hence, we took a step in this direction and found that professors, students, and hobbyists find it comparatively easy to use during their jewelry-making process. Interestingly, a high-resolution 3D printer might not be something that every jeweller has access to. This could be due to the financial expenses involved in purchasing and maintaining such dynamic machines. To sum up, there still remains an uncertainty between designers on the investment value and the contribution 3D printers make in the jewelry-crafting process.

Access to high resolution 3D printers is difficult

Curious about the effects of technological advancements, we cross-examined the effect software has on the jewelry-making process. This shed light on the psychological thinking of designers, and we found that not all designers are open-minded about the introduction of new software tools. The hobbyists were found to be more scared than students. This could be attributed to the limited support available for these software tools. Additionally, in the case of students, if they need assistance for using such software tools, they have professors and software communities to help. In contrast, the hobbyists are limited to only the software communities present online.

Hobbyists more scared of new software and technologies

When looking in-depth into the software tools, several tools were found, each with its unique capabilities and functionalities. Most interesting out of these remain KeyShot and Illustrator due to their intuitive nature. Another software tool named Grasshopper was found to be challenging to learn for students compared to hobbyists. From this, we can conclude that along with the assistance provided for learning software tools, an individual's experimentation with the software plays an equally important role in the learnability of the tool. Besides these, we found that CATIA remained an unpopular software tool as out of all the participants involved in the study, only two professors were actively using it. This could be because CATIA is tailored for the automotive and aerospace industries and not for the jewelry industry. Overall, there is a debate amongst the individuals between the ease of use and learnability of software tools, which can be traced back to their background, experience, and comfortability.

Experimentation and playing with software helps in learning

Owing to the introduction of 3D software, enhancement of certain steps in the jewelry-making workflow is possible. In the designing step, software tools have enabled better idea communication as individuals can now create virtual prototypes rather than a 2D drawing. In the case of smart jewelry, where multiple domain experts collaborate to create a piece, software tools have played a role in their collaboration. It becomes a common ground where collaborators share their ideas and opinions on the design. Since hobbyists usually work individually on their jewelry pieces, they did not see software tools as a collaboration medium. Furthermore, even though varied opinions among designers exist regarding the acceptance of software tools, it is good to know that all the designers consider it like any other tool on the jeweller's workbench.

Designers consider 3D software as an essential tool to craft jewelry

Each new technology has its flaws. Software tools are no exception to this. An indefinite amount of time has to be invested in learning and experimenting with software tools, which can be associated with their learning curve. Also, individuals have to start thinking in the software's language to accomplish day-to-day designing tasks. Together, this adds to the challenges beginners and experts feel when introduced to new software tools. Another challenge that professors pointed out was prior knowledge of programming required for working with software tools. However, this remained contracted by hobbyists and students. One potential reason for this could be due to the several different software tools that professors have worked with compared to the limited number used by hobbyists or students.

Designers have to think in software's language to design something

From this study, it is evident that the term "smart jewelry" is used in an exploited manner. Some designers think smart jewelry has technology associated with it; some say it can be without technology and has a secondary purpose, while others debate on the aesthetic value of these jewelry pieces. Consequently, no definite meaning of smart jewelry exists, which underlines the importance of having a standardized definition of the term rather than an individual's interpretation of it. Generally, designers like the idea of smart jewelry and are willing to craft smart jewelry products, but they remain hesitant about their abilities to do so. Furthermore, they realize that there has to be a collaboration with different domain experts, and the knowledge of 3D software could be advantageous for crafting smart jewelry.

Smart jewelry can be crafted by collaborating with domain experts

Being a relatively novel field, smart jewelry requires a lot of research and experimentation. The research is mainly dedicated to electronic components needed to make smart jewelry. This is especially important for designers from a jewelry background and having no prior knowledge about electronic components. While the experimentation part involves finding the combination of the right components to make the smart jewelry work. This is also an exhaustive process and comes with experience. Lastly, there remain difficulties in crafting smart jewelry if programming knowledge is absent because programming would enable one to create functional smart jewelry.

Experimentation and research are key elements for crafting smart jewelry

The study also highlighted several potential improvement ideas. These ideas included introducing voice command as input to software tools, a software tool that could be used for the whole jewelry-making process, and an augmented reality tool enabling designers to play with objects in a virtual space, to name a few. All users were fascinated by the idea of having a software tool that can perform all the tasks from the jewelry-making process. Without such a tool, a designer has to switch between task-specific software tools for crafting a jewelry piece. Furthermore, looking at the rate at which advancement of technology is taking place, designers feel confident that there would be a possibility to visualize and play with virtual models in a virtual reality space in the future. This might not be the only reason for supporting this idea; the designers could have also believed that such a concept could help in reducing the gap between the digital and the physical world.

CAD AR tool can bridge gap between analog and digital worlds

Chapter 5

Summary and future work

5.1 Summary and contributions

As evident from Section 4 of our thesis, we try to find answers to our research question with the help of interviews and survey studies. The research question is as follows:

What are the difficulties in fabricating smart jewelry and how to overcome them?

This question covers a wide range of topics. The first topic that it highlights is finding novel processes and techniques in the fabrication of smart jewelry. As the jewelry industry moves towards digitization, designers adapt to practices that make the jewelry-making process easy and efficient. From our study, it can be denoted that designers have shifted their attention from traditional tools to using high-end machines such as 3D printers and 3D scanners. Also, traditional designers would start with a design and follow a step-by-step approach to craft the jewelry. However, with the modernization of the domain, the designers take freedom from this strict approach and consequently follow a less-restricted one where they have the flexibility to experiment and research on their design.

Crafting approach

Tools used

The second topic underlines the use of different tools used for making jewelry. These range from basic traditional tools such as soldering machines and torches to electronic tools such as computer numeric control (CNC) machines. The third topic focuses on a specific tool used in crafting smart jewelry, the software tools. Several deductions regarding the benefits and challenges of software tools can be made from our study. The 3D software tools are collaboration tools that help in the clear communication of ideas with the help of its visualization capabilities. Along with visualization, these tools help analyze the requirements such as shape, size, or material type for the jewelry piece. Moreover, the efficiency that the use of 3D software tools adds to the jewelry process is commendable. This could be ascribed to its ability to adjust digital models faster than analog and preserve models and data over time. Ultimately, it provides a great way to reduce the material wasted in creating different designs, thereby aiding researchers in finalizing the material they would want their jewelry piece to be crafted in.

Benefits of using software tools

Despite these benefits, designers find software tools inaccurate as they do not follow a WYSIWYG (What You See Is What You Get) system. Another challenge that designers face is with the user interface (UI) of the software tools. During the process of crafting smart jewelry, many different software tools need to be used. Neither is the UI nor the naming of the tools consistent between these software tools and as a result, designers have to learn many different software languages to communicate with the tool. These challenges thereby affect the time efficiency of the jewelry-making process, making this step the most time-consuming step in the process and makes it difficult for beginners to learn software tools. Besides this, the designers have to "think in the software's language" to use the software.

Difficulties encountered while using software

The fourth topic involves finding out why some designers do not use software tools despite their benefits. The major reason found for this was the steeper learning curve associated with learning the software-specific languages. This learning curve was pointed out to be a never-ending process as with new updates or new software, and new techniques need to be learned in order to use the software.

Reasons for not using software

Along with this, the 3D software tool skills correlate with the design of the jewelry. Hence, a poor skill of working with 3D software tools will limit the designing of jewelry pieces by designers. Last but not least, when working with software tools, there is an absence of haptic feedback making designers less confident to use.

Problems for crafting smart jewelry

The fifth topic revolves around finding problems and solutions to the problems encountered while crafting smart jewelry. The major problem that was discovered in this thesis was the unanimous definition of the term "smart jewelry". The solution for this could be a formulation of a definition of smart jewelry. Furthermore, there are several other problems associated with the process of crafting smart jewelry. Since smart jewelry involves the collaboration of different domains, it is essential that there is teamwork between these domains. Certain designers might not be comfortable with this approach as they prefer doing all the work themselves rather than distributing or collaborating with colleagues. Also, the smart jewelry crafting process requires prior knowledge of software and programming skills due to the involvement of digital components. The key to creating smart jewelry is finding the correct combination of electronic and jewelry material to provide both aesthetics and functional elements. In general, finding this combination can be tedious as it involves a lot of research and experimentation, and not all designers would be ready to invest such high amounts of time. Lastly, designers must also consider the environmental factors associated with the smart jewelry piece, apart from the crafting process. These environmental factors include water (addition of waterproofing feature), vicinity of the product to children (additional of child-proofing feature), etc. We believe that to solve these smart jewelry-making challenges, the issues related to software tools should be solved first as they remain the basics of crafting any smart jewelry product.

Potential solutions

We also discussed these potential solutions with our participants. It was discovered that creating a single software that can be used for any of the steps in the jewelry-making process could be one such solution. This can thus help designers to learn and work with just a single software tool rather than transitioning between different software tools depending on the designing step. Also, the idea of CAD augmented reality (AR) tool could help designers to work with software tools in a somewhat haptic manner.

Enabling students to craft smart jewelry

The sixth topic uncovers the potential of enabling students to fabricate smart jewelry. From the discussion with participants, it can be inferred that a step-by-step guide to introducing digital components into students' coursework would be a possible way to introduce them to crafting smart jewelry. Furthermore, the addition of programming courses to the curriculum would be beneficial as well.

Suggestions for problems encountered by goldsmiths

The last topic of the research question was to find out answers on how to overcome the difficulties faced by goldsmiths. The thesis pointed out that organizing tutorials and workshops for goldsmiths or at least encouraging goldsmiths to attend workshops for beginners could be a good starting point for them to overcome difficulties faced while working with software tools. In the end, the more the goldsmiths practice using software tools, the better they would learn them.

5.2 Future work

An analogous study with a more extensive user group

Developing prototype of CAD AR tool and conducting user study

Our study was not able to cover the whole scope of our research question. There were certain aspects that we could not cover, and we regard these aspects as future work. Carried out during the pandemic, the current study and results have a limitation based on the number of participants involved in the study. Thus, we suggest that conducting an analogous study with a more extensive user group could provide valuable insights. Furthermore, we believe that participants could be biased towards the CAD AR tool merely due to the hype of AR. To disprove this theory, we suggest creating a prototype of the CAD AR tool followed by a user study. Also, the current study was limited by professors, students, and hobbyists. Other user groups such as professional designers would provide concrete proof of concepts based on the results obtained. One more drawback of our study is that we did not look at cosplayers' perspectives of smart jewelry as they did not look like a perfect fit for our study. Thus in the future, the cosplayer's understanding of smart jewelry could reveal novel deductions. In conclusion, one way to help goldsmiths craft smart jewelry could be with the help of an apprenticeship model. In this model, the students from universities could intern under goldsmiths learning the jewelry-making process, and in return, they could help goldsmiths learn the different software tools taught in universities. This is just an idea; a small prototypical model of this kind could provide more evidence on whether such an idea would be scalable or not.

Apprenticeship model for goldsmiths and students to exchange knowledge

Appendix A

Interview Questions

Background

1. Could you please tell us about yourself?
    (a) Job
    (b) Job since
    (c) Experience in CAD
    (d) Training in jewelry making/design

Product Making

1. What would the rough workflow look like for making an object?
2. Do you make the whole product yourself or distribute/outsource some of the work?
3. How much time do the individual steps take?
4. In which steps do you use software?
5. Should these steps need to be done in the software? If yes, why?
6. How does the transition work between the software work steps to the non-software work steps?

7. Have you used any fabrication devices like 3D printer, laser cutter, etc? What was the purpose for using it? What do you think about their usefulness? Do you have any thoughts on using them?
8. How is working in jewelry different today from when you first started out? (processes)
9. What kinds of materials have you worked with and which work well together and which ones do not?

Teaching

1. Can you please tell us what you teach?
2. Out of the whole workflow, which parts are covered during teaching? (major focus?)
3. What were the challenges that you experienced while teaching?

Computer Aided Design (CAD)

1. Which CAD software is used? Have you used others? If yes, which ones? Are there any reasons for preferring one over other(s)?
2. If CAD software were used:
   (a) How long has the software been in use?
   (b) Is CAD software used for teaching/personal use? If using some other software, why and which one?
   (c) How many software have you had experience with? which? (any specific reason?)
   (d) What positive experiences have you had with CAD software?
   (e) What negative experiences have you had with CAD software?
      i. How frequently are there updates and how frequently do you update? Any reasons?

   ii. How is the learning for students/beginners?, How is the learning curve for that specific software?
   iii. What are the problems faced? How are they solved?
  (f) Which functions are missing in the existing software? (that you would like to be added)
  (g) What are the things that still need to be adjusted/done after using the software?
  (h) What do you think about the following? (CAD issues)
   i. What is your opinion on the UI of the software?
   ii. What is your opinion on the language used by the software for naming its tools?
   iii. Have you ever required software support initially while learning or in-between while designing or working with the software? When? Why?
  (i) Do you use prefabricated model feature? Why?

3. If CAD software is not used:
  (a) What are your opinions about CAD software?
  (b) Are you planning to switch to software?
  (c) What keeps you from doing so?
  (d) Are there things that are not implemented in software the way you want them?
  (e) What is your Current workflow (without software)/work environment like?
  (f) What tools do you use?

Smart Jewelry

1. What do you think of smart jewelry and what do you understand by this term?
2. Have you already had contact with Smart Jewelry?
  (a) - Contact- (yes)

   i. To what extent was the contact with Smart Jewelry? Self-made/learned making/sold/during teaching?
   ii. Which object(s) did you already come in contact with?
   iii. Do you make smart jewelry yourself?
   iv. Would you like to make smart jewelry yourself? (if not made already)
   v. What changes for you (in the workflow) from traditional jewelry to smart jewelry?
 (b) - Contact- (no)
   i. Would you like to make smart jewelry yourself?

3. How is the Interest in smart jewelry among customers/students/colleagues?

4. Future of Smart Jewelry
 (a) Do you support the idea behind smart jewelry?
 (b) What status do you think Smart Jewelry is at? (developed/research stage/..)
 (c) What do you think should be improved?
 (d) Do you think, smart jewelry can be made using the current equipment/ technology?
 (e) What significance would smart jewelry have? (Health, added functionality, etc)
 (f) Would you like a CAD software that can be used to make smart jewelry?
 (g) What would change for the workflow from traditional jewelry to smart jewelry? (if not answered already)
 (h) What are your thoughts on warranty of the electrical parts inside the jewelry? repair work?
 (i) What are your opinions on smart jewelry fabrication being taught at university level?

5. Would you use a software that has built-in models or meshes for digital objects?

6. What are your views on CAD tool that works with voice commands?

7. What are your views on CAD tool that will make it simpler to make objects by giving suggestions of next steps?
8. What are your views on CAD AR tool? (interacting with 3D models using 3D interactions)

Suggestion for goldsmiths

1. What would you suggest goldsmiths to enable them to make smart jewelry?

Appendix B

Codes

1. Background
    - Projects
2. Course details
    - Challenges for students
3. Outsource
    - Reason to outsource
4. Workflow
    - General Process
        - Designing step
        - Experimenting and research step
        - Material selection step
        - Production step
        - Post production step
        - Marketing step
    - Tools used
        - Specific tool problems
        - Specific tool advantages
    - Whole Workflow
    - Jewelry Material
    - Techniques

- Technique description

5. Software
   - Reason to use software
   - Reason to not use software
   - Challenges while using software
   - How software are taught
   - Opinion on pre-fabricated models
   - Specific software positive points
   - Specific software negative points
6. Potential solution
   - Pre-build models for electronics
   - Voice commands in CAD
   - CAD AR tool
   - Smart CAD suggestions
7. Smart Jewelry
   - Contemplation
   - Fabrication
   - Smart jewelry projects
   - Teaching fabrication of smart jewelry
   - Smart jewelry interest
   - Challenges while fabricating smart jewelry
8. Suggestion for Goldsmiths

Appendix C

Survey Form

Demographics Questions

1. Age
    - Under 16
    - 16 to 20
    - 21 to 25
    - 26 to 30
    - 31 to 40
    - Over 40
2. Gender
    - Male
    - Female
    - Other
    - Prefer not to say
3. Current course name (Example: Masters in Jewelry Design)
4. Course location (City)
5. Current semester
    - 1 to 2

- 3 to 4
- 5 to 6
- Over 6

6. Experience in making jewelry
    - Less than a year
    - A year to less than 2 years
    - 2 years to less than 3 years
    - Greater than 3 years
7. Experience in using 3D software
    - Less than a year
    - A year to less than 2 years
    - 2 years to less than 3 years
    - Greater than 3 years

Outsourcing

1. Have you outsourced anything while making jewelry?
    - Yes
    - No
2. Have you outsourced any of the following? (Yes or No)
    - Model designing in a software
    - 3D Printing
    - Laser Cutting
3. How difficult is it to find a company that will 3D print your products? (Rate between 1 to 5, where 1 is Not at all difficult and 5 is Very difficult)
4. How intimidating is it to approach someone who's going to make your work? (Rate between 1 to 5, where 1 is Not at all intimidating and 5 is Very intimidating)

5. How scary is new technology to you? (Rate between 1 to 5, where 1 is Not at all scary and 5 is Very scary)
6. How much do you agree with the following statements: (Select from Strongly agree, Agree, Slightly agree, Neither agree nor disagree, Slightly disagree, Disagree, Strongly disagree)
    - Outsourcing helps to parallelize tasks
    - Outsourcing helps to be more efficient.
    - Outsourcing saves time.

Tools

1. Have you used a laser cutter?
    - Yes
    - No
2. Have you used a 3D scanner?
    - Yes
    - No
3. Have you used a 3D printer?
    - Yes
    - No

3D printing

1. Complete the following statements: (Select from Extremely easy, Easy, Somewhat easy, Neither easy nor difficult, Somewhat difficult, Difficult, Extremely difficult)
    - Using a 3D printer is
    - Getting access to printers with high resolution is
    - Making Jewelry using a 3D printer is

Software

1. How scary is using software for you? (Rate between 1 to 5, where 1 is Not at all scary and 5 is Very scary)
2. Have you used the following software? (Yes or No)
   - Rhino
   - Meshmixer
   - Blender
   - Illustrator
   - Keyshot
   - Indesign
   - Photoshop
   - Catia
   - Grasshopper
   - Zbrush
3. How difficult are the following software to learn? (Please fill only for software used) (Select from Extremely easy, Easy, Somewhat easy, Neither easy nor difficult, Somewhat difficult, Difficult, Extremely difficult)
   - Rhino
   - Meshmixer
   - Blender
   - Illustrator
   - Keyshot
   - Indesign
   - Photoshop
   - Catia
   - Grasshopper
   - Zbrush
4. How difficult are the following software to work with? (Please fill only for software used) (Select from Extremely easy, Easy, Somewhat easy, Neither easy nor difficult, Somewhat difficult, Difficult, Extremely difficult)
   - Rhino

- Meshmixer
- Blender
- Illustrator
- Keyshot
- Indesign
- Photoshop
- Catia
- Grasshopper
- Zbrush

Potential benefits of using software

1. How much do you agree with the following statements? (Select from Strongly agree, Agree, Slightly agree, Neither agree nor disagree, Slightly disagree, Disagree, Strongly disagree)
    - Visualisation using a 3D software helps communicate an idea better than drawings.
    - Software and 3D printing help to understand the shape and size of the object before actually making it.
    - Designing using software makes the jewelry-making process faster.
    - Making adjustments in digital models is easier than in physical objects.
    - Making 3D prints with different materials (having the same digital model in software) helps to select the jewelry material faster.
    - 3D software make collaboration easier.
    - 3D software are just like any other tool on jeweller's workbench.

Potential challenges while using software

1. How much do you agree with the following statements? (Select from Strongly agree, Agree, Slightly agree, Neither agree nor disagree, Slightly disagree, Disagree, Strongly disagree)

- 3D software interfaces are difficult to understand.
- 3D software take a lot of time to learn.
- Quality of product achieved without using software is better.
- Programming needs to be learned in order to use 3D software.
- Many software need to be learned just to make a single product.
- 3D software skills limit the design.
- 3D software are expensive.
- Different software are not consistent in their UI (User Interface) design.
- Different software are not consistent in naming their tools.
- Making jewelry with software takes more time compared to making jewelry without using software.
- Many things like shortcuts, tool names, tool functions need to be remembered for every software.
- While using a 3D software, it is difficult to find the exact step where a mistake was made.
- Digital problems take more time than analog problems to solve.
- I have to think in the software's language to design something. (Software's language is a way in which you need to interact with a software to work with it)

Potential improvement ideas

1. How much do you agree that the following things can make 3D software more user-friendly? (Select from Strongly agree, Agree, Slightly agree, Neither agree nor disagree, Slightly disagree, Disagree, Strongly disagree)
    - All software use the same language for their UI.

- A single software providing all the functions needed to make a product.(From designing to 3D printing)
- Interactive voice command feature with the software.
- A smart suggester that suggests the next possible steps while designing.
- A software in which glasses are worn via which the object can be seen in the real world and can be manipulated by hands.

Smart jewelry

1. What do you understand by the word smart jewelry?
2. How much do you agree with the following statements: (Select from Strongly agree, Agree, Slightly agree, Neither agree nor disagree, Slightly disagree, Disagree, Strongly disagree)
    - Current smart jewelry focuses more on technology than the aesthetic part of the jewelry.
    - Current smart jewelry uses jewelry as outer-packaging to bring some technical functionality on the body.
    - I would like to work on a project involving smart jewelry.
    - I can make smart jewelry myself.
    - Knowledge of 3D software is a must to make smart jewelry.
    - To make smart jewelry it is important that people having different expertise come together and work as a team.

Challenges while making smart jewelry

1. How much do you agree with the following statements: (Select from Strongly agree, Agree, Slightly agree, Neither agree nor disagree, Slightly disagree, Disagree, Strongly disagree)

- Current electronic components are not enough to make smart jewelry.
- Current 3D software are not enough to make smart jewelry.
- Process for making smart jewelry is not properly documented.
- One needs to learn programming to make the smart jewelry working.
- A lot of research on electronic components needs to be done to make smart jewelry.
- A lot of experimentation is required to make smart jewelry.

Bibliography

Abrar. 11 of the best smart jewelry tech products, 2020. URL https://www.smartgeekwrist.com/best-smart-jewelry/.

Judith Amores and Pattie Maes. Essence: Olfactory interfaces for unconscious influence of mood and cognitive performance. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*, page 28–34, New York, NY, USA, 2017. Association for Computing Machinery. URL https://doi.org/10.1145/3025453.3026004.

Roberta Bernabei, Alba Cappellieri, Secil Ugur Yavuz, and Livia Tenuta. Cad/cam and jewellery design education. *Making Futures, Plymouth College of Art*, 4, 05 2015.

Kathy Charmaz. *Constructing grounded theory : a practical guide through qualitative analysis*. Sage Publications, London; Thousand Oaks, Calif., 2006. URL http://www.amazon.com/Constructing-Grounded-Theory-Qualitative-Introducing/dp/0761973532.

Margarita Dekoli and Bakhtiar Mikhak. Codachrome: A system for creating interactive electronic jewelry for children. In *Proceedings of the 2004 Conference on Interaction Design and Children: Building a Community*, page 139–140, New York, NY, USA, 2004. Association for Computing Machinery. URL https://doi.org/10.1145/1017833.1017859.

C Duke Woolley and S Romeo. *Wearable Technology - the Fashion Tech Era: Towards a Multidisciplinary Approach*. Beecham Research Limited, England, 2014.

Patrick Feser. *Foundations of Interactive Jewelry: Understanding Crafting Practices*. Master's thesis, Media Computing Group, RWTH Aachen University, 2019.

Jutta Fortmann, Vanessa Cobus, Wilko Heuten, and Susanne Boll. Waterjewel: Design and evaluation of a bracelet to promote a better drinking behaviour. In *Proceedings of the 13th International Conference on Mobile and Ubiquitous Multimedia*, page 58–67, New York, NY, USA, 2014a. Association for Computing Machinery. URL `https://doi.org/10.1145/2677972.2677976`.

Jutta Fortmann, Heiko Müller, Wilko Heuten, and Susanne Boll. How to present information on wrist-worn point-light displays. In *Proceedings of the 8th Nordic Conference on Human-Computer Interaction: Fun, Fast, Foundational*, page 955–958, New York, NY, USA, 2014b. Association for Computing Machinery. URL `https://doi.org/10.1145/2639189.2670249`.

Jutta Fortmann, Wilko Heuten, and Susanne Boll. User requirements for digital jewellery. In *Proceedings of the 2015 British HCI Conference*, page 119–125, New York, NY, USA, 2015. Association for Computing Machinery. URL `https://doi.org/10.1145/2783446.2783573`.

Barney G. Glaser and Anselm L. Strauss. *The Discovery of Grounded Theory: Strategies for Qualitative Research*. Aldine de Gruyter, New York, NY, 1967.

Gülay Hasdoğan. The role of user models in product design for assessment of user needs. *Design Studies*, 17 (1):19–33, 1996. URL `https://doi.org/10.1016/0142-694X(95)00007-E`.

Selin Insel, Oğuz Turan Buruk, Mehmet Cengiz Onbaşli, and Oğuzhan Özcan. Snowflakes: A design speculation for a modular prototyping tool for rapidly designing smart wearables. In *Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems*, page 1–6, New York, NY, USA, 2018. Association for Computing Machinery. URL `https://doi.org/10.1145/3170427.3188676`.

Alexandra Ju. Functionality in wearable tech: Device, as jewelry, as body mediator. In *Proceedings of the TEI*

'16: Tenth International Conference on Tangible, Embedded, and Embodied Interaction, page 641–646, New York, NY, USA, 2016. Association for Computing Machinery. URL `https://doi.org/10.1145/2839462.2856348`.

Ruth Kikin-Gil. Buddybeads: Techno-jewelry for non-verbal communication within teenager girls groups. *Personal Ubiquitous Comput.*, 10(2–3): 106–109, 2006. URL `https://doi.org/10.1007/s00779-005-0015-x`.

Jon Krosnick and Leandre Fabrigar. *Designing Rating Scales for Effective Measurement in Surveys*, pages 141–164. Wiley Series in Probability and Statistics, 08 2012. URL `https://doi.org/10.1002/9781118490013.ch6`.

Victor Latour. A beginner's guide to zbrush!, Jan 2021. URL `https://www.schoolofmotion.com/blog/beginner-guide-to-zbrush`.

Jonathan Lazar, Jinjuan Heidi Feng, and Harry Hochheiser. *Research Methods in Human-Computer Interaction*. Morgan Kaufmann, Cambridge, MA, 2 edition, 2017. URL `http://www.sciencedirect.com/science/book/9780128053904`.

Jack Meyer. Jewellery cad training resources, jewellery industry information, new technology trends and other discoveries by jack meyer, Mar 1970. URL `https://www.cadjewelleryskills.com/`.

Jochen Meyer, Jutta Fortmann, Merlin Wasmann, and Wilko Heuten. Making lifelogging usable: Design guidelines for activity trackers. In *MultiMedia Modeling*, pages 323–334, Cham, 20150. Springer International Publishing.

Groover Mikell and Zimmers Emory. *CAD/CAM: Computer-Aided Design and Manufacturing*. Pearson Education, 1984. URL `https://books.google.de/books?id=18cy2E-o8gIC`.

Cameron S. Miner, Denise M. Chan, and Christopher Campbell. Digital jewelry: Wearable technology for everyday life. In *CHI '01 Extended Abstracts on Human Factors in Computing Systems*, page 45–46, New York, NY, USA, 2001. Association for Computing Machinery. URL https://doi.org/10.1145/634067.634098.

Karin Niemantsverdriet and Maarten Versteeg. Interactive jewellery as memory cue: Designing a sound locket for individual reminiscence. In *Proceedings of the TEI '16: Tenth International Conference on Tangible, Embedded, and Embodied Interaction*, page 532–538, New York, NY, USA, 2016. Association for Computing Machinery. URL https://doi.org/10.1145/2839462.2856524.

Maho Oki and Koji Tsukada. Sparklry: Designing "sparkle" of interactive jewelry. In *Proceedings of the Eleventh International Conference on Tangible, Embedded, and Embodied Interaction*, page 647–651, New York, NY, USA, 2017. Association for Computing Machinery. URL https://doi.org/10.1145/3024969.3025053.

Judith S. Olson and Wendy A. Kellogg. *Ways of Knowing in HCI*. Springer Publishing Company, Incorporated, 2014.

Colm O'Muircheartaigh, Jon A. Krosnick, and Armen Helic. Middle Alternatives, Acquiescence, and the Quality of Questionnaire Data. Technical report, Harris School of Public Policy Studies, University of Chicago, December 2000. URL https://ideas.repec.org/p/har/wpaper/0103.html.

Amit Patel. What is catia?, Feb 2021. URL https://www.technia.com/blog/what-is-catia/.

Les Piegl and Wayne Tiller. *The NURBS Book*. Springer-Verlag, Berlin, Heidelberg, 1995.

Inka Rantala, Ashley Colley, and Jonna Häkkilä. Smart jewelry: Augmenting traditional wearable self-expression displays. In *Proceedings of the 7th ACM International Symposium on Pervasive Displays*, New York, NY, USA, 2018. Association for Computing Machinery. URL https://doi.org/10.1145/3205873.3205891.

Erno Salmela and Ivary Vimm. Digital smart jewelry: Next revolution of jewelry industry? In *IntechOpen*, 2018.

Yulia Silina and Hamed Haddadi. New directions in jewelry: A close look at emerging trends and developments in jewelry-like wearable devices. In *Proceedings of the 2015 ACM International Symposium on Wearable Computers*, page 49–56, New York, NY, USA, 2015. Association for Computing Machinery. URL https://doi.org/10.1145/2802083.2808410.

Kerry Stevenson. Why is autodesk meshmixer still alive? " fabbaloo, Jul 2020. URL https://www.fabbaloo.com/blog/2017/4/6/why-is-autodesk-meshmixer-still-alive.

Anselm L. Strauss and Juliet M. Corbin. *Basics of qualitative research: techniques and procedures for developing grounded theory*. Sage Publications, Thousand Oaks, Calif, 1998.

Ivan E. Sutherland. Sketchpad: A man-machine graphical communication system. In *Proceedings of the May 21-23, 1963, Spring Joint Computer Conference*, page 329–346, New York, NY, USA, 1963. Association for Computing Machinery. URL https://doi.org/10.1145/1461551.1461591.

William T.C., Nov 2014. URL https://www.freelancer.com/u/wtcunningham/portfolio/CATIA-Jewelry-Design-1378354?w=f&ngsw-bypass=.

Leann Troutner. The difference between adobe photoshop and adobe illustrator, Aug 2017. URL https://www.cia.edu/blog/2017/08/the-difference-between-adobe-photoshop-and-adobe-illustrator.

Somlak Wannarumon. Reviews of computer-aided technologies for jewelry design and casting. *Naresuan University Engineering Journal*, 01 2011. URL https://doi.org/10.14456/nuej.2011.8.

Index

Access Bracelet, 19
Augmented reality necklace, 28–29

Blender, 36
BuddyBeads, 22–23

CATIA, 34
Cnick Ring, 16
CodaChrome, 12–13

Earring Backing, 20
Essence, 25–26

Flex 2, 18
Future work, 114–115

Gemio Band, 19–20
Grounded theory approach, 47

Illustrator, 35

KeyShot, 37

Leaf Urban, 17–18
Luxe Smart Bracelet, 18–19
Luxe Smart Ring, 15–16

MAXQDA, 46–47
Memento, 26–28
Meshmixer, 37
Misfit Shine, 18

NFC Ring, 16
Nimb Ring, 16
Nod Ring, 17

Oura Ring, 16

Photoshop, 35
Preliminary study, 41–42

Previous work, 30–31

Research question, 40
Rhino, 35–36

Sesame Ring, 16–17
Smart Cufflink, 20
Snowflake, 13–14
Sparklry, 21, 22

Toy-based sentimental jewelry, 23–25

Ungaro Smart Ring, 16

Wellness and Activity Bracelet, 19

ZBrush, 36–37

Typeset June 22, 2021