SOUND DATA AS DESIGN MATERIAL: A MULTISENSORIAL AND INTERACTIVE TRANSFORMATION PROCESS FOR MATERIALIZING PERSONALLY MEANINGFUL DATA INTO MEANINGFUL ARTIFACTS

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ABSTRACT

SOUND DATA AS DESIGN MATERIAL: A MULTISENSORIAL AND INTERACTIVE TRANSFORMATION PROCESS FOR MATERIALIZING PERSONALLY MEANINGFUL DATA INTO MEANINGFUL ARTIFACTS

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Emotional connections with the products increase product lifetimes, thus decreasing waste and providing prolonged value. In creating this emotional connection, personally meaningful data (sonic memories) offer benefits that cannot be obtained by any other means in determining the meaning and value of a personal artifact by adopting the personalization approach. However, adaptation and mass-customization that can be attained with conventional design and production methods are far from exploiting these potentials due to the nature of their inflexible and limited processes. This research presents a method namely, Interactive Data Transformation Interface (IDTI) that uses sound data connected to memories as a source of meaning and value by converting sound data into three-dimensional forms. Using a research through design approach, this transformation method is developed as a result of primary user research that generates the dimensions of this transformation (meaning, clarity, accessibility, aesthetics, social clarity, and permanence). IDTI is implemented in a remote design workshop and refined with insights from both studies regarding creating meaningful and valuable artifacts. Findings of the process and implications are discussed and presented in this research.

Keywords: Data Physicalization, Co-design, Product Longevity, Personalization, Generative Design Research

ÖZ

TASARIM MALZEMESİ OLARAK SES VERİSİ: ÇOKLU DUYUSAL VE ETKİLEŞİMLİ BİR DÖNÜŞÜM SÜRECİ İLE KİŞİSEL OLARAK ANLAMLI VERİLERİN ANLAMLI NESNELERE DÖNÜŞTÜRÜLMESİ

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Ürünlerle kurulan duygusal bağlar, ürün ömrünü uzatır, böylece atıkları azaltır ve uzun süreli değer sağlar. Kişiselleştirme yaklaşımını benimseyerek, bu duygusal bağlantıyı oluştururken, kişisel olarak anlamlı veriler (ses anıları), kişisel bir eserin anlam ve değerini belirlemede başka hiçbir yolla elde edilemeyecek faydalar sunar. Ancak yaygın olan tasarım ve üretim yöntemleri ile sağlanabilen uyarlama ve kitle özelleştirme, esnek olmayan ve kısıtlı süreçlerinin doğası gereği bu potansiyelleri kullanmaktan uzaktır. Bu araştırma, ses verilerini üç boyutlu formlara dönüştürerek, anılara bağlı ses verilerini anlam ve değer kaynağı olarak kullanan Etkileşimli Veri Dönüştürme Arayüzü (EVDA) yöntemini sunmaktadır. Bu dönüştürme yöntemi, tasarım yoluyla araştırma yaklaşımıyla bu dönüşümün boyutlarını (anlam, anlaşılabilirlik, erişilebilirlik, estetik, sosyal netlik, ve kalıcılık) oluşturan temel kullanıcı araştırmaları sonucunda geliştirilmiştir. EVDA, çevrimiçi bir tasarım çalıştayında uygulanır ve anlamlı ve değerli eserler yaratmaya ilişkin her iki çalışmadan elde edilen içgörülerle geliştirilir. Sürecin bulguları ve çıkarımları bu araştırmada tartışılmakta ve sunulmaktadır.

Anahtar Kelimeler: Veri Fizikselleştirme, Ortak Tasarım, Ürün Uzun Ömrü, Kişiselleştirme, Yenilikçi Tasarım Araştırması

To…

My Family,

Canik,

The victims of the Feb. 6th Kahramanmaraş Earthquake,

& The Ones Who Never Give Up

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My Doctoral Thesis Examining Committee Members, Prof. Dr. Arzu Gönenç Sorguç, Prof. Dr. Gülay Hasdoğan (former committee member), Prof. Dr. Owain Pedgley, and Assoc. Prof. Dr. Harun Kaygan (former committee member) provided valuable feedback on my research, so I can't thank them enough for their time and contributions to improving this thesis.

I think pursuing a Ph.D. degree, among other life occurrences, appears to be a psychologically demanding task. No matter what you need to do in normal life, there is always a "Ph.D." file open in your mind that affects your psychology and many short and long-term decisions. In overcoming these side effects, I believe the family is the strongest aid to all. I am really, really, and deeply grateful to my family for being there all the time. Their patience, understanding, and unwavering belief in me kept me going, even during the toughest times.

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CHAPTER 1

INTRODUCTION

Humankind's relationship with the creation of artifacts has a long history of being tangible in which the artifact and the maker reside in the same space-time. Fast forward to the end of the 20th century, mass manufacturing and overseas production separated the maker and the artifact with standardized and automated manufacturing systems. The premise of manufacturing for the masses and making them affordable for the public has brought the standardization of needs and shrinkage of individual needs to idealized specific consumer types. For more than a century, the artifact has been no longer a result of self-expression but an alienated entity from its maker and its future owner.

Before starting my doctoral studies, I realized the potential of sound as a tool for creating and modifying forms via a project I named Malfunktion (Alpay, 2013a) in the ID707 Critique of Design course I took as part of my Ph.D. in the 2013 Fall Semester. In this project, I plugged a bass guitar into the head of a 3D printer to modify the built artifact in real time by playing the bass guitar and playing audio loops. In another project, Gestural Modelling, I developed a method for users to alter the form of an object with sound and body movements. These two studies had a common intention of facilitating form creation methods by letting anyone use an interface they already know, their bodies, and sound. Those studies aimed to empower users of the systems to create forms without knowing any CAD software. However, an unforeseen result arose. In the two projects I mentioned, the generated forms and manufactured artifacts started to have a story, thus meaning. This hands-on experience later inspired me to use sound as a tool to attach meanings to the form-creation process.

After realizing the meaning of objects regarding their creation story, I conducted a literature survey starting with the meaning and value of the artifacts. Artifacts can bring order to one's life by connecting past, present and future together and making him/her feel complete (Adler et al., 1983). Their symbolic meaning creates a reflection of ourselves and can act as connection mechanisms to our social environment while accumulating meanings over time (Csikszentmihalyi, 1991). Meanings of artifacts cannot be thought of in isolation but in their cultural context (Gosden & Marshall, 1999; McCracken, 1986). Through their connection with memories, artifacts can take us back to different times (Desmet & Hekkert, 2007; Tsai & Hoven, 2018). The meanings assigned to the artifacts can cause emotional bonds to form, preventing the possessor from throwing the object away even if it loses its function (Mugge, 2007; Mugge et al., 2014; Mugge, Schoormans, & Schiffersteinb, 2009).

To establish this meaning and value in artifacts, I extended the literature to co-design and design for longevity fields. The evolution of co-design has a decades-long history, and involving the user in an artifact's creation process is known to have significant benefits. Increased product lifetime (Chapman et al., 2018) and forming emotional bonds with the artifact (Casais et al., 2018; Mugge, Schoormans, & Schiffersteinb, 2009) can be given as examples of the most critical implications from the perspective of this thesis. Thus, involving users in the artifact creation process would create bonds with its user, causing the resulting artifact to be more meaningful and valuable for the possessor.

In terms of meaning generation and emotional bonding with artifacts, designing for personal memories has excellent potential (Hoven et al., 2012). Although memories are substantial assets in meaning-making and emotional bonding, their potential has not been explored extensively in the practice of design (Orth et al., 2018). Inspired by this and based on the two personal studies mentioned above, I decided to use sound as a carrier of memories and create forms generated from sounds. I chose sound as a source for memories since they create strong connections with memories. Audio recordings can take people back in time, and their recording technology has been there for a long time. It is relatively low technology compared to photographs, so it is widespread (Oleksik & Brown, 2008). In addition to these benefits, the absence of visual stimulus provides a richer experience that elicits "vivid mental images of events and recapturing lost moments" (Oleksik & Brown, 2008, p. 171).

Moreover, transforming sound into an observable three-dimensional form makes the experience of that sound multisensorial. Sound, as a source, creates a gap in the translation from the seeing to the hearing process, which leaves more room for personal expression.

The decision to use sound as a source for meaning-making led to research in *sound visualization* and *data physicalization* fields. The process of using sound and transforming it into visual forms is a highly active field (Barrass, 2011; Han et al., 2013; Hansen, 2013; Louvel, 2019; Melle, 2015; Niemantsverdriet & Versteeg, 2016), which utilizes computational tools to analyze audio waveforms and spectrum data. Also, studies that research the connection between sound and memories are found. Oleksik and Brown (2008) conducted an exploratory study by designing an audio recording device for sentimental memory capture. Their user studies resulted in the types of sounds people cherish the most. It is also found that sometimes not the sound recording itself but the associations of that sound with memories are more important. Niemantsverdriet and Versteeg (2016) designed a piece of interactive jewelry for memory cueing in the shape of a locket. From the psychological perspective, Janata et al. (2007) conducted a study that characterized music-evoked autobiographical memories over 329 participants. They found that familiar music evokes autobiographical memories to some extent, and most songs evoke emotional responses. Also, the evoked emotions are mostly related to positive ones. However, *this research mainly focuses on using sound-related memories to design artifact forms and establish a connection between the memories and the form. Thus, it aims to create a meaningful and valuable artifact connected to the person's memories.* The creation of meaning and value in the newly created artifacts, especially through their connections with the memories, has high potential in terms of establishing emotional bonding, thus, contributing to product longevity and sustainability measures. However, this research is focused on the design, development and implications of a method that enables those potentials to be fulfilled through the involvement of the user in the personalization process.

After exploring the research conducted in the field, I have found that *none of them primarily focused on the transformation moment* but instead on the results and their implications. For this transformation to become meaningful and valuable, it must be a process of *translation* in which the input-output difference and connection are understandable by the observer. For this transformation to become more accessible to the people who experience it, I have decided to *focus on the moment of transformation and search for ways to make the process understandable.*

Figure 1 on the next page shows the milestones of the research spanning through the years.

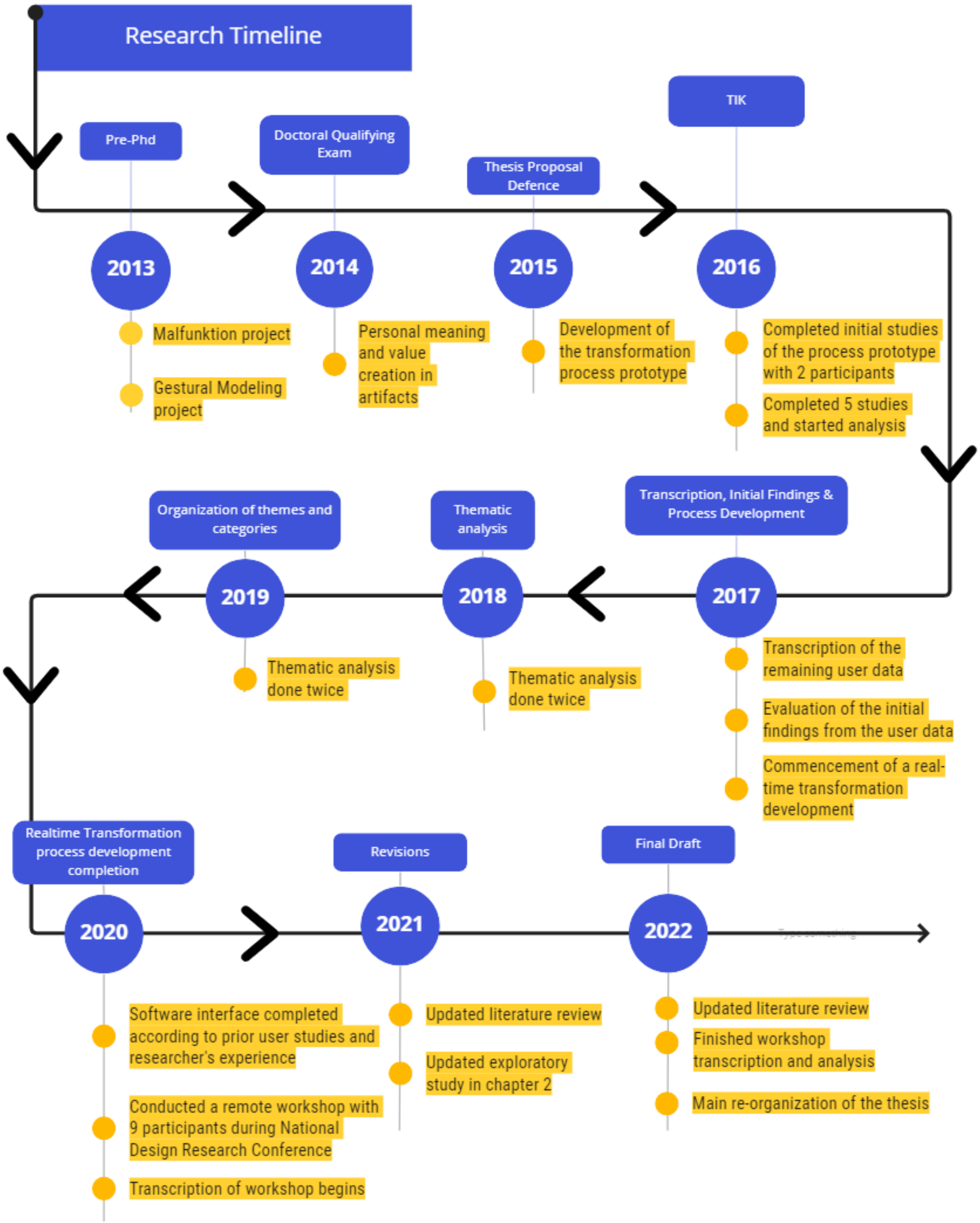


Figure 1.1 Milestones of the study

This study is concerned with designing and experimenting with a translation method that empowers users to convert emotionally engaging sound memories into artifacts.

After developing an initial process for the translation method, with research through co-designing adopting action and generative research approaches, this Ph.D. attempts to map the requirements and dimensions of the transformation process for creating meaningful and valuable artifacts that establish a connection with their makers/designers/possessors from the moment of their creation.

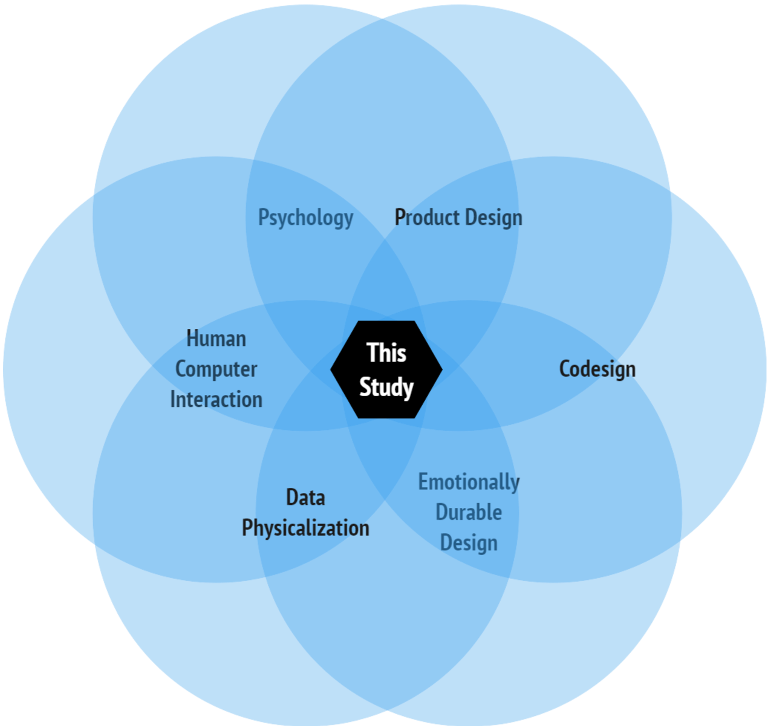


Figure 1.2 The placement of this study among different research areas.

This study gathers insights from different fields of expertise to design and test the translation method mentioned above. Figure 1 above illustrates how this study is situated with other research fields.

1.1 Significance of Research

In the last two decades, product lifecycles' importance has increased due to the environmental waste they cause. No longer "needed" products are discarded in junkyards, causing a significant amount of waste each year. More than half of the still functional products are thrown away just because they fail to create meaningful connections with their owners (Chapman, 2015, p. 25).

When a person forms emotional bonds with an artifact, s/he is less likely to throw that artifact away (Schifferstein & Zwartkruis-Pelgrim, 2008). Personal meanings related to artifacts increase the strength of individuals' emotional bonds with artifacts (Grosse-Hering et al., 2013). The meanings (private or public) surrounding the artifact are only perceivable by its possessor. These meanings (which might be related to many things such as loved ones, memories, deceased relatives, and places) take time to gather. In other words, these meanings and corresponding values emerge as the possessor invests his/her time into the artifact. However, condensing time into an object has not been possible since collecting memories around an object goes in sync with time. Involving users in the design process and empowering them in the making process increase the meaning and value of the artifact (Nissen & Bowers, 2015). The artifact's amplified value and meaning due to the unique bonds formed during its design/making or history with its owner expand its lifespan.

Memories are strong carriers when personal meaning and value are concerned (van den Hoven et al., 2021). The studies in various fields of HCI explore the use of narratives, data visualization, designing objects and processes for triggering memories, and memories in creating engaging, interactive experiences (Elsden et al., 2016; Lupton, 2015; Nissen & Bowers, 2015; Odom et al., 2012; van den Hoven, 2014; van Gennip et al., 2015). However, there is a gap between the before and after phases of transforming data into an artifact. In other words, how meanings related to memories and the end artifact are connected. During such transformation processes, the viewer has no idea about the connection between the input/output and how that transformation occurs. When the viewer does not understand how the transformation occurs, the result is no more than an artistic expression of the input data having an ambiguous connection with the source. Thus, the form and meaning become loosely connected, failing to exploit the full potential of meaning and value connection that emerged from memories.

1.2 Aim, Goal, and Research Questions

This Ph.D. aims to develop and investigate the dimensions of a transformation method that can create meaningful artifacts by using personally meaningful data, specifically focusing on sounds related to memories, into 3-dimensional forms.

This research has the following goals:

1. To explore how artifacts become personally meaningful and valuable to individuals and approaches that create this meaning and value
2. To analyze existing applications of various visualization methods of data as (physical or digital) artifacts to propose an initial prototype for transforming data into artifact forms through a co-design approach.
3. To develop a method for the transformation process and explore the dimensions of transformation by using *research through a co-designing* approach
4. Analyze the outcomes and implications of the method in developing the dimensions of transformation for creating meaningful and valuable objects.

Within the context above, this study asks the questions below to reach its goals:

1) What are the main design approaches for meaning and value and what would be the role of memories and personalization in creating personally meaningful and valuable artifacts?

2) How can data in the form of sound be transformed into artifacts by adopting the data physicalization approach? What would be the nature of user involvement in creating personally meaningful and valuable artifacts?

3) How can personal data (in particular: sound) be transformed into meaningful and valuable artifacts through research through a co-designing approach? What are the means of using sound data to create artifacts?

- What are the means of transforming personally meaningful sound data into artifacts?
- What are the design dimensions for enabling the transformation of sound into meaningful and valuable artifacts?
- How does the active participation of people in the design process (i.e., selecting intangible sources, transforming this source into a form, and getting feedback for the user experience regarding the process and outcome) impact the creation and understanding of meaning for the process and the resulting artifact?

1.3 Structure of Thesis

Chapter 2 provides the theoretical background for the study, consisting of surveys on the meaning and value of artifacts and their connections with memories, followed by exploratory research on using data as design material. With my experience before my Ph.D. studies, this chapter provides a ground for the next phase. Chapter 3 introduces primary studies with a prototype transformation process of memory-connected sound data into artifacts. Chapter 4 evaluates the initial user studies using thematic analysis, and the issues in the initial prototype are discussed. Chapter 5 presents the thematic analysis results under themes and categories. Based on the evaluation results and the shortcomings of the prototype. In Chapter 6, an interactive transformation process developed according to the findings of the previous chapter is presented. The developed method is tested in a workshop (remotely conducted due to the COVID-19 pandemic) at the UTAK conference, and its results are evaluated. Chapter 7 presents the main contributions of this thesis with answers to the research questions.

CHAPTER 2

LITERATURE REVIEW

> "We are mysterious creatures who mark our time on earth through tangible remembrances. We transform time itself, as it were, into tangible space through our makings and doings, personalizing our environment while objectifying ourselves." (Rochberg-Halton 1986, 188)

This research pursues new ways of creating artifacts that are representations of ourselves. In a world that is becoming increasingly digital, the ways we make things are getting digital. This digital transformation has advantages as well as disadvantages. Digitizing our memories and personal information can cause security and privacy issues. However, at the same time, they can be used as a material for new design flows and manufacturing processes. Different kinds of data can be used as a source of meaning and value. This literature research aims to understand how meaning and value emerge in objects (sections 2.2 and 2.3). The following sections provide the theoretical framework to understand the meaning and value-led approaches to design and how emotional bonding can be established with the artifacts (section 2.4), the connection of memories with meaning in artifacts (section 2.5), using memories and data as materials for design (section 2.8), and ways of translating data into artifacts (section 2.7).

2.1 Background

As mass manufacturing technologies, systems, and processes are perfected, the artifacts we own and share become more standardized. Although we obtained predictability and consistency at the price of uniformity, at some point, the aesthetics of these artifacts became so predictable that they inevitably became boring (Dogan

& Walker, 2008). Hinte argues that the modernist focus on function decreases the importance of an artifact's characteristics (1997, p.103). Also, this rendered attachment to products obsolete by leading "us away from matter towards the idea of function" (Hinte, 1997, p.104). We owned things that were not meant for our uniqueness and character but standardized and imaginary users representing the average opinion of the masses. The only way to make that artifact ours is to spend time with them, building memories and experiences around them.

The arrival of Japanese products in the US market in the 1970s led to a realization of mass manufacturing's shortcomings, such as being unable to address the individual needs of the consumers (Hu, 2013, p.5). Companies that utilize mass manufacturing methods started using individualization methods to meet the unmet needs of consumers and gain a competitive advantage (Hu, 2013).

Aiming for competitive advantage by addressing the individualized needs of consumers leads to customization and personalization concepts, which are hard to separate from each other (Sel, 2013). Some sources used them interchangeably, but this also depends on their perspective. Marketing, manufacturing, industrial design, and design for longevity fields have varying approaches to these concepts. The common perspective of these different fields are summarized in Table 1 (adapted from Avci, 2019 and Sel, 2013), and then the definition of personalization in this thesis is presented.

Table 2.1 Differences between personalization and customization (adapted from Avci, 2019 and Sel, 2013)

Statement	Personalization	Customization
	an umbrella term for intervention to products at different levels	one of the paths to personalization
The Customer/User is:	the design authority	the design chooser

Table 2.1 (Continued)

Performance	The user defines, modifies, or adapts a product's aesthetic or functional attributes to fit personal preferences	The user selects from a set of pre-defined options or combines modules related to personal preferences
Performer:	the user	manufacturer- initiated, but the customer is the performer
Solution space	a specific individual	a specific individual intersecting with flexible product design constraints
Result	increased attachment, increased personal relevance	meeting customer needs with near-mass manufacturing efficiency, increased competitive advantage, and sales

Personalization involves an artifact's aesthetic and functional attributes in the above definitions. It is argued by Janiszewski, Kaiser, and Schreier (2017, p. 817) that aesthetic properties are more critical in creating personal meaning and attachment, and changing the core functional attributes of a product can be challenging. Furthermore, it is argued that aesthetic choices are "easier to imagine and elaborate than functional choices" (Adzhiev et al., 2018, p.377). Also, it is found that users with a need for a deeper level of uniqueness and that are more sensitive towards aesthetics are more satisfied with the final product (Adzhiev et al., 2018, p.380).

With advancing technology in manufacturing systems (such as additive manufacturing), and research, these limited customization systems started to transform into specialized personalization systems (Hu, 2013; Turner et al., 2020). Personalization options presented in such systems are generally limited to various properties such as color, material, texture, and engraving. Hermans (2012) compares the level of personalization such as functional, ergonomic, and aesthetic, each having sub-categories, and argues that these can influence each other.

Another study's findings outline seven dimensions of personalization: mental effort, physical effort, flexibility, initiation, the goal of product personalization,

personalization moment, and deliberateness (Mugge, Schoormans, & Schifferstein, 2009). Mental effort is related to the amount of *creative involvement,* whereas physical involvement is related to the physical involvement of the user in the personalization process. This study proposes a method in which the user is mentally and physically involved in the personalization. The flexibility dimension means the affordance of the product/artifact to multiple times of personalization. The initiation dimension concerns whether the designer or the consumer initiates the personalization process. Although the user studies conducted through the thesis had the researcher's supervision, the proposed method allows users to realize personalization unattended. The goal of personalization is related to whether the driving force behind personalization is *utility-related* or *appearance-related.* This study focuses on creating meaningful forms connected to memories and thus has an appearance-related personalization goal. Personalization moment is related to whether the personalization takes place before purchase, before usage, or during usage. This study focuses explicitly on before-purchasing and before-usage periods. The seventh dimension, deliberateness, is related to the intentional personalization of the artifact, separating the personalization from aging over time or marks that happen unintentionally on the object's surface. This study focuses on users having complete control over the form creation, allowing them to personalize the form according to their preferences related to their memories.

In Hermans' later work, he proposes a toolkit that empowers the "layperson" to "personify" a product (Hermans, 2015). Studies and initiatives based on generative systems output unique iterations of a predetermined design system, empowering users to create *unique* versions of a product or adjust dimensions and forms to fit their needs (H. Zhao et al., 2019a). Although there are theories on how to create systems for personalization, most provide no information about the effectiveness of those methods and theories (H. Zhao et al., 2019a, p. 14). The dimensions of the personalization process are explored more thoroughly in the 2.3.4 Dimensions of Personalization section.

In this thesis, the term *artifact* is specifically used to ignore an object's financial and marketing value and focus solely on its meaning and value. Thus, after this initial core value transfer is understood, the applications of the methods developed can be transferred into other fields, from product design and marketing to manufacturing. For this reason, in this thesis, a more general definition of the term *personalization* is adopted from Blom (2000, p.313) with a focus on the creation of artifacts rather than systems, and defined as *"a process that re-creates or alters the visual or mental appearance, the functionality, meaning or distinctiveness of an artifact to increase its relevance to an individual."* The personalization process in this study involves the active participation of users in the form-creation process that the designer supervises. Although the personalization concept has connections with pre and post-purchase behaviors, the method developed here is intended for *before* using any artifact.

After the initial inspiration from Malfunktion (Alpay, 2013a) and Gestural Modeling projects mentioned in the Introduction section, various searches on the Internet and academic sources have been conducted to develop the initial ideas further. During the research phase, a Ph.D. journal is kept to take notes on relevant examples and applications related to sound and form generation. Initially, I focused on the examples provided by additive manufacturing services such as shapeways.com, i.materialise.com, and sculpteo.com. In addition to application examples, I also conducted software-related research concerning new software tools, plugins, and tutorials that can help me develop the initial ideas I generated from the two studies mentioned above. The primary sources during the software and tool-based research were

- Grasshopper3d.com: the website of a parametric design addon for Rhinoceros 3D software that contains the plugin and related documentation
- food4rhino.net: parametric plugins that extend the capabilities of Grasshopper for Rhinoceros 3D
- Processing.org: an open-source programming environment that lets the creation of audiovisual works that are generated by code

In addition to the sources above, blog entries, other software tutorials, and creativeapplications.net (a website where projects realized with the fusion of coding, art, and design are presented) are scanned. While looking at the sources mentioned above, the main keywords used were: *audio, sound, visualization, memory, audiovisual, additive manufacturing, 3d printing*. Through the search results, the ones that have a relation to personal meaning and memories have been selected. In the beginning, the selected examples range was too diverse, and academic work in this field was not common. However, after realizing the existence of the data physicalization field, more academic examples have been found, and the included examples in this thesis have been revised. The focus of the examples' domain is narrowed down to those incorporating data translation from an intangible domain to a tangible domain and personal meaning creation potential. Also, an extensive and continuously updated online data physicalization collection (Data Physicalization Wiki) prepared by Dragicevic & Jansen has been found (Dragicevic & Jansen, 2021). In addition, a Google Scholar search with the keywords *data physicalization* is conducted to extract possible additions into the examples section. The most important inclusion criterion is whether the example embodies personal/public meaning or has the potential to be used for the embodiment of such meanings. Therefore, among the examples found the ones that are related to

- inclusion of personal data or meaning source for the creation of the artifact
- involves co-design, including the user in the design process
- creation of artifacts with private and/or public meanings
- ways of creating artifacts that create or increase attachment/bonding

were included in the thesis. Examples narrowed down from the previous research and those from Data Physicalization Wiki are presented and discussed in the 2.9 Data Physicalization Examples section. In parallel to the application examples research, a literature search on meaning, value (section 2.2), and memories (section

2.4) are conducted to understand how personal meaning and value are manifested in artifacts and the function of memories in this manifestation process.

2.2 Meaning in Artifacts

From the semiotics perspective, meaning is an observer's interpretation of an observable possession according to some rules in a particular context (Richins, 1994, p. 505). Csikszentmihalyi's findings on the household artifacts' meaning point to a solid symbolic value originating from our relationships with these artifacts (Csikszentmihalyi, 1991). Csikszentmihalyi (1991, p. 34) explains the elements of meanings in our daily lives as

> "…an old china cup, a houseplant, a ring, or a family photograph has symbolic power if it produces a sense of order in the mind. This happens when the owner, in seeing the artifact, feels that: his or her desires are in harmony; his or her goals might be reached; the past and the future are related in a sensible way; that the people who are close to them are worthy of love and love them in return. Without such feelings, life is not worth living. The artifacts we surround ourselves with are the concrete symbols that convey these messages. The meaning of our private lives is built with these household artifacts."

Gosden and Marshall state that artifacts (products) are not invested in meaning by themselves but with "social interactions they are caught up in" (Gosden & Marshall, 1999, p. 170). Then the meaning emerges from these interactions. These social interactions construct the notion of the biography of artifacts, which starts with Kopytoff (1986), who argues that none of the artifacts can be understood in isolation. Instead, their production, exchange, and consumption cycles should be considered. Artifacts can also accumulate other meanings by becoming the signifiers of connections to people and events. According to Gosden and Marshall, gaining new meanings or values can happen without any physical change to the artifact itself (1999). As Gosden and Marshall state in *Cultural Biography of Artifacts* (1999, p. 174) and cited in Hanson (2010, p. 1):

> "…as people and artifacts gather time, movement, and change, they are constantly transformed and these transformations of person and artifacts are tied up with each other. "

Therefore, even without changing the physical attributes of an artifact, time can cause a change in meaning. The transformations and context changes also change the meaning and value of the artifact. Thus, a biography of the artifact is needed to fully understand its meaning and value (Kopytoff, 1986; Tilley et al., 2006).

In addition to the culturally existing meanings, new meanings can be associated with existing artifacts. McCracken argues that the advertising industry is "unhooking" the culturally constituted meaning from the artifact and transferring them to old or new artifacts through advertisements (1986, p. 76). Advertising (and marketing) assigns new meanings to old and new artifacts (Timur, 2022, p.360). On the other hand, McCracken argues that the "fashion system" uses a more complex workflow in which "agents of transfer" and "media of communication" (McCracken, 1986, p. 76). As exemplified by McCracken, in consumer culture, the ways of change occur by the transfer of existing meanings through advertising and the invention of new meanings through opinion leaders. Although this thesis does not aim to develop a method involving fashion or opinion leaders, it is important to understand the social dynamics of how these meanings live in society. This understanding especially becomes important when private and public meanings are discussed in the following sections.

When the artifacts we keep in our homes are considered, even old and aesthetically unpleasant artifacts can continue to exist because of their accumulated meanings (Csikszentmihalyi 1991). These things can remind us of our accomplishments, deceased relatives or loved ones, important personal ties, or people who made them. For instance, one participant of Csikszentmihalyi's study (1991) sees "an image of"… "a capable, successful businessperson" when looking at a cheap replica of Venus. This accomplishment feeling comes from the statue's story: that statue was given to her as a prize for the amount of merchandise she sold. Similarly, when graphic artworks were considered in the same study, only 16 percent of the participants were into how the pictures looked. For the rest of the participants, the visual appearance was not significant. The essential things for them were memories (sixteen percent), reminiscent of family members (seventeen percent), or friends (thirteen percent). Thus, the appearance of the artifact alone cannot be evaluated. Truckenbrod defines the connection between artifact and meaning: “Objects are powerful cultural artifacts and icons, embedded with highly charged symbols with social and personal meanings” (2012, p. 1). Thus, objects can be interpreted as symbols for memories and the things they represent.

Similar to Csikszentmihalyi’s study, as Desmet and Hekkert (2007) exemplify, a record player can be a reminder of a childhood memory. The design of the artifact itself can be related to the meaning. In contrast, other factors such as price, advertisements, opinions of others, and prior experiences (Desmet & Hekkert, 2007) can cause a relational meaning to emerge. Desmet and Hekkert argue that these meanings related to artifacts (products) will differ since different people interpret them. Therefore, as the authors state, those meanings will cause different emotional responses.

Mugge (2007) outlines why people consider their possessions meaningful by categorizing studies conducted by several consumer behavior researchers (Furby, Kamptner, Csikszentmihalyi and Rochberg-Halton, Dittmar, Hirschman and LaBarbera, Richins, Dyl and Wapner, Prentice as cited in Mugge 2007, p.27). Mugge (2007) outlines them regarding *product attachment* and includes terms from previous research such as “treasured,” “special,” “important,” and “favorite.” Artifacts become meaningful because they (Mugge, 2007, p. 27):

- Express or reinforce identity,
- Represent ties with other people,
- Symbolize personal history,
- Include intrinsic qualities that include meanings related to their physical properties
- Are functional / have utilitarian meaning,

- Evoke enjoyment or sensory pleasure,
- Have finance-related meanings such as price,
- Have cultural-religious meanings, and
- Have human qualities and personalities.

Among the meaning sources above, the ones that are closely related to this research are adapted below:

- Identity expression
- Representation of interpersonal ties
- Evoking of enjoyment
- Symbols for personal history
- Symbols for cultural-religious meanings
- Symbols for human qualities and personalities

Although there are different sources for meaning in artifacts, the ones adapted above are related to the properties beyond an artifact's financial and utilitarian value. Also, they are the ones that memories might trigger since the memories can have connections to identity (Bursan, 2011; Richins, 1994; Csikszentmihalyi, 1981; Bechler and Wheeler, 2021), interpersonal ties (Richins, 1994; Csikszentmihalyi, 1981), enjoyment (Zijlema, 2018, p.111), personal history (Durrant et al., 2016; van Gennip et al., 2015; Zijlema, 2018), symbols for cultural or religious meanings (Ahde-Deal et al., 2017; Mead and Baumeister, 2021; Walker, 2006).

This research is interested in the type of meaning that creates value from the connections with memories so that the owner of that item becomes willing to keep it. Therefore, the six sources of meaning listed above are focused on in this research. In product design literature, bonding to an artifact is called product attachment and is strongly related to the focus of this thesis. Literature around product attachment is presented in more detail in section 2.4.3.

From the psychological perspective, things we make today serve us to improve our lives and "stabilize and order the mind" (Csikszentmihalyi 1993, p.23). They help to objectify the self by first demonstrating the owner's power and place in a social hierarchy and then revealing and positioning oneself through time. They act as reminders of the past and indicate things desired to happen in the future. Furthermore, they are solid evidence of a person's place in a social network signifying valued relationships (Csikszentmihalyi, 1993). In the ways mentioned above, "things stabilize our sense of who we are; they give a permanent shape to our views of ourselves that otherwise would quickly dissolve in the flux of consciousness" (Csikszentmihalyi, 1993, p. 23). Things also help support the sense of self by creating an *extended self* (Belk, 1988; Mugge, 2007; Tian and Belk, 2005). Thus, artifacts have meanings as personal reminders of whom we are (Mugge, 2007), and they become extensions of the self from the perspectives of psychology, consumer research, and material culture (Mittal, 2006; Mugge, 2007; Schifferstein & Zwartkruis-Pelgrim, 2008; Tian & Belk, 2005).

2.2.1 Interconnection of Meanings

The connections between an artifact's meaning and the collective interpretation create metaphors, personality, or other expressive characteristics (Desmet & Hekkert, 2007). By recognizing these, "we assess the personal or symbolic significance of products" (Desmet & Hekkert, 2007, p. 62), e.g., a car resembling a shark or a nostalgic teddy bear. Banks, Kirk, and Sellen (2012, p. 69) argue that sentimental artifacts become sentimental since artifacts reach beyond their borders, embodying associations with other things. Usually, this is their connection with memories and feelings (Banks et al., 2012). Thus, the object starts to have a web of connections that carry it into a different level of existence, making it sentimental.

Accordingly, as people and artifacts are transported from one place to another through time, they are "constantly transformed, and these transformations of persons and artifacts are tied up with each other" (Hanson, 2010, p. 1). Therefore, as the time spent with an artifact increases, the potential for forming meaningful connections increases; in other words, an increased time frame causes an expansion of artifact-meaning space.

2.2.2 Irreplaceability of Meaning and Artifact

Irreplaceable artifacts are those that people resist replacing since they feel that the new one will not carry the same meaning as the original (Grayson & Shulman, 2000, p. 17). Artifacts become irreplaceable when a genuine connection exists between the artifact's meaning and itself (Mugge, 2007). In Schifferstein's words, the artifact "has a symbolic meaning to its owner that is not present in other products, even when they are physically identical" (Schifferstein & Zwartkruis-Pelgrim, 2008, p. 2). Raz (2001) argues that the shared history with an artifact makes the possessor's relation to the artifact unique and thus irreplaceable. An artifact perceptually being de facto unique can be important for its irreplaceability since it is very improbable to acquire another artifact with precisely the same appearance. However, logical uniqueness may be as important as the other, and having a common history with the artifact is the only way of achieving it (Raz, 2004, p.23). The author gives an example of *irreplaceability* from parents' attachment to their first child. The parents' experience of their first child makes their attachment special and "gives it a flavor no other can have for them" (Raz, 2004, p.26).

2.2.3 Private and Public Meaning

According to Richins (1994), private (personal) meanings arise from personal experiences with possessions, and artifacts collect these subjective meanings. The private meanings arise from a personal experience with possessions. Although they can contain public meanings, the possessor's personal history with the object has an important role. If the artifact is likely to afford "personally tailored experiences," there is a greater chance of constructing *private meanings* (Richins, 1994, p. 517).

On the other hand, the public meaning of an artifact is the collection of the subjective meanings of society on that artifact. These meanings are constructed as a result of consensuses in society. Since public and private meanings do not emerge from a single source, there is also a *multidimensionality of meaning,* as Richins (1994) argues. A pair of diamond earrings, for instance, can have meaning in different dimensions, such as symbolic meaning as a gift from a husband on a wedding anniversary, a shared meaning on the financial worth of diamonds, and some private meanings that only the owner knows. Although private and public meanings seem different sources, Richins' study (1994) argues that many overlapping areas make it hard to separate. This study and the transformation method developed lean towards private meanings. However, depending on users' choice of memories and how they are communicated through the artifact, public meanings can affect the final interpretation of the artifact. For example, a collective memory such as a moment from a volleyball competition can create meanings for all the competing teammates so that it becomes a mixture of public and private meanings. Also, the transformation of an anthem, which can have connections to public memories, into an artifact form can create a symbolic object with many private meanings attached to it and a common public meaning that rises from the common symbolic meaning of the anthem for society.

Meanings develop throughout a "common history and work" with an artifact (Raz, 2001, p. 20). Although *cultural meanings* are attached to the artifacts, the individuals' experience (common history and work) makes the artifact's meaning unique to the owner. Raz (2001) exemplifies his arguments over Antoine de Saint-Exupéry's Little Prince, who, at first glance, loves a rose just because of its appearance. However, the prince later discovers that there are many identical roses. He later understands that what makes that rose "his" is the shared history he spends with it because it transforms into an entity that embodies all the meanings it gained through his experience with it. The author also argues that although perceptible qualities of objects can cause a unique value, visual qualities alone sometimes might fail to create uniqueness. In those times, the shared history with an artifact can ensure uniqueness.

Reflecting upon the author's description, as someone spends time with an artifact, its meanings increase with its description.

While the historical description correlates with uniqueness and value, uniqueness can be the source of value because it can differentiate oneself in society. Symbolic meanings related to a product can alter the self-image by transferring those symbolic meanings to the self (Timur, 2022, p.358). In her Modes of Representation article, Timur (2022, p.359) classifies three modes of representation as *iconic*, *indexical,* and *symbolic*. She argues that they operate in visceral, behavioral, and reflective processing levels and are related to *instincts, body (function),* and *mind (meaning)* in the same order. Among these representation modes, symbolic signs are the focus of this research since they are processed in the mind to create meaning and connect with thinking, evaluation, analysis, responsibility, and memory.

The products' symbols and meanings should be publicly recognizable to enhance the self-image (K. T. Tian et al., 2001, p. 52). The authors' (2001) perspective is more from the consumer side, involving public meanings and values. In contrast, Raz's (2001) value under the historical description concept is from the perspective of personal meanings related to artifacts and creates value through the shared history with the artifact. When the two views are compared, the first one uses the accumulated values that exist culturally, exploiting public value to enhance self-image. The second view remains in the personal domain in which the created value and meaning exist within the person that assigns the meaning.

2.3 Value of Artifacts

Although an economic value can be given to many artifacts, it is also believed that this value cannot fully account for the value of many artifacts owned by consumers (Richins, 1994). The author exemplifies this with a man owning a photo of his deceased wife and argues that the possessed is not the physical artifact or photograph but the memories and experiences. Since experiences and memories cannot be bought with monetary value (at least with the technological affordances of today), asking that man for the price of the photograph would be meaningless. Thus, some artifacts contain meanings and values that grow over time as memories and experiences are gathered. This example can be further developed from cases with heirlooms. The price of a watch that can still be bought from a shop cannot compare to the worth of a watch gifted by a relative who is no longer alive. This thesis does not consider the value in terms of financial value. Value in terms of *meaning* is meant where the term *valuable* is used.

Many researchers argue that the value of possessions is acquired from meanings (Adler et al., 1983; Baudrillard, 1981; Douglas & Isherwood, 1996; Richins, 1994), and meanings emerge from our connections to the external world through memories. Also, the value of an artifact is not an intrinsic property, yet judgments the subjects make about artifacts give them value (Simmel, 2004).

An artifact's value depends on its meaning, which can change over time. Thus, the value of possession can vary over time due to changes in meaning (Karanika and Hogg, 2012). The variations are classified under three different "trajectories" by Karanika and Hogg (2012):

- Possessions of rising value to the self
- Possessions of declining value to the self
- Possessions of steady value to the self

As the individual spends time with the possession, more and more meanings are accumulated in the product, thus making it more valuable for the owner. Similarly, Csikszentmihalyi (2002, 8) discusses the value of an artifact in terms of the lifetime that is captured by the artifact. The artifact maker invests his/her life into the artifact, thus giving his/her lifetime to the artifact. Then that artifact becomes valuable since it embodies a certain period of life of its maker. On the other hand, the possessor also invests a portion of his/her lifetime in the artifact. Thus, its value increases as the possession represents more of a lifetime or related memories. Examples of possessions of rising value to the self were given in Karanika and Hogg's study as baby clothes, possessions related to family members and loved ones, jewelry, gifts, and things that represent “associations with important others and the preservation and maintenance of interpersonal and intergenerational ties” (Karanika & Hogg, 2012, p. 3). Such possessions are generally classified as “irreplaceable.” After an increase in the artifact's meaning, usage of it is often terminated and taken to a safe place by its possessor to prevent loss. Also, these artifacts *preserve their value* even though they lose their aesthetic beauty or function while becoming “strong markers of memory” (Karanika & Hogg, 2012, p. 3).

Karanika and Hogg (2012) state that possessions of *declining value* are divided into possessions associated with standing out/positive distinction and those associated with autonomy/control. In the study, an example of a contact lens is given that maintains a positive distinction, such as feeling beautiful. Fashionable accessories are possessions that lose value over time as possessors get used to them or the distinctions from their newness diminish over time.

One of the sources of value in Karanika and Hogg’s study that have *enduring value* is the possessions used for recreational reasons. The possessions valued for recreation often are: “music CDs, musical players, pianos, books, movies, county houses and equipment related to hobbies such as riding, tennis, painting, gardening or pottery” (2012, 5). Another type of possession with enduring value is physical and financial security. The examples of such possessions are given as follows:

> “…organic healthy products, exercise-related items, medication, religiously linked for possessions such as crosses and chains and the Bible, items used for educational or professional reasons such as books and PCs, houses and mobile phones for the sense of security…” (Karanika & Hogg, 2012, p. 5)

Possessions related to connections to loved ones are also categorized as having a constant value. Connection types exemplify marriage, motherhood, and engagement to be married. Examples of these connections' possessions are “engagement and wedding rings, jewelry gifts or self-gifts to celebrate the birth of a son or daughter.” Such possessions mainly represent positive feelings and are “valued intensively from the acquisition onwards" (Karanika and Hogg, 2012, 5). Artifacts can also create mutual relationships with people through which they gain and give value:

> The fame of artifacts and the renown of people are mutually creating, so that artifacts gain value through links to powerful people and an individual's standing is enhanced through possession of well-known artifacts. There is a mutual process of value creation between people and things (Gosden & Marshall, 1999, p. 16).

The unwillingness to "swap pets, wedding rings or children, even when the alternative offered is demonstrably superior to our own" is caused by this strong bond between meaning and value (Richins, 1994, p. 505).

According to Csikszentmihalyi's research (1993), different age groups value different possessions. Young people value things according to the artifact's current interaction potential, whereas their parents (adults) have a more balanced distribution among past, present, and future. They value things from the past as mementos, signifiers of relations with family members and loved ones. Older people are more into the meanings and memories of the past, especially valuing photographs and things that evoke memories. However, they still cherish things from the present and future (Csikszentmihalyi 1993). Time-range difference and time direction are evident as a difference between young, adult, and elderly participants. Younger participants are more focused on the present, adults span more equally between past-present-future, and the elderly are more focused on the past.

2.4 Meaning and Value-Led Approaches to Designing Artifacts

2.4.1 Sensing the Artifact

Desmet and Hekkert's Product Experience Framework presents a flow that explains the generation of meaning by connecting the perception of an artifact to the cognitive processes that result in an emotional experience (Desmet & Hekkert, 2007). The product experience framework explains the path from experiencing an input that can be perceived with our senses to the emergence of emotions through the meaning-making process. Experience of an artifact (the authors use the term *product*, but the term *artifact* is used to establish a coherent flow throughout the thesis) starts with an aesthetic experience. It is defined as an artifact's "capacity to delight one or more of our sensory modalities" (Desmet & Hekkert, 2007, p. 59). Physical properties detected by our five senses are inputs for this experience, requiring no cognitive processing. For example, a product that: is beautiful to look at, makes a pleasant sound, feels good to touch, and smells nice.

The meaning-making process starts in the cognitive domain, and through interpretation, memory retrieval, and associations, it leads to the recognition of metaphors, personality assignments, and artifacts' expressive characteristics. However, this process is vulnerable to cultural and individual differences (Crilly et al., 2004; Desmet & Hekkert, 2007). Thus, the emergent meanings resulting from this process can be very subjective and different from one person to another.

The *product experience framework*'s emotion level results from the cognitive process in the *experience of meaning* stage. Therefore, "contrary to popular belief, an emotion is thus the result of a cognitive, though often automatic and unconscious, process." (Desmet and Hekkert, 2007, 61). Emotional experiences drive us towards or from the artifact according to the "appraisals." If the result of the emotional experience is felt to be beneficial, the appraisal moves us toward the artifact. If detriment is felt, the appraisal pulls us back from the artifact.

The following example sums up the different experiences mentioned in the paragraphs above: According to the framework, a Chinese teacup purchased on a China trip can evoke an *aesthetic experience* from its fragile lid's sound when placed on the mug. The cup can elicit attachment since it represents the person's trip to China (*experience of meaning*). The third level of the framework, *emotional experience*, is exemplified by the satisfaction the person experiences from discovering the perfect match of his drinking needs and the size of the cup (Desmet & Hekkert, 2007, p. 59).

2.4.2 Emotionally Durable Design

Every day, we are bombarded with shinier objects than we already own. "Like an itch that can never be scratched," the search for self-expression is never-ending (Chapman, 2012, p. 30). Still, material consumption is far more complex than the desire to acquire new and shinier objects. It is more related to realizing an "ideal or desired self." In *Emotionally Durable Design* (Chapman, 2012), *need* is explained with the sense of *lack*. Consumption is founded on this feeling, feeling the absence of something that is not there. Thus, after having something, the self searches for the next lacking thing, causing a loss of value as soon as that is acquired. This loss of value usually becomes the reason for thrown-away products, although they are still functional. Among all different types of needs, Chapman (2012) argues that "meaning" is the least researched and the most complex need since it is affected by the consumer's previous experiences and the context of the subject.

Design for emotional durability is a user-centric approach aiming to increase the longevity of products/artifacts that we use. The complex emotional relationships between reasons for the usage, consumption, and disposal of products are explored to reach this aim. By examining these relations and understanding why some products are discarded before they cease functioning, emotionally durable design (EDD) aims to increase product lifetimes, thus reducing the waste of valuable natural resources (Chapman et al., 2018, p. 2). The authors argue that the physical life of a product is significant, and the psychological lifetime should be considered if we want to design products that are desired to be kept.

Chapman (2012, p. 18) paints a perfect picture of our relationship with products in his book and imagines a future free of "obsolescence, waste, and serial dissatisfaction" related to products. He suggests a relationship with "attachment, evolution, and mutual growth." He criticizes the throwaway culture and indicates that we should be developing *emotionally durable objects and experiences*.

In a later article, for ways of establishing emotional longevity, the authors summarize different strategies to establish product attachment as follows (Chapman et al., 2018):

- Memories / Longevity / Nostalgia
- Pleasure
- Enjoyment
- Self-expression / Support self-identity
- Usability
- Sensory Design
- Superior Appearance
- Utility & Reliability
- Product Personality
- Group Affiliation

As mentioned by other scholars in the previous sections, using memories is one of the ways to create meaning and connection between the artifacts and the user. The role of memories is also mentioned in emotionally durable design as one of the ways of providing meaning and value that can increase the psychological life of a product. The 2.4 *Role of Memories in Meaning Creation* section explains their potential to create meaning in more detail.

2.4.3 Product Attachment

Schifferstein and Pelgrim define the degree of product attachment as “the strength of the emotional bond a consumer experiences with a durable product” (2008, p. 1). According to Raz (2001, p. 16), meanings arise from the objects we feel attached to and their association with other things. However, it is not always the case, as some of our attachments lack value. His argument is not only based on artifacts but also individuals. Raz’s definition of attachment assumes that the attachment is worthwhile to form and keep. Thus, attachment is not like an addiction that the addict knows is not a good or worthwhile habit but cannot help himself/herself free of that addiction. Moreover, “our attachments are endorsed by us, which means that they are seen as valuable” (Raz, 2001, p. 17).

From Raz’s arguments on becoming attached to things that an individual finds worthwhile and meaningful, it can be deduced that the things (artifacts that the person becomes attached to) have value and meanings for the attached person. When the attachment is related to artifacts that connect with the possessor's identity, they are less likely to be discarded (Bechler and Wheeler, 2021, p. 6).

The unique value of the artifact is not the sole reason for valuing it or forming an attachment to it. If so, we could quickly become attached to another artifact because it was unique. Instead, it is the artifact under the historical description, e.g., “my first child” (Raz, 2001, 28). Reflecting on Raz’s (2001) arguments, as individuals interact with artifacts, the chance of bonding between the person and the artifact increases since that person starts to spend time with the artifact. It is important to note that spending more time does not guarantee the chance of bonding but only increases the chance of bonding. Also, this might not always be preferred since the time spent can be related to the artifact’s problem or a reminder of difficult times. Still, from my personal experience, artifacts that remind me of the hard times I have been through can have another type of special meaning for me. However, that is not in the scope of this thesis.

The product design field has developed ways of creating products closer to the users’ needs. Mass customization, advancing manufacturing technologies, and design methods allowed for meeting users’ needs with existing manufacturing methods. This way, it is aimed to increase the value given by the user to the artifact and induce attachment. Examples of these methods are explored in the following section.

2.4.4 Product Personalization

More than two decades ago, Fischer and Scharff (2000, p. 1) argued that the invention and design of mediums humans could use to express themselves and engage in meaning creation is a challenging area. The main limiting factor behind this was the perception of humans primarily as consumers (ibid, p1). In the last two decades, many advancements in the design field allowed the co-creation of personalized artifacts (H. Zhao et al., 2019c, p. 181). With the emergence of digital tools, users become more empowered to become their designers through the systems designed around personalization needs. However, not all types of personalization offer the same amount of control to the user. Also, leaving too much to the user or presenting too many options can overwhelm the user (H. Zhao et al., 2019b, p. 182). Some only include texturing, coloring, and combining modularly prepared design options. In contrast, some offer parametric interfaces like the Nervous System's Kinematics application (Figure 2).

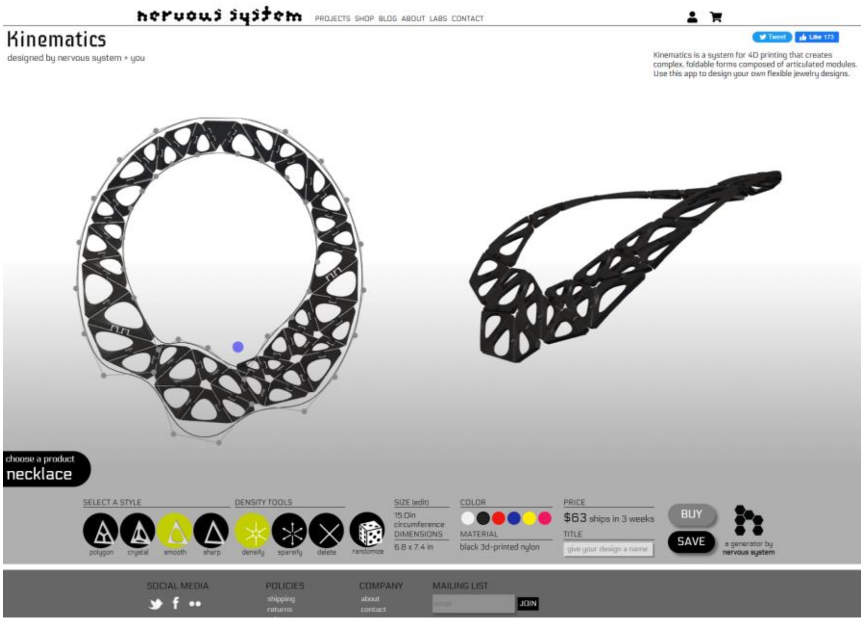


Figure 2.1 Nervous System Kinematics Interface (Rosenkrantz & Rosenberg, 2014b).

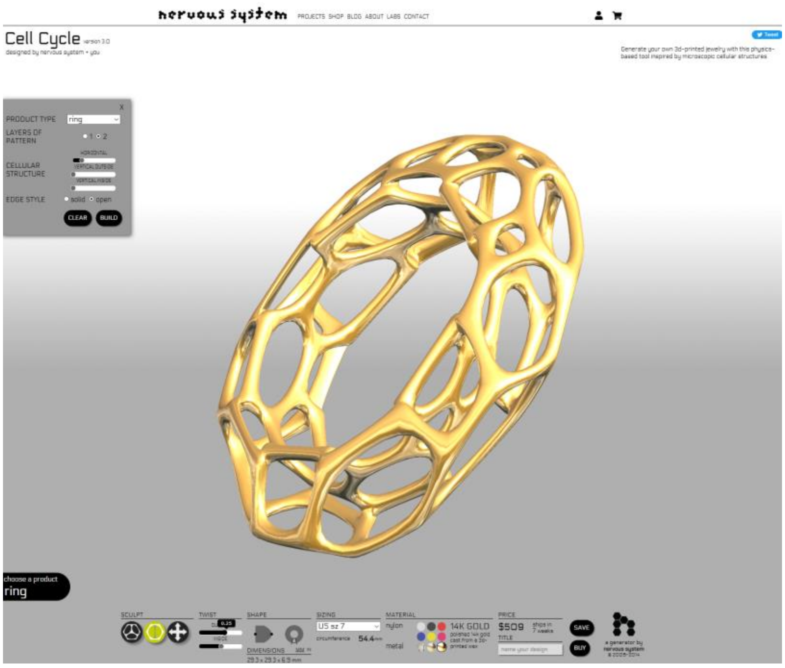


Figure 2.2 Nervous System Cell-Cyle Interface (Rosenkrantz & Rosenberg, 2014a).

Nervous System designers use a custom-developed interface that lets users personalize products according to their preferences, such as diameter, cell division amount, and shape. Upon completing the desired product, the user can order the finished piece through the online 3D printing service shapeways.com. Then the product becomes the physical representation of the user's intention (within the borders drawn by the system's designers).

Zhao et al.(2018) argue that Nervous System's applications allow a higher degree of personalization than other systems mentioned in the article since it generates the form through interactive algorithms. Still, the user is kept inside the visual and formal language created by the designers/coders. No matter what the user wants, this becomes the only way the forms appear. This limitation becomes a *virtual cage* coded into the generative system. It enables the creation of personalizable artifacts that keep the generated form's visual language no matter how far the user personalizes the form. This protection of the core design intent can also ensure that the generated designs are manufacturable. In addition, users being able to personalize the form of an artifact without destroying the visual language (assuming that visual language is what attracts the user in the first place) can provide a safe zone where the user can do whatever s/he wants; within the borders of the personalization system.

There are different methods and examples of personalization systems, each with a different solution space and degrees of personalization (Ling et al., 2020; H. Zhao et al., 2018, 2019c, 2019a, 2019b). Hermans (2012) categorizes personalization mechanisms into four main types: veneer, modularity, parametric and generative. These mechanisms are in a circular quadrant graph (Figure 4) and depicted in the core and outer layers. Core layers represent product attributes such as function, features, and structure, whereas the outer layers represent material, shape, dimensions, and skin. Figure 4 shows them as a diagram:

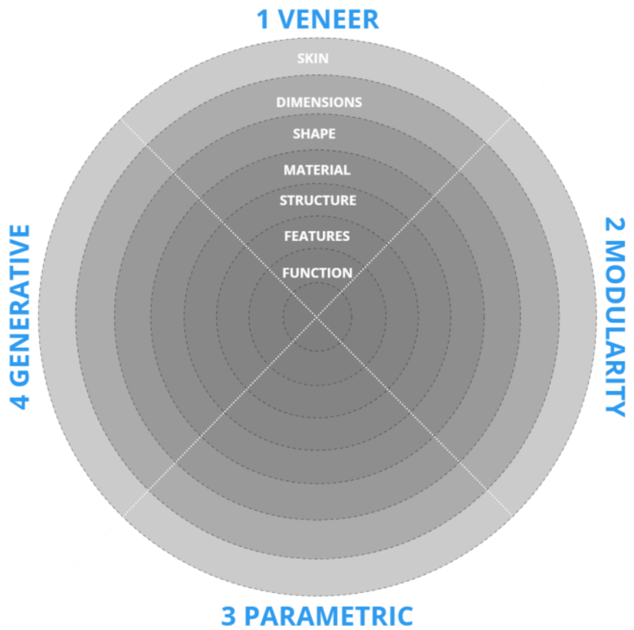


Figure 2.3 Solution space evaluation chart adapted from Hermans (2012)

Veneer is defined as adding a layer for decoration to a mass-produced artifact. This decoration is usually done by printing, engraving, etching custom graphics, or marks on the surface of an artifact. E.g., customizing the name of an iPad on the back surface and printed mugs. *Modularity* is a method that uses combinations or assembly of different mass-produced modules to create different options for the user.

Parametric personalization is a three-dimensional system that can be personalized by changing single or multiple parameters, dependently or independently. E.g., a vase form can have parameters such as radius, height, and width. Contrary to the previous two, parts are not manufactured in this method but postponed until the final form is set.

The last one, *generative*, usually involves algorithm-based design systems that generate the final two or three-dimensional form. The solution space of these mechanisms increases when moved from *veneer* towards *generative*, which means increased complexity, design options, and/or personalization.

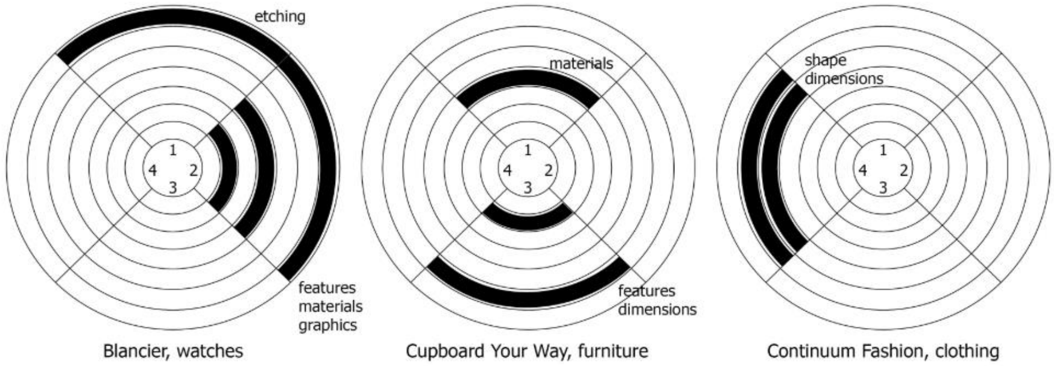


Figure 2.4 Comparison of modular, parametric, and generative toolkits by Hermans (2012, p. 212)

Using this graph, Hermans compares the solution spaces of different online configurators that different brands use for customization. Although this categorization gives clues about to what extent the personalization method provides autonomy and through which mechanisms and layers it establishes, it lacks a connection to meaning and value. The main focus of value in these evaluations is the act of personalization itself. Thus, for an evaluation in the direction of this thesis' aims, a connection with meaning and value sources will be integrated.

2.5 Role of Memories in Meaning Creation

As seen in the previous sections, personal meaning and value can be used to create emotionally durable artifacts that people want to keep. The term memory in this research refers to *autobiographical memory* -personal history and life events- which supports identity construction and development. This section explores their role in the creation of meaning and value.

When embedded with memories, artifacts can contain a place, nation, city, mountain, sea, events, person, “a confession,” or a very complex experience (Bursan, 2011, p. 9). In the case of souvenirs, they are more likely to be associated with memories since they are gathered to remember something (such as an experience, place, or a thing that happened). Although Bursan’s (2011) argument considers souvenirs, it can be induced to the whole set of artifacts with personal meanings. Therefore, according to Mugge (2007), they may arouse emotional bonding. They become representations of the possessor’s lifetime spent in or around the place they are acquired. Schifferstein and Pelgrim (2008, p.1) state that only memories and positive feelings can increase attachment to the artifact. From the perspective of design, Schifferstein and Pelgrim (2008, p.8) argue that designers should design products/artifacts that induce enjoyment and lead to the construction of connections between products, people, places, or events (memories) to increase attachment (emotional bonding) to products.

The embodiment of memories in artifacts mentioned in the above paragraph happens mainly in the cognitive domain (explained in the *Sensing the Artifact* section). According to Hinte (1997, as cited in Schifferstein & Zwartkruis-Pelgrim, 2008, p. 9), if artifacts show physical signs of events, e.g., the damaged surface of an artifact, those artifacts may intensify the remembrance of memories.

An example of memory-embedded artifacts can be given from the ritualistic events in ancient cultures. For Kwakwaka'wakw (Pacific Northwest Coast Indigenous people), meaning and value emerge from performing and witnessing since the artists crafted masks during the "privileged ceremonies" that made those moments and performances material (Gosden and Marshall, 1999, 175):

> "Masks were a vehicle through which ceremonial privileges were made material and the best available carver would be sought because the dramatic impact of a performance depended a great deal on his skill. But, it was the act of showing which was powerful and which established a mask's meaning. Possession of a mask was not in itself significant because the mask possessed meaning only in the context of its performance."

Since (probably) the same artist makes all masks, a foreign eye can interpret these masks as very similar artifacts. However, each mask has a unique meaning for the ceremony participants (having a memorial record of the moment of creation). Each mask becomes a memento for a different ceremony, and the variations on the mask start to have meanings as they become representations of specific moments in each ceremony. They "play important roles as triggers for personal and shared memories" (Odom et al., 2012, p. 338).

2.5.1 Common History

The time spent with an artifact can affect its meaning for the possessor as there starts to be a shared history and work invested in that artifact. These create a unique meaning for that artifact (Raz, 2001). For example, possessing an artifact can result from years of hard work, like a certificate or an economically low value but meaningfully highly valued prize.

Csikszentmihalyi (1993, p. 25) exemplifies the value of artifacts for the continuity of the self from an interview with a wealthy attorney. Among many rare art items, the attorney shows an old trombone he used to play in college as his most special item. He explains that he plays this trombone whenever he feels depressed, which reminds him of the times when life was "fresh and spontaneous." Csikszentmihalyi argues that artifacts connected with memories enable the "continuity of the self through time" by establishing a focal point in the present (1993, p. 25). In the author's same study, nearly half of the participants valued visual arts in their homes not because of their financial worth or aesthetic beauty but because of the memories associated with them.

Therefore, the presence of time as a dimension has significance for the meaning and value of an artifact. *No matter an artifact's economic or exchange worth, the story behind it creates value from the meanings generated by the union of memorial fragments related to the artifact.*

2.5.2 Heirlooms

Mugge’s study on product attachment argues that the most treasured possessions are generally limited to family heirlooms and jewelry. However, from the designer’s perspective, "research on these most treasured possessions is less interesting" (Mugge, 2007, p. 23). There are various studies on the value of memories and heirloom-like artifacts in our lives (Ahde-Deal et al., 2017; Banks et al., 2012; Baytas et al., 2018; Odom et al., 2012; Hoven et al., 2021). Although Mugge argued in 2007 that there was not much interest from a design perspective in designing these treasured objects, it is seen that through the years and with the advancing methods for personalization, there have been attempts to use memories to design heirloom-like artifacts (Banks, Kirk & Sellen, 2012; Odom et al., 2012; Baytas et al., 2018).

Heirlooms are good examples since they illustrate the meaning and value potential of memories when embedded into artifacts. Usually, after producing an artifact, *it gains an aura, a vapor-like surrounding layer consisting of meanings, memories, and a resultant value.* Initially, it has a value related to its economic, cultural, and aesthetic meanings. Nevertheless, after a common history with the artifact, it gains values related to memories that are only attainable by a common history with the product. Thus, in a way, the product becomes the objectified representation of the user/consumer. Even though heirlooms are treasured, as Odom et al. argue (2012), *designing an heirloom* seems contradictory by definition:

> “ …it is important to point out that the notion of ‘designing an heirloom’ can seem contradictory. The ways in which an artifact achieves heirloom status is highly

> idiosyncratic and heterogeneous; what one family may regard as an heirloom will likely not retain the same meaning for another. Additionally, heirlooms often directly owe to the people that possessed them previously and the material histories inscribed through their use over time." (Odom et al., 2012, p. 339)

Heirlooms are strongly associated with memories and meanings that can live through generations by transferring narratives. An artifact can be transferred from the initial possessor to the proceedings and kept safe since it represents an heirloom status and meaning for the next possessor. At its core, *heirlooms are artifacts that contain history with the help of their connections to personal memories and stories.* Therefore, connecting *old memories and stories to a newly manufactured artifact would enable deeply meaningful and highly valued artifacts.*

2.5.3 Artifacts as Memory Cues

People modify their surroundings as extensions of their identity through a selection of mementos to express themselves through the symbols of the self (Csikszentmihalyi and Rochberg-Halton, 1981; Kirk and Sellen, 2010 as cited in Gennip, Hoven and Markopoulos, 2015, p. 3444). Artifacts can trigger personal and shared memories (Banks, Kirk, and Sellen 2012; Odom et al. 2012). Artifacts that belong to a person's past can bring back memories and emotions related to those times. Their function as memory cues has diverse implications across research areas such as marketing, consumer behavior, psychology, material culture, human-computer interaction, and design (Haven, Orth, Zijlema 2021, p. 95). Artifacts associated with memories are known to elicit attachment experiences and have been explored by product attachment literature examining the value and meaning of possessions (ibid.). In addition to physical artifacts, research in the last decade has shown that digital artifacts can elicit memories and create attachments (Durrant, Elsden, Kirk, 2016). Despite being more focused on creating physical artifacts at the beginning of my research, this study's focus evolved to include both physical and digital due to the blurring lines between the two in the last few years. Thus, artifacts that can be used as memory cues in both realms, physical and digital, are in this study's focus. Still, the lack of devices or accessible ways of reaching the digital in the physical realm decreases the value of digital artifacts (Gennip, Hoven, and Markopoulos, 2015).

As mentioned before, although a person may own rare art pieces and expensive furniture in his/her home, an ordinary and relatively cheap trombone might be much more special to the owner than other expensive artifacts (Csikszentmihalyi 1993). The trombone triggers memories of a time when the owner was young and free of worries. Thus, some of his worries disappear whenever the owner plays a few tunes with the trombone. Csikszentmihalyi explains the effect of the mentioned trombone:

> "So, the trombone helps both focus attention, reducing entropy in consciousness, and vividly brings back old memories and experiences, thus adding a sense of depth and wholeness to the self of its owner. For this man the expensive collection of art and furniture served as power artifacts, as signs of his status and achievements. But the most meaningful symbol of his private self was the trombone, which alone had the power to put him back in touch with himself." (Csikszentmihalyi 1993, 25)

It can be understood from the author's example that the artifact can take us from the current time to the past, in which we find serenity. Thus, they can act as tranquilizers in stressful times. For instance, jewelry can function as memory containers from the past and help their owners to maintain, organize and transfer memories from one generation to another (Ahde-Deal, Paavilainen, and Koskinen, 2017, p. 34). The authors point out that memories exist without the artifact, but the jewelry triggers them and brings them to someone's mind.

The importance of heirlooms and memento artifacts has been recognized by Mugge (2007). However, the author's argument on the impossibility of designing products according to an individual's memories was mainly due to the conventional manufacturing systems approach. A conscious design mechanism was missing due to conventional manufacturing methods' nature and personalization limitations. In the last decade, there has been a significant amount of research that aims to create frameworks guiding designers to create more meaningful personalized products (Chapman et al., 2018), co-design approaches (Bakirlioglu, 2017; Bingham, Porter, and Green, 2017) and personalization systems (Nachtigall et al., 2019a; Nachtigall et al., 2019b; Ariadi et al. 2012; Zhao et al., 2019) that offer different ways of making an artifact more personal.

The artifacts in Csikszentmihalyi’s (1991) study were valued because they reminded their owners of significant personal ties and qualities of the people who made them. Therefore, they are valued because they make connections with meaningful memories. Of 537 reasons for cherishing the 136 graphic works, only 16% dealt with how the pictures looked. Those pictures' formal qualities and appearance did not matter to their owners but only to the memories associated with them. Also, in rare cases, the artifact was special because of its aesthetic qualities. However, in those cases, the artifact owner participates in the creation process, which makes the artifact special in his life (Csikszentmihalyi, 1991, p. 28).

When the value and meaning brought by memories into the products are considered, as shown by prior literature, ways of creating/designing artifacts that have connections with personal memories present a huge opportunity (van den Hoven, Sas, and Whittaker 2012) for

Increased meaning and value in artifact
Increased emotional durability of the artifact
Elicitation of attachment to the artifact

When the added value and meanings to the artifacts are considered in the paragraphs above, great potential is seen in designing for personal memories. Building on this knowledge, ways for incorporating memories are further explored in the following sections of this thesis.

2.6 Memories as Data

Memories can become useable for the transformation process that will be discussed in this thesis only if they can be transformed into numerical representations. If the memory-related content is something like a photo or a pattern, it is not included in the scope of this thesis as memory-related data. Those items have already been used in everyday personalization scenarios, such as printing photos and sticking to surfaces, covering artifacts with textures or custom designs, etc. Then, memory-connected records of any *translatable material* can be accepted as data in the method proposed in this thesis. For example, not the contents of a diary (words, sentences, paragraphs) but the number of entries in a year can be data. Entries of the journal can be used as a texture, and something can be covered with it.

Figure 2.5 Personalized plates (concept) from personally meaningful data manufactured with additive manufacturing (Bingham, Green & Porter, 2017)

Bingham, Green & Porter (2017) designed and rendered (artifacts are not manufactured but presented as if they are, via three-dimensional renderings, Figure 2.5) a conceptual personalization scenario in which a personally meaningful lace pattern is used to modify the surface design of a plate. They also argue that the resulting render resembles *bespoke surface decoration.* The authors are more concerned with finding *product attributes* to elicit product attachment through exploiting personalization potentials brought by additive manufacturing technologies. However, this thesis is interested in using personally meaningful recordings to *create or modify three-dimensional forms* that can create indirect meaning without publicizing private data and meanings.

The thesis is concerned with developing a transformation method by using different kinds of data as probes to memories so that when a user interprets that data, it helps to trigger related memories, thus becoming meaningful and valuable. The data types selected in the examples are sound data (intensity and frequency), biometric data, position data, and social data. However, the data, in the end, is to be interpreted in the form of a physical artifact. Thus, the data is first transformed into a virtual three-dimensional representation on screen, then manufactured through additive manufacturing / 3D printing. The resulting three-dimensional and tangible artifact is planned to function as a bookmark for special memories and generate meaning in the minds of the possessors of those memories.

2.7 Translating Data into Artifacts

From wearable tech to weather information, from our childhood videos to financial information, even the number of breaths can become a source for creating meaning. However, translating these numeric data into more meaningful forms by normalizing the data is needed to create appropriate visualizations (Butz et al. 2017, p.93). In *Data Objects*, the authors (Esparza et al., 2018) present a methodology for using data as a material for design. They suggest a set of principles and propose two different ways of using them: data-to-object and object-to-data. The first method starts with selecting data and then translating that into a new object. In contrast, the second method suggests selecting the object and extracting its appropriate features for data representation. The first method, *data-to-object*, consists of the following steps:

1. the decision of data type and filtering out material properties that can be related to the design intent of the artifact
2. choosing an easily recognizable object for the (re)interpretation of data,
3. designing a path to emotionally and cognitively engage with that data
4. Prototype and evaluate the final design by involving target users in the evaluation. When necessary, re-interpret the decisions made when connecting data to object features.

The second method, *object-to-data*, consists of the following steps:

1. Selection of the object to be redesigned or re-interpreted.

2. Searching for related data concepts that can be connected to the artifact chosen.
3. Exploration and design of conceptual and perceptual mappings between data and the artifact with their possible ways of interpretation. In this step, the physical parts and features of the data are connected.
4. Prototype and evaluate the final design by involving target users in the evaluation. When necessary, re-interpret the decisions made when connecting data to object features.

Among these approaches, the data-to-object method is more relevant to this study since it prioritizes data over objects. This study focuses on personally meaningful sound data applied to various objects to create meaning and value. A study is designed to create meaning and value by incorporating all four steps mentioned above (see Chapter 3, Primary Research).

In addition to connecting *features of data* to *features of objects,* Bingham, Green & Porter (2017) suggest two different approaches to personalizing forms. In one of them, a pre-existing form is modified with data. In the other approach, there is no pre-existing form, and the form is generated from the data. Concerning these two different approaches mentioned by the authors, *modifying a pre-existing form is preferred* over generative methods since designing a system that generates a form from scratch would introduce invisible variables to the participant, which might make the transformation process harder to understand.

2.7.1 Data Physicalization

While searching for literature on transforming memories into artifacts, I came across the *data physicalization* field. In the last decade, this field of research, also connected with *tangible user interfaces* and *human-computer interaction,* has produced work that is very relevant to this thesis. As mentioned above, a connection between memory and artifact can be established by using memories as data and transforming that data into an artifact with methods inspired by data physicalization examples. In the following sections, an introduction to data physicalization is made and followed by relevant concepts and benefits.

The following section presents the most common personal data sources, followed by a section about the tools used in visualizing data as three-dimensional forms (Detailed information on 2D and 3D CAD techniques used in data physicalizations can be found in a detailed survey by Djavaherpour et al., 2021).

> “The sundial, for example, transforms shadows into a readable representation of time of day, the mercury thermometer transforms temperature into a displacement along a number line, and a scatterplot transforms the values of two variables into a form that allows the reader to interpret correlation. Our first data representations were based on natural objects, such as charcoal scraped onto walls or built from clay, or later, ink on paper. With the advent of computers, we’ve substituted physical representations with pixels on a computer screen. The resurgence of physicalization asks what we have lost in this transformation” (Dragicevic et al., 2019, p. 128).

In ancient cultures, physical artifacts used for personal record-keeping were part of daily life. However, with the increasing digitalization, these representations have been simplified into the unsophisticated surface mapping of two-dimensional graphics onto surfaces and screens (Esparza et al., 2018, p. 1686). Then it might be argued that the tangibility of data and its understandability with our senses have become more challenging as we increased our distance with data putting it behind digital screens. Also, since digital files or representations are not parts of our daily lives, our relationship with them has decreased.

Screen-based visualizations cannot capture reality and its rich experience due to their inability to stimulate other senses than visual perception. However, we are used to interacting with the real world with our multi-sensory perceptions. Thus, physicality is essential in understanding our environments (Zhao and Moere, 2008). However, until recently, visualizing information as physical artifacts have not received intense attention from the information visualization field, which is explained by the "physical superiority of personal computers over physical matter" (Dragicevic et al., 2013, p. 2593). Compared to computer visualization systems' dynamic, interactive nature, physical visualizations are static, and creating them requires time, as the authors argue. With the advancing digital fabrication technologies and increasing work in tangible computing and information augmentation fields, physical visualizations are believed to be more widespread and dynamic (Dragicevic et al., 2013).

Data physicalization is defined by Jansen et al. (2015, p. 3230) as: "a research area that examines how computer-supported, physical representations of data (i.e., physicalizations) can support cognition, communication, learning, problem-solving, and decision making." Data physicalizations represent numbers and relationships using physical and tangible displays (Dragicevic, Yansen, Moere, 2019, p. 127). By externalizing numerical and abstract concepts, data physicalizations help reasoning, remembering, and communication (ibid.).

Data sculpture, as a term, emerged before *data physicalization* and is often used interchangeably. However, according to Dragicevic et al. (2019, p.1), a *data sculpture* is a representation of data that “aims for more artistic expressions of data in physical forms.” This study is interested in both representation ways, the one with a more artistic aim and a data-oriented approach. Therefore, in the following sections, both labels will be used during the selection and discussion of examples.

Representing data in physical forms by 3D printing has gained validity recently (Butz et al., 2017). 3D printing allows the easy transformation of abstract digital data into tangible forms that help reasoning, remembering, and communicating the data by creating a multisensorial enriched experience (Butz et al., 2017; Dragicevic et al., 2019). Therefore, the ease of manufacturing, even the most complex forms, provides freedom to explore new forms of physicalization, such as manufacturing highly intricate and complex forms generated by computer code.

2.7.2 Embodiment in the Representation of Data in Physical Artifacts

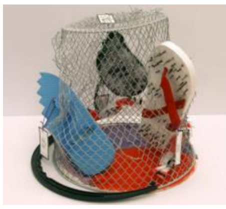
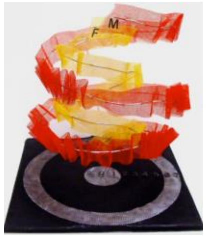
The embodiment concept in *data-oriented artifacts* with virtual and physical components is one of the crucial elements of data physicalization. Embody means converting something abstract into something visible and tangible (Zhao & Moore, 2008). This conversion occurs through a process called *data mapping* that translates data into representations through *metaphors* (ibid). *Data mapping* aims to represent something unfamiliar with something familiar, thus helping people to understand an unfamiliar domain through relatable metaphors (Zhao and Moere, 2008).

Embodiment is measured with the distance between the data and its representation through *modes of embodiment.* In other words, embodiment modes are determined by the distance between abstract data and physical representation (Zhao and Moere, 2008). The table below explains different types of embodiment with examples and their metaphorical distances.

Table 2.2 Modes of embodiment (adopted from Zhao & Moere, 2008; Moere & Patel, 2009)

	Indexical relationship	Iconic relationship	Symbolic relationship
Distance between data (signified) and its representation (signifier)	Close	Moderate	Far
Definition	Signifier has either a physical or causal connection to the signified (Moere & Patel, 2009)	Signifier has some resemblance to the signified. The connection is created through a *defined metaphorical relationship.* A metaphor is carefully chosen to convey meaning	Signifier bears no resemblance to the signified. The connection exists in a *defined convention.* No meaningful connection between artifact and data

Table 2.2 (Continued)

Example data	Number of physical injuries caused by wearing thongs	Relative growth of the Australian economy between 1979 and 1981	Unemployment rates (male and female)
Example representation	 Thongs: Every nail represents a thousand thong-related injury (Moere and Patel, 2009)	 Budget Flower: 12 petals with three layers represent the growth of Australian economy between 1979-1981. The uneven distribution of the sizes of the petals illustrates a "monthly periodicity in economic growth while the perimeter of the petals represent revenue (Moere and Patel, 2009)	 dataLix: Helix revolutions symbolize work-seeking people while the creases represent the rate of data change (Moere and Patel, 2009)

In addition to the definition of symbolic relationship defined in the Table above, Moere & Patel (2009) give another example of symbolic representations: "abstract symbolic data sculptures." They do not have chart or graph aesthetics but rather focus on the sculptural aesthetics of an artifact. Still, all the data values are *translated* into distinct visual elements. For instance, the translation of the existing data determines visual qualities such as position, size, direction, or color. In this type of physicalization, according to Moere and Patel (2009), "data is used as a ground material to be sculpted into a free form" (Representational Fidelity section). Therefore, in symbolic data sculptures, rather than aiming for a very close relationship between data and its representation, the data can be used as the building blocks of a more aesthetically pleasing artifact.

The Data Physicalization Examples section in this thesis explores various applications of data to create artifacts. *This thesis explores the symbolic relationship between data and artifacts since it can be applied to a broader field through different form generation methods.* However, because of the *increasing distance between data and its representation, the need to explain how that transformation occurs becomes inevitable to exploit the meaning-generation* potential of such methods. Therefore, the presented examples are evaluated from a participant's perspective and to what extent the process remains understandable to him/her.

2.7.3 Benefits of Data Physicalization

Digitized visualizations allow easier manipulation and better data inspection. However, they can detach the relationship from the natural world and isolate the experience from "touch, feel and emotion that comes from interacting with real objects" (Dragicevic, Yansen, Moere, 2019, p. 128). The presence of materiality and placement of a physicalization "embodies" data rather than communicating it. This physical nature of the representation allows it to be sensed, thus stimulating hedonic senses (ibid.). The physical and material existence of data enables experiencing data through tactile and visual metaphors, offers new ways to approach data, and “unlock(s) new insights and emotional responses” (Dragicevic et al., 2019, p. 127). For instance, converting digital models into tangible physical artifacts in architecture brings the advantage of comparing the past and present versions of a project, idea, or data. Because it allows the easy arrangement of different models in the same space (Hull & Willett, 2017, p. 1225), physicalizations serve as tangible or external memories for an architect during the design process. Also, the physical nature of tangible models allows the architects to reconfigure different designs together while also building the documentation of the process that is distributed in the studio space (Hull & Willett, 2017). Moreover, data physicalization can support remembering and reflection through multiple senses, such as hearing and seeing (Karyda, Lucero & Mekler, 2021).

Although a "pixel-less" representation of data can lose some detailed information, it can create a richer, more engaging, and memorable experience that "nonetheless communicates complex information and insight" (Vande Moere, 2008, p.469). Physical data representations evoke emotional responses (Wang et al., 2019). They also allow more freedom for information encoding in a perceivable form. This freedom is brought by a rich feature set, such as physical material and kinaesthetic properties that enable the exploration of the artifact with all sensory and motor skills (Dragicevic et al., 2019). Khot et al. (2019) argue that the ways of using physical representations of data for sustained interest in the artifact should be explored more by designers.

In addition to the benefits above, the most obvious advantage is that data physicalization enables data to live in the physical world (Chiang, 2018). So when the data is memories, it allows memories to live in the physical world. This way, the data can be reached without opening the computer and navigating to the designated folder since the data is reachable in the physical world (Andres et al., 2016). Wang et al. (2019) argue that tangible interactions are more enjoyable and meaningful. Using different materials in the physicalization process can speak to different senses and evoke affection (Wang et al., 2019). Also, as argued by the authors, tangibility introduces an emotional connection. The object's surface and internal properties start to introduce new emotions, making the experience with the artifact more permanent. In my research, in the initial studies part, I gave the participants 3-D printed artifacts and observed the immediate pleasure on the faces of the participants. I could not test this in the second part of the study since it was a remote workshop due to COVID-19. However, as the authors argue, touching creates an immediate sense of affection, which can increase the meaning and value of the resulting artifact.

Combining the interest in making and collecting artifacts with the tangible nature of data is argued to create more engaging experiences while interacting with data (Butz et al., 2017; Zhao & Moere, 2008). As artifacts are extensions of our identities (Belk, 1988), it can be argued that artifacts created as representations of personal data can deepen this connection, thus increasing the chance of attachment to the artifact

(Mugge, 2007). Therefore, data physicalization has a *self-expressiveness* value for people since it allows them to express themselves with artifacts embodying their lives, personalities, emotions, and achievements (Butz et al., 2017, p. 86). In other words, physicalization also becomes a medium for self-expression. Also, they "spatially denote the identity of an individual and trigger reminiscence of good moments at a later point in time" (ibid). When gifted, data physicalizations introduce a sense of privacy since only the people with prior information about the data share the same symbolic value and function as conversation starters (Dragicevic et al., 2019). Like possessing memories through souvenirs, data can be possessed through data sculptures with the translation of data into physical artifacts (Vande Moere, 2008, as cited in Butz et al., 2017). Making data tangible through a physical artifact brings the affordance for data to be owned (Zhao & Moere, 2008).

Physicalization of personal data can also become a driving force for behavior change since physical rewards feel more satisfying than virtual counterparts (Butz et al., 2017, p. 92; Karyda, Lucero & Mekler, 2021). Democratizing the creation of data visualization and conversion to tangible artifacts can facilitate social and collective understanding of data. Creating tangible artifacts from data can spur meaning-making processes that are collectively made and discussed (Dragicevic et al., 2019). The physical properties of a data sculpture democratize its reach and understanding of information by making it accessible to the masses (Zhao & Moere, 2008).

The benefits of data physicalizations summarized by Dragicevic (2015) are presented as a list until bullet nine and extended with the discussions above in clauses ten and eleven.:

1. Leveraging Perceptual Exploration Skills
2. Active perception
3. Depth perception
4. Non-visual senses
5. Intermodal perception
6. Increase data accessibility

7. Cognitive benefits
8. Bringing data into the real world
9. Engaging people
10. Induction of attachment
11. Creation of private and public (shared) meanings

Concerning the focus of this thesis, all of the benefits listed above add to the creation of meaning and value of the resulting artifact that will be generated from the sound data connected to autobiographical memories.

Regarding the ease of fabrication with 3D printing, this research chooses 3D printing as the manufacturing method since it also provides form complexity and form freedom. These benefits of 3D printing technologies can help a more precise representation of data in the resulting artifacts.

2.7.4 Data Physicalization from the Perspective of Personal Meaning and value Creation

In their user studies, Andres et al. (2016) argue that the meaning is generated in the mind of the possessor of the memory, not on the object. Aftab & Rusli (2017) argue that users rather than designers give meaning. Thus, these private objects made from personal data and memories are most valuable to their owners, who own the memory themselves. In this way, a seemingly ordinary object, e.g., a cricket ball played in an iconic match, can gain tremendous meaning and value for the person who has been to that match. On the other hand, strangers can not relate to the meaning of it since they do not have the memory to unlock the signified iconic match (Andres et al., 2016).

Similarly, Karyda, Lucero & Mekler (2021) state that to understand the meaningfulness of the data representations, one must understand how the data owner has an experience with that data. There are two ways meaning resides in artifacts in literature: the first is an organic connection between the memories and the artifact which happens with time, and the other is an artificial construct that uses some data that bridges the memory with the artifact. Since the organic way can only be attained with common history with the artifact, *this thesis is interested in constructing connections using data that bridge memories with artifacts.*

The availability of data in the physical environment allows easy access and facilitates the review by the possessor of that data under different circumstances and environments. The small size of the artifacts enables easy transportation to different locations while also making them comparable to each other (Karyda, Lucero & Mekler, 2021). On the other hand, larger physicalizations increase impressiveness, facilitate shared experiences of data, and induce discussions in communities. Contrasting with shared experiences, abstraction in data representation introduces the function of privacy. Also, abstractions motivate discovery and "tend to support reflection in users" (Dumicic et al., 2022, p. 21). Therefore, the physicalization's size and publicity affect the artifact's collective meaning and value. Reflecting on the research findings of Duminic et al. (2022), larger physicalizations afford a shared meaning more than smaller-sized ones. This study focuses on physicalizations with smaller dimensions within the limits of personal belongings since the research field is within the product design area.

2.7.5 Relation of Data Physicalization to this Thesis

In the data physicalization field, the main aim is to represent data by mapping it onto the physical properties of a three-dimensional artifact situated in the real world. When the metaphorical distances between the data and the artifact are considered, there are different levels of concern about making the data understandable. For example, closer metaphorical distances mean that the understandability of the final representation needs less explanation since the direct mapping of data onto physical artifacts can be directly understood without any additional definition. So the concern for data's understandability and clarity can be considered high while creating such a relationship. When the metaphorical distance is greater, such as in symbolic relationships, understandability without further explanation or shared symbolic cultural common ground becomes impossible (Moere & Zhao, 2008). Still, this might be the case when the concern is to create public awareness. However, as Andres et al. argue (2016), meaning is created in the memory possessor's mind. Thus the whole meaning and value will emerge only in the minds of the memory possessor, leaving the ones without the memory as strangers to the artifact's meaning.

Data physicalization is related to creating tangible representations of abstract connections with data into tangible artifacts. Thus, the methods and explanations in the data physicalization field can be transferred into the field of product design and guide the process of connecting memories with artifacts.

The concept of embodiment explains the connection between the data-driven artifacts and the source data (Moere & Zhao, 2008). This framework is essential for this thesis since sound data that connects with memories is used in the studies. Therefore, while explaining the connection between sound and then the memory, how *data mapping* takes place and what modes of embodiment are present in the translation process will be discussed in the following sections.

When the benefits of data physicalization are considered, embedding the data into a physical artifact allows the data to be approached in new ways by users. New ways emerge since the conventional display of data through two-dimensional screens remains limited. Making information physical introduces many ways of representing the data, such as material, color, physical dimensions, different forms, and metaphors, so that the experience of understanding the data becomes multi-sensorial rather than interpreting something that we only see. The *multi-sensoriality* of interacting with physicalizations can create a more engaging experience when the data becomes personal memories. The reason lies in the ways of interacting with the memory. After the memory's transformation into an artifact, experiencing it becomes multi-sensorial, thus leading to new realizations through self-reflections triggered by memories.

People can even use industrially made objects to create a personalized surrounding that extends their unseen personality to the physical world through tangible objects. When personal photography is considered, it is known that taking personal photographs or selfies has a function in configuring self-identity (Lupton, 2015). The author argues that personal photography "not only represents but enacts selfhood and self-identity" (Lupton, 2015, p. 11). In this manner, photographs can be considered semi-tangible artifacts created from the personal memories of a person. So, when the artifacts people use are created from their memories, it enables an even more personalized curation of surroundings with personal memories creating bonds with the self and identity.

2.8 Personal Data as Design Material

With the increasing number of sensors, camera-embedded environments, and accessories, the human body becomes a source of data that can be used in a design system as material. Data extracted from the body will be used to create new extensions for the self and new ways of self-expression. These new ways of self-expression will create new meta-products that live in both physical and digital worlds (Lupton, 2015, p. 11). The increasing use of data collection in a data-driven world brings opportunities for creative design action (Esparza et al., 2018). In the methods like sketching, sculpting, modeling, and prototyping, the designers intend to make sense of the materials. Esparza et al. (2018) argue that the same can be valid for data as a design material.

Different data types can be extracted from smartphones, smart watches, or wearable self-tracking devices. These devices contain information on personal images and significant others, text messages and emails, calendar entries, geo-location information, physical activity, and status updates from social media platforms. All this information is unique to the individual and becomes a part of their lives and autobiographical memories. They become repositories of emotional memory and social relationships (Lupton, 2015). Data collected in various ways allows a *quantified self-image* to be constructed. Our online existences have also become sources of personal data, while widespread usage of smartphones facilitated the collection of high-quality audio-visual data (Bingham, Green & Porter, 2017).

Sound is selected as a data source in this study among many readily available data types. It is one of the most readily available data forms that can also be quantified, digitized, and sensed with less effort. Since it is a widespread technology and has a relatively long history, it is an established cultural practice (Bijsterveld & Dijck, 2009) and thus is a richer source of data in terms of having a chance to contain memory-related data. Also, it becomes multisensorial when transformed into visuals and forms, thus enriching the experience.

Esparza et al. (2018) argue that designing *usable, functional, and meaningful artifacts that encode data* (Esparza et al., 2018, pp. 1685, 1687) is not about designers' views but rather about empowering users by giving them agency. Thus rather than providing a specific perspective on data, they are better at sparking conversations that can support multiple ideas.

Transforming intangible data into tangible artifacts converts ephemeral into permanent, freezing ephemeral digital data in the physical world by making it a solid artifact. Then they can become self-representations and biographical objects, “mementos and signifiers of important or intimate events in people's lives” (Lupton, 2015, p. 12). Also, converting personal data into a tangible physical object can establish a sense of mastery over something that the self continuously produces but is ephemeral (ibid.). So instead of these data disappearing into the environment, Lupton (2015, p.13) argues that the person has selective control over the data by converting it into an artifact after selecting what is valuable or beautiful for himself/herself. Data from various devices that generate data, such as smartphones, smartwatches, and wearable trackers, can be used as meaning sources for transforming data into tangible artifacts. These devices can provide all kinds of personal information about the self, like “images of the self and significant others, text messages, e-mails, calendar entries, geolocation information, details of physical activity and functions, and status updates on social platforms" (Lupton, 2015, p.11).

Using wearable trackers, Karyda, Lucero & Mekler (2021) conducted a study in which they collected personal tracker data and used them to design physical artifacts that are representations of that data. Then the artifacts were given to the participants as gifts. They aimed to create meaning by using personal data as a design material. However, the people who received the gifts were not involved in the design process of the artifact, so they cannot involve their interpretations of the memory. When the literature about the co-designing and participatory design approaches is considered, it is known that the user's participation in the design and making of an artifact dramatically enhances the meaning and value of the resulting artifact. Therefore, involving the user in the design, data translation, or data mapping process of the artifact can enhance the meaning and value of the artifact even further. Bingham, Green & Porter (2017) hypothesize that the objects connected to meaningful data will be able to trigger memories of an event and thus will be more likely to elicit *product attachment*, increasing product lifespan. However, they argue that designers' challenge while designing artifacts incorporating data will be deciding on the types of data and setting the limits for the effect of the data on the product's form while keeping the product or artifact still functional and aesthetically congruent with their intent.

In Karyda, Lucero & Mekler's study (2021), three different artifacts were created with a critical design approach due to three different sessions. All three artifacts acted as triggers for memories. This connectedness also served as a motivation for further unintentional reflection upon the memory and data. For example, in one of the three case studies, a participant's heart rate data during a celebration (during which he had taken lots of alcohol) were collected and transformed into a beer bottle with his heartbeat data visualized on the labeling of it. Upon seeing the visualization, he realizes the rise in his heartbeat during that event, and this realization causes him to stop drinking afterward. They stated that the gift-receiving moment also became a part of the memory. The resulting physical artifact did not only connect the memories and experiences of the participants but also made the participants make sense of how these objects and data related to their lives. The availability of data in the physical environment allows easy excess to that data and facilitates the review by the possessor of that data under different circumstances and environments (ibid.). The small size of the artifacts enables easy transportation to different locations while also making them comparable to each other (ibid.).

Personal data physicalizations become like a piece of that person or an extension of the self (Karyda, Mekler & Lucero, 2021). One of the study participants was given a physicalization of his heartbeat during a concert he played. When reflecting upon that gift, he comments that the piece is like a souvenir from the place and time but also a piece of himself. Still, visualizing data through physical artifacts may not always work when the connection with the presented data is not personal (ibid.).

Bingham, Green & Porter (2017) have identified three product attributes brought by using personally meaningful data while designing products: *abstractness*, *visibility,* and *obtrusiveness*. *Abstractness* is defined as the symbolic obviousness of the information embedded in the artifact. It is the degree of need for an explanation for a stranger to identify the meaning by only assessing the artifact aesthetically. The second attribute is *visibility*, which defines the amount of visibility of the data representation used to personalize the artifacts. In other words, it is the ease of spotting the changes caused by the data on the artifact. The third one is the *obtrusiveness* attribute. Obtrusiveness is used to define to what extent the personalization applied to the object prevents the artifact's usability. For example, a surface texture, when slightly applied, would not prevent usage. However, if that texture is applied in a very highly relieved way, the usage of the object would be difficult, and the aesthetics of the artifact would be dramatically altered.

The first two attributes, abstractness and visibility, are closely related to the focus of this thesis since they affect the interpretation of the artifact. Although important for creating usable artifacts, *obtrusiveness* falls out of the scope of this research since the study's primary concern is creating meaning and value in the artifact. Still, in the user studies section, the usability of the objects is evaluated in some participants' comments.

2.9 Data Physicalization Examples

The categorization of the examples is done according to the user's involvement in the form-generation process. They are categorized as *inactive participation, deferred active participation,* and *real-time active participation.* Examples are presented in this order and with increasing personal meaning and value from the user's perspective. Since most examples below are not concerned with personal meaning generation, the prior literature explored in the previous sections guided presented examples' evaluations.

Inactive participation means the user exists as the observer in the process instead of actively or indirectly participating in the creation of the form. The included examples are mainly from art and design projects that explore the relationship between sound and form. They are included to illustrate different ways sound can be used to generate forms and possible meanings and interpretations they can generate. *Deferred active participation* is defined as the participation of users with various kinds of data; however, there is a lag between the usage of data and the interpretation of the resulting form. This lag happens either by researchers/designers doing the transformation themselves and showing the result after it is completed or through a process hidden from the participants. *Real-time active participation* means the user can see the result of his/her actions and see the representation of data immediately. Concerning personal meaning, as the examples presented progress from inactive participation to real-time active participation, personal meaning and value increase. The examples are arranged in an order with increasing personal meaning and value.

2.9.1 Inactive Participation: Observer

Figure 2.6 Voice sculpture created by Gilles Azzaro from Barack Obama's speech on 3D printing called “Next Industrial Revolution” (Azzaro, 2013)

Data Type: Sound frequencies over time

This 3-D printed voice sculpture is made by analyzing Barack Obama’s speech about the third industrial revolution. Although not stated by the artist (Azzaro, 2013), the geometry points to a method that allows the extraction of different sound frequencies constituting the sound wave (Fast Fourier Transform: FFT). This way, different sounds in the recording can be visualized, e.g., a bird chirping and speech frequencies from the same recording. More detailed information about the sound analysis technique can be found in the *3.6.2 Audio Analysis and Visualisation Method* section.

Using the method explained in the paragraph above, the virtual geometry is generated, and the form is 3D printed. The exhibited unit has a button that plays the audio of the speech. While that audio recording is heard, a green laser scans over the 3D printed form in sync with the corresponding surface deformations on the printed artifact. The artist Gilles Azzaro has several other sculptures in which he materializes different voice recordings and presents them in different ways. The resulting artifact’s understandability and what it represents are enhanced with the scanning laser. The scanning laser also connects hearing to seeing so that the viewer understands where the sound belongs on the artifact. Since the data used in this physicalization is public, the artifact becomes a symbol of public meaning. Thus, the person who views this artifact can derive two different meanings. First, meaning is connected to the public event. If the speech's moment or content has a personal significance for the person viewing this artifact, it can create meaning and value from his/her perspective. The second meaning comes from interpreting this artifact as a piece of art combined with technology.

This example is related to this thesis to explore possible implications of the participant not being involved in the process with his/her data but only by the role of observer and meaning maker. Observing the artifact, in this case, is done according to the cultural conventions the observer lives in.

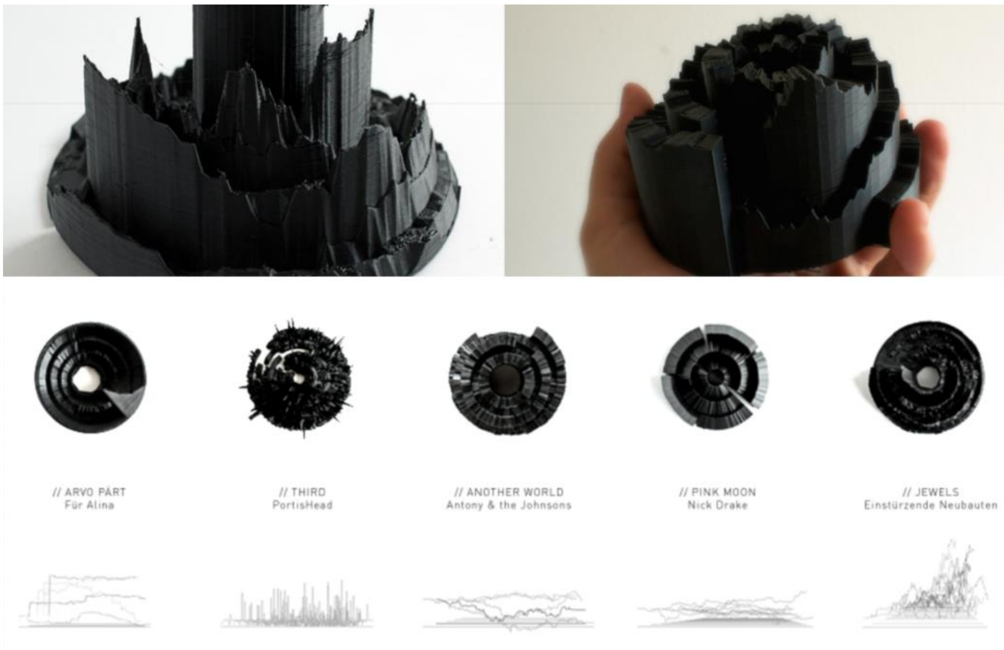


Figure 2.7 Microsonic landscapes (Microsonic Landscapes, 2012)

Data Type: Sound frequencies over time

The Microsonic Landscapes project is realized by a duo of creative coders and designers who have converted songs into physical representations. The project's goal is “algorithmic explorations” of the music the designers like, as stated on the project’s website (Microsonic Landscapes, 2012).

There is not much information about the technical details of the project. However, the line graphs under each transformed artifact (Figure 2.7) point to the usage of FFT (Fast Fourier Transform) for the analysis of different frequencies over time. Then they most likely use those frequency data to generate a circular artifact that is displaced according to the intensity of those frequencies over time. This project is more of a personal visual and physical exploration of music the creators liked; thus, not much information is present on their website. However, it differs from the other examples in this thesis since they represent a much longer duration of data, a complete song. Thus, the object becomes the representation and visualization of a whole song. Again, the artifact's meaning would be closely related to the song's content.

There is little clue about the process and how the data mapping takes place. Because of this, the produced artifacts, although interesting, do not have much meaning to a foreign eye. Thus, they can be evaluated from an aesthetic perspective instead of a meaning-based interpretation.

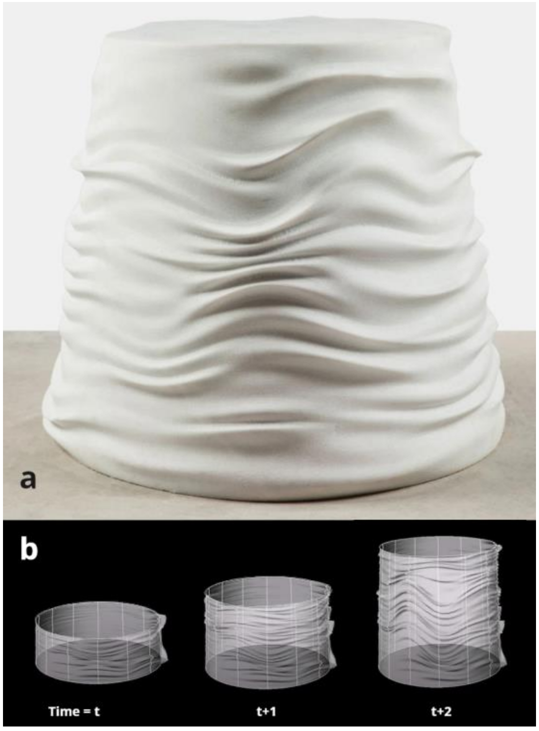


Figure 2.8 Samba stool: a generative stool made out of samba songs by Guto Requena Studio (Requena, 2014b) a) Physical artifact b) Generative process of the virtual model

Data Type: Sound frequencies over time

In this project, different samba songs were selected and used as a material to create a stool design. As the song starts to play, a circle that distorts according to audio frequencies starts to move upwards (Figure 2.8b time = t) and generates a cylindrical form as time progresses to t+1 and t+2 with a distorted surface that is modified by sound frequencies coming from the song. After the digital form is generated, the design is manufactured by a CNC machine carving the form out of a marble block.

There is not much information about the process; however, on the project's web page, a video shows the real-time generation of the stool while the song is playing. This video helps the viewer to understand how this form is created. However, the low framerate and the angle of view of the visualization make it hard to understand precisely which parts of the stool are modified with which frequencies of the sound. Still, the real-time generation of the form facilitates understanding the connection between the data and the generated form. However, without the video showing the generation of the form with sound, it becomes impossible to understand the artifact's meaning.

The sound data in this example is used as a material to create surface variations. When combined with the stool's name, samba, the sound data’s content also gives context to the artifact. The process results in a functional artifact that is created for a gallery. There is not much contextual information and audience. Therefore, completing the manufacturing and placing the artifact in the real world, it becomes detached from the story of its making.

Moreover, the meaning of the artifact remains buried in the process. From the perspective of meaning generation, it is a physical representation of various samba songs used in their generation and resembles *Microsonic Landscapes* and *Reify* examples discussed above. However, there is a difference between the mentioned examples. In *Microsonic Landscapes* and *Reify* projects, there are no visualizations of the form generation moment of the artifacts (at least in the reachable and published information). In this example, the designer has created a video showing the generation moment of the surface forms of the stool. Since the intentions behind this work are unknown, it is presented here as an example of sound data being an inspiration for the design.

Figure 2.9 Sound surfaces: Vase forms generated from sound data of various songs and sound recordings (Keep, 2012)

Data Type: Sound intensity over time

The Sound Surfaces project of Jonathan Keep explores the textures and forms created by sound on the surfaces of pottery artifacts. Jonathan Keep is a potter who has developed his clay 3D printer and using it to explore the intersection of digital fabrication and traditional crafts. He is also sharing the plans and procedures of his work in his studio journal on his website. Similar to the *Microsonic Landscapes* and *Samba Stool* projects, Keep (2012) uses sound to distort the surface of the digital pots with the help of custom-developed software. The digital pots are then 3D printed from clay.

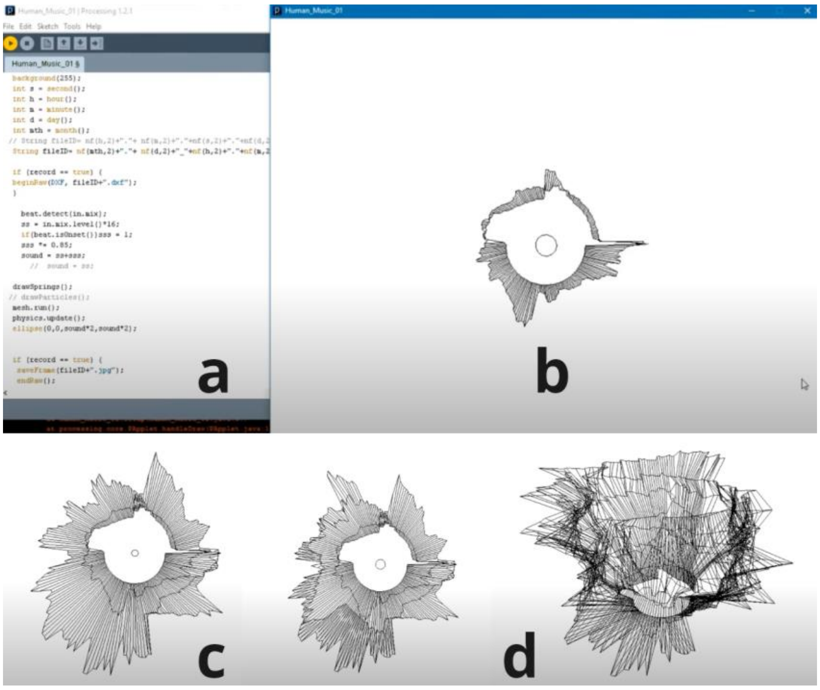


Figure 2.10 Processing software and generation of the vase forms (Jonathan Keep, 2017).

Using Processing software scripts (Figure 2.10a), the artist explains in his YouTube channel video (Keep, 2017) that he coded a point moving with time over an upward-facing spiral, as seen from the top in Figure 14b. That point moves away from the spiral according to the volume intensity in the music, and the points generated in three-dimensional space are connected as meshes to create a vase-like virtual form. Figure 2.10c shows the growing form from the top view, and Figure 2.10d illustrates a wireframe perspective view of the same form. The length of the song determines the height of the form.

Keep (2017) creates sound sculptures for himself, and no other participant is involved in the making process. Thus he is the coder, designer, and manufacturer of the project. These sculptures are displayed in exhibitions as artifacts. There is no information about whether they are exhibited together with their process. If they are presented as they are, then a similar detachment between the form and meaning occurs in this project.

As mentioned in the paragraph above, Keep (2017) has no participants in the generation process. The artist also selects the songs used as data himself. Thus, their meaning is also in his mind only. Since these artifacts are generated more for art's sake, he is more concerned with representing sound in tangible forms than any communicable or understandable connection between the data and its representation. Still, the preparation of explanatory videos about the process might give some clues about the need realized by the artist for an explanation of how these forms come into existence. Without any explanation, for a foreign eye, the rhythmic bumps on the surfaces might give some hints about different songs and recordings. For that interpretation, an explanation about the existence of a connection to sound should be given. Thus, although these artifacts might create a sense of curiosity in the audience, they lack meaning for the viewer. Still, if the song used in the generation of the vase has significance for the viewer, and at the same time, there is an explanation about the data, then the artifact might gain value since the viewer will have data for meaning-making.

Therefore, for a viewer to be able to interpret the artifact, the sound data used, the song or audio recording, and the way of transformation should co-exist with the artifact and become a part of the interpretation of the artifact. Also, for the generated form to connect with the data, the sound should be reachable to understand possible connections and create a personal translation between hearing and seeing.

2.9.2 Deferred Active Participation

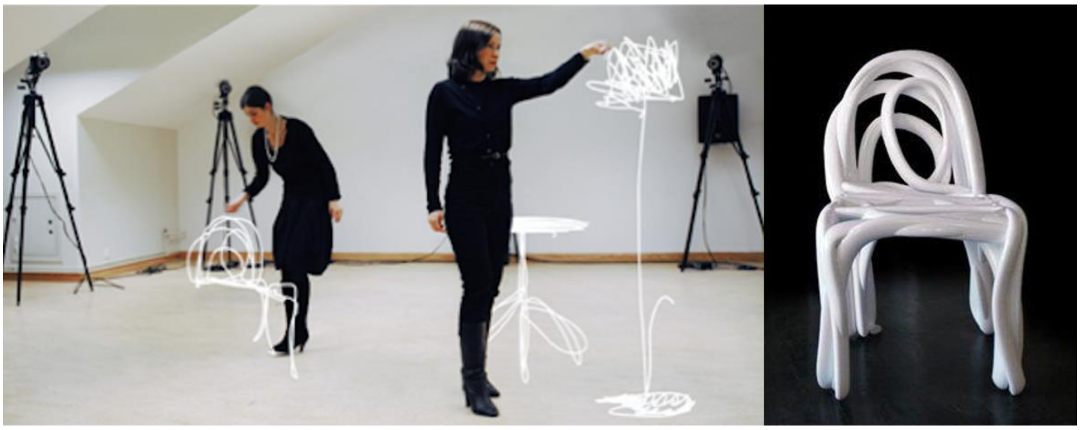


Figure 2.11 Sketch furniture Front Design (Lindgren et al., 2011)

Data Type: Position over time

Sketch Furniture is an exploratory work conducted by Front Design in which the user or the designer uses a special pen to sketch the furniture in the air. A motion capture device records the movements of the hand during sketching. Then the motion capture data is used to construct the 3D model of the drawing, which is later manufactured as life-size artifacts using 3D printing (Lindgren et al., 2011). The resulting artifacts come into existence with their design method, and it becomes hard to separate the resulting artifacts from its process.

Thus, Sketch Furniture needs an additional presentation to realize the meaning of its existence fully. They become the direct representation of the moment of sketching in the air and materialize every exploratory intent that is sketched in the air. Still, without any additional presentation, they communicate the design intent that is sketch-like artifacts. However, without additional explanation of the process, the forms might be interpreted as being modeled by hand to have the appearance of a sketched look. *Thus, the artifact's meaning resides in the story of its making, which requires narrating a story for its creation*.

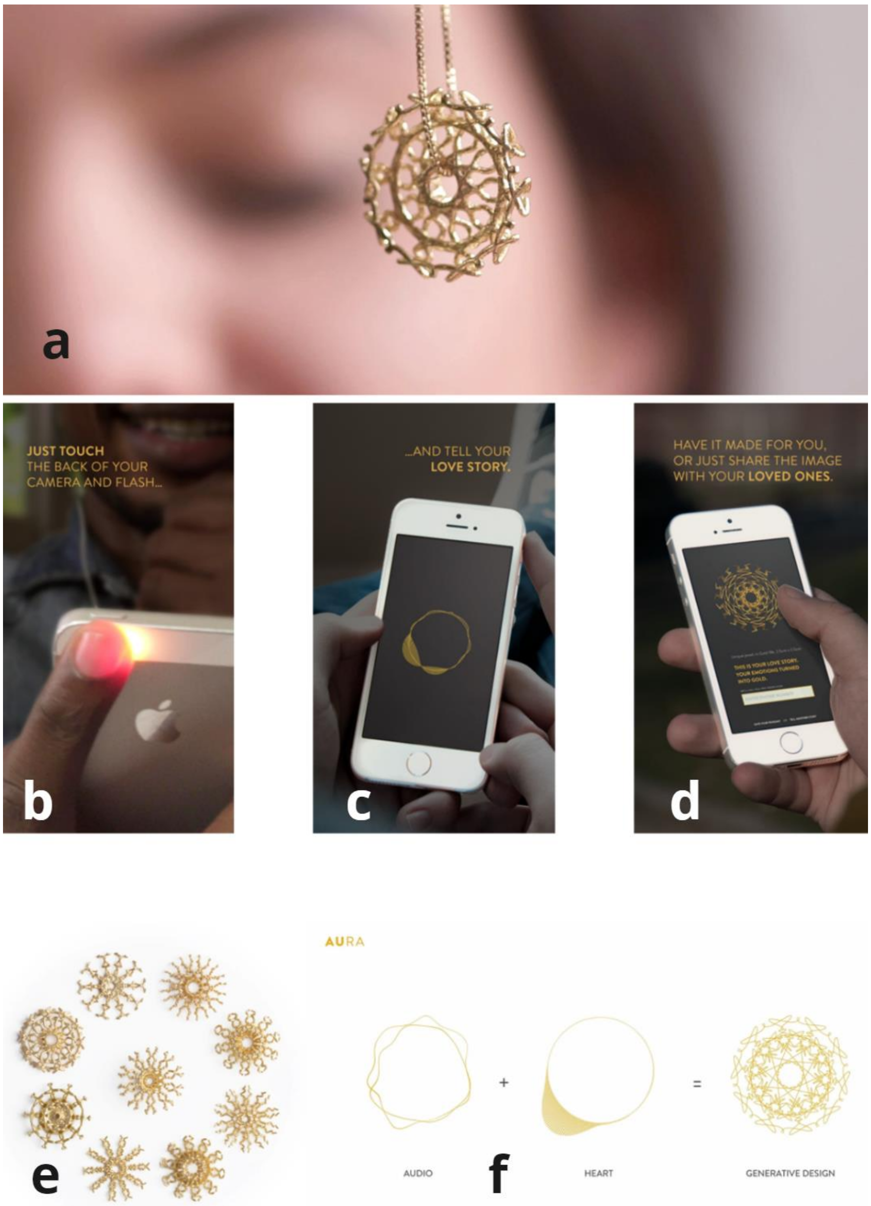


Figure 2.12 Aura pendant application (Requena et al., 2018)

Data Type: Biometric and sound data over time

Aura App is an iOS application developed by Estudio Guto Requena that also realized the Love Project that will be discussed in the following *Real-time Active Participation* section. Compared to the Love Project, this application is much more reachable by the public since it is a free application that everyone with an iPhone can download from iOS Appstore and use. It uses the user’s heartbeat and sound data to generate bespoke jewelry pendants (Figure 26a). The application uses a smartphone's camera LED light for heartbeat data and a microphone for sound recording. After opening the application, it prompts the user to wear headphones and only allows proceeding after plugging in headphones. Then a narrator explains the application idea by saying, "What if you could touch your love story, make the intangible tangible…." Then it continues guiding the user to find a quiet and comfortable place and wants the user to place the finger over the camera to detect the user's heartbeat (figure 26b). With some additional prompts, the user sees a real-time visualization of his/her heartbeat and voice on the screen while recording takes place in the background. When the finger over the camera is taken away, the application stops recording and automatically passes to the next step; a loading screen showing the pendant is generated. Finally, the generated form is visualized on the screen (figure 26d), and options like ordering it or saving it as an image to our phone are shown.

The application guides the user skillfully in terms of user experience. However, when the abstractness of the data representation is considered, the Aura application is even more abstract than the Love Project. This is probably due to some limitations of using a mobile app and device. Still, the main issue with the result is that the user cannot connect data to the resulting form other than believing something sophisticated is happening inside the phone that generates this unique form. On the project's Kickstarter page (Requena et al., 2018), if the project reaches its second funding goal, the project's creators mention that they will develop a system to store and listen to the recorded messages in the app. This feature would enable the user to uncover what the artifact represents by reaching the audio recording. However, there is no such feature in the published application since the project could not reach its second funding goal.

The project presentation on Kickstarter repeatedly mentions that each form is unique to each story so that the resulting form will be one of a kind. Although each form is unique, as seen in figure 26e, the resulting forms would be hard to differentiate and connect with data because of the symmetry and the small scale of the mandala-like representations. *Despite being aesthetically pleasing, it becomes impossible for the user to decode the meaning since the translation process is hidden from the user*.

Figure 2.13 Printed by Parkinson's: An art collection created by the first machine affected by the human disease (Innocean Europe, 2020).

Data Type: Biometric data over time

Printed by Parkinson's is an art collection of artifacts and a project to raise awareness about Parkinson's Disease. The presentation video (Innocean Europe, 2020) introduces the collection as "an art collection created by the first machine affected with a human disease." Six patients were selected that lived through problems related to their professions because of Parkinson's Disease (PD) (Feldmann & Kühn, 2020). They were interviewed about an object or activity they had trouble with because of the illness. During the interviews, their EEG data is recorded and then used to distort the surfaces of objects that symbolize their difficulties. For example, if the patient is a photographer, a camera model is used and distorted according to the EEG data. The conceptual connection between the nature of the disease, trembling, and the surface distortions of the objects creates a significant connection with the manufactured objects. Even without the explanation, the surface distortions can give clues about a connection between the disease and the difficulty it creates for the patients.

This example is different from the others that it connects personal data (EEG and other sensor data obtained from the patients) with symbols (artifacts that patients have trouble using) and projects the meaning arising to communicate an idea to the public. Since the project's primary goal is to raise awareness, it establishes that through using data and physicalization to create tangible evidence of the effects of Parkinson's Disease.

In this example, the creation process of the artifacts and the data used for its generation convert the artifact into a symbol for communicating an idea, which is PD's complicating effects on a person's life. Also, the choice of objects effectively illustrates the strength of using symbols to convey a message to the public. The illustration of the main idea, the tremor brought by Parkinson's Disease, becomes more important than the accuracy of the representation of the captured data. The variable becomes not the user data but the symbols that are changed to represent different stories of patients. Of course, the words like "machine affected by human disease" is a marketing trick to enhance the message since the 3D models of the artifacts are "affected" before 3D printing by using the collected data by the designers. Still, the design of the physicalization makes the questioning of the accuracy obsolete.

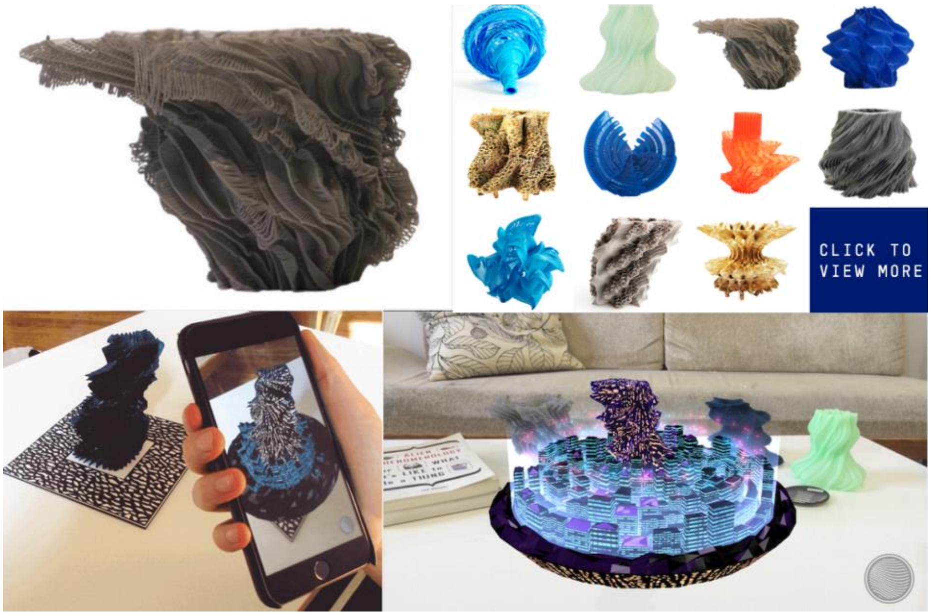


Figure 2.14 Reify project creates artifacts from songs and overlays that song onto the physical object with augmented reality (Wood & Gowda, 2015).

Data Type: Sound frequencies modified to match user interpretation of sound (no exact information)

Reify started in 2015 as a Kickstarter project in which Wood & Gowda (2015) aimed to re-create the tangibility of music CDs, as Wood stated in a TEDx talk (2015), in a technology-driven manner. The project involved designers, programmers, and artists who generated these artifacts from the songs by analyzing audio signals (Figure 2.14).

However, no detailed information is provided anywhere about the process. In the updates section of their Kickstarter page (Wood & Gowda, 2015), Wood explains that she was printing direct physical representations of sound by herself two years before the launch of this campaign (Figure 2.15). She adds that she was not satisfied with a mere representation of the sound but wanted to "capture the way" she felt when she heard those sounds. Then she transformed her need into the project's goal "to create a new visual language for sound, one that simultaneously represents the sound and the human experience to it" (ibid.). The user studies in this thesis back this comment since nearly all participants tried to represent their feelings about the memory or sound they brought. In other words, they have manipulated the artifact in ways that align the result with their emotions and interpretations about the sound recording they have brought.

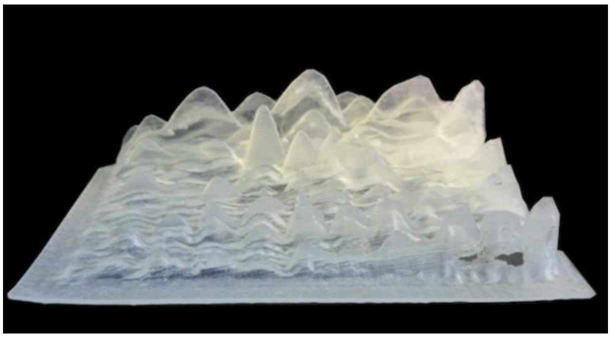


Figure 2.15 Allison Woods's initial trials with making sound tangible (Wood & Gowda, 2015).

According to the project description on Kickstarter, their process consists of four stages: mapping, design, production, and release. In mapping, they partner with the artist and present visualization templates they have developed using parametric design software. The abstract 3D model generated in the first stage based on the artist’s preferences becomes the foundation of the next step: design. At this stage, the designer and the artist/band collaborate to match the artist/band’s creative intentions and visual aesthetic. Then in the production stage, generated and further customized models are 3D printed and encoded with augmented reality using Unity 3D Engine (a cross-platform game engine that allows the development of applications and games for mobile and desktop platforms) and Vuforia (an augmented reality development platform that works in Unity 3D Engine). The final release stage involves making the experience public through their custom-developed AR application.

The forms generated have some visual connections to a previous project called Microsonic Landscapes. However, due to the artists' preferences, they are further modified by some geometry deformations such as twisting and bending.

From the meaning generation perspective, the artifacts were made for not everyone but for selected artists/bands with whom they co-worked during the creation process. The resulting artifacts, therefore, have become representations of the preferences of these artists/bands. Then, these resulting artifacts became meaningful for these bands and their fans. This argument can be supported by a comment on Reify's Kickstarter page made by a visitor to the project page (Wood & Gowda, 2015):

> ”Pity I don't know any of the bands. I suppose it's not possible to create totems for more mainstream bands because of artist rights, is it? If you had some Coldplay totems, I'm sure this would have gone through the roof.”

Since the music bands are unknown to the commenter above, the resulting artifact might not have any meaning. Thus, for public physicalizations of sound/data, the data source's familiarity is crucial in a meaning generation.

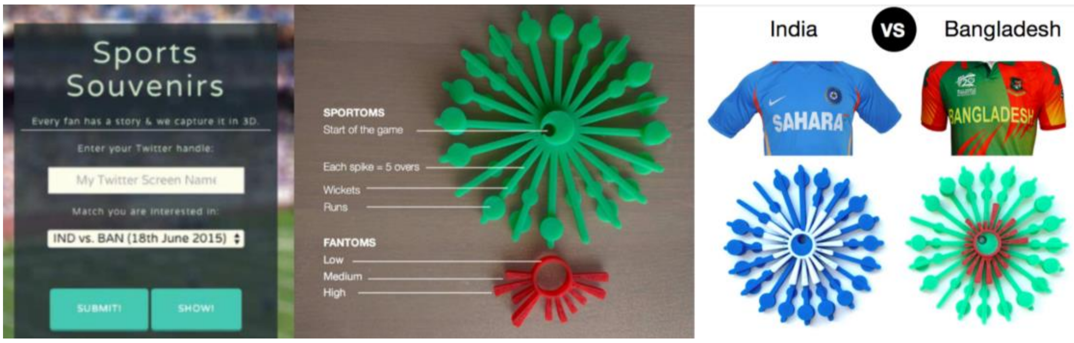


Figure 2.16 Fantibles: Resulting artifacts from Andres et al.'s study (2016).

Fantibles (Andres et al., 2016) research project is an example from HCI and interaction design field that aims to create memorabilia by capturing nostalgic moments in artifacts. The study is conducted in India, where cricket teams have devoted fans and are so passionate about their teams that a team's success can mean their success or failure. Fans that go to the stadium can collect mementos such as tickets, selfies, and video clips from the match, but not everyone can go to the stadium. The authors argue that since home viewing of these matches does not afford the collection of physical, permanent artifacts, the memory of the matches fades slowly over time.

To create artifacts for reminiscing, they designed a method to transform match data with Twitter data to create physical artifacts. The artifacts called Fantibles (*fan-made collectibles*) are 3D printed representations of cricket match scores over time (the green object in Figure 2.16) overlapped with participants' tweets about the match and the excitement level in that tweets. This way, they combine the moments in the match with the excitement level of the participant, creating an emotional representation of the match. This example is explicitly selected because of its unique combination of public data with personal data and because it aims to create an artifact based on memories.

Making the data of the cricket match physical and a tangible artifact enabled *frequent engagement with the memory* since the participant did not need to open files on the computer to reach the data. The making of the artifacts from a biodegradable material PLA is well received from the perspective of durability by the participants. They appreciated that these materials would not wear and tear easily or degrade colors. However, two participants wished the artifacts could be made of bronze, silver, and gold.

Adding the tweets layer over the match statistics enabled *personalization with personal data* and made the artifacts unique to the owner. Also, they triggered self-reflection and facilitated remembering the moments in the match according to their emotions. After realizing the effect of tweets on the artifact form, they started to tweet more during the next matches trying to alter the form of the artifact. This behavior change also made the artifact a tool for self-expression.

The resulting artifacts enabled the participants to take their "feelings offline" (Andres et al., 2016, p. 890) even after the event was finished. Also, they could keep their memory as a tangible artifact. The abstract shape of the artifact enabled privacy so that they could showcase the artifacts in public without being concerned about revealing their emotions if they did not want to. The abstractness also facilitated *personal narration* of their experience to the ones who showed interest in the artifact.

This gave the feeling of *encoding* their emotions in the artifact, making it unreadable to the foreign eye.

From the perspective of meaning and value generation, this Fantibles study (Andres et al., 2016) illustrates how integrating personal data into public data can significantly enhance the personal meaning of an artifact.

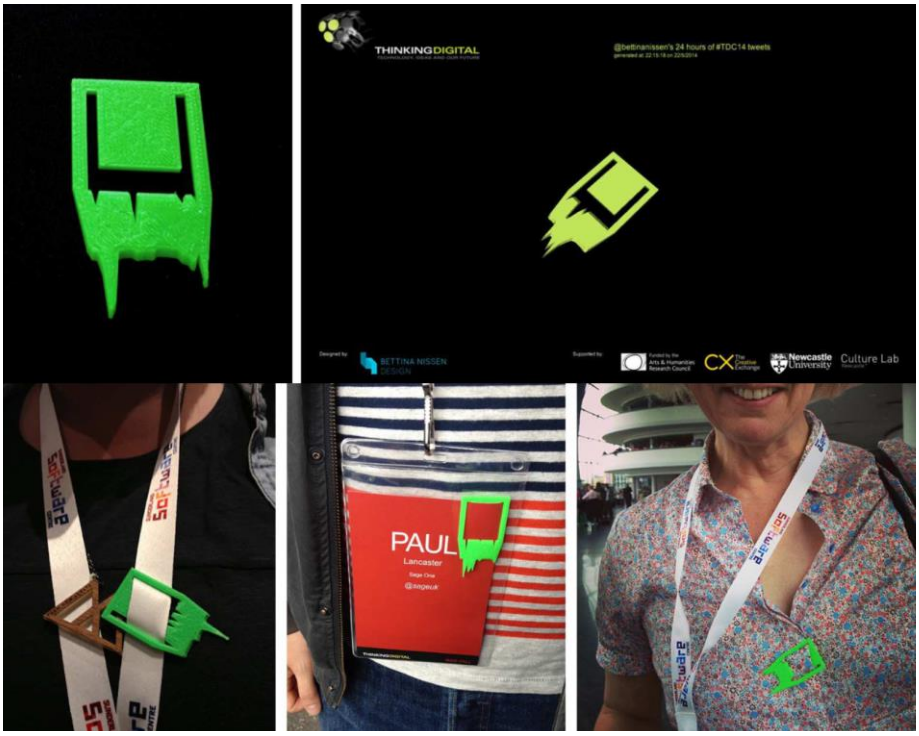


Figure 2.17 Conference tweet translations in the form of wearable clips (Bowers & Nissen, 2015)

In their Data Things article, Bowers & Nissen (2015) conducted two participatory design studies, one of which was situated in a conference environment. They argue that involving the participant in the process allows them to "invest meaning into" the artifacts, encourage social interactions, and facilitate self-reflection. They have developed an "algorithmic design system" that translates a participant's tweet intensity about a conference into physical artifacts in the form of a wearable clip shape (Figure 2.17). The artifact represents a 24-hour time frame; the tweet count per hour is “graphed” as two parallel ridges that the tweet counts modify. They have used custom scripts using Processing (www.processing.org) to automatically track hashtags related to the conference and algorithmically generate the 3D forms accordingly. The spikes in the form represent periods with high numbers of tweet activities. Two lines are used to represent tweet activity: top and bottom. The top one symbolizes personal tweets, while the bottom represents public tweets related to the conference. It was designed in the shape of wearable clips so that people could wear them and act as objects of conversation. Visualizing personal data as tangible artifacts creates a common ground for people to talk to each other in a conference environment. When the representations are recognized, they create a common ground for communication. People can start asking questions about someone else's artifact and start new conversations. They also become a way for self-expression. People can compare their tweet counts or activities with others by comparing personal and public timelines of the tweets.

Personal data enables the creation of social products that can help communication and act as conversation starters. This argument can be supported by a participant response in this thesis' user studies. When reflecting upon the artifact created by his sound recording, the participant calls the artifact "talkative" and "curious" objects, referring to the interesting shape of the artifact (as discussed in CHAPTER 4)

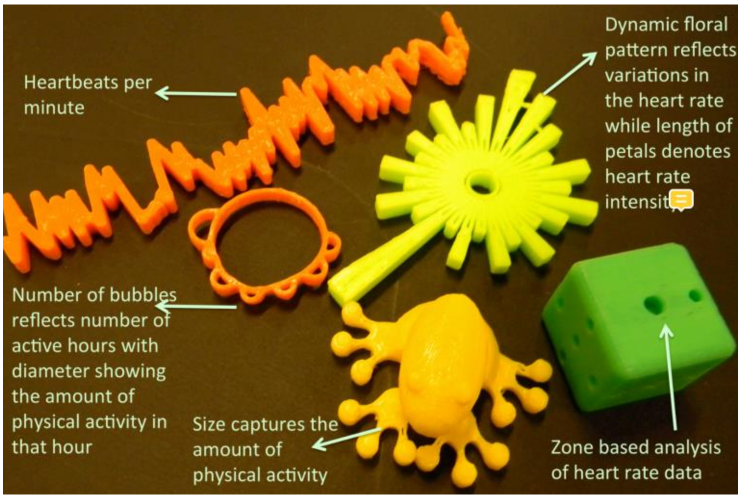


Figure 2.18 SweatAtoms: data physicalizations of personal activity (Hjorth et al., 2014)

Data Type: Biometric data over time

Hjorth et al. (2014) created physical artifacts from physical activity data to understand how those artifacts can help self-reflection. They tracked several participants' heart rates via personal trackers and converted them into five different artifacts manufactured with 3D printing. The study was conducted on seven participants who were required to track their daily heartbeats and 3D print the artifacts in dedicated 3D printers placed in their homes. In addition to the heart rate data, they were required to keep a diary.

The representation of data is presented in five different versions: graph (abstract and reflective representation of heartbeats over time in a graph-like physical artifact), flower (abstract and unique representation of a flower shape where petal length is determined by the heart rate and width by the duration of that heart rate), frog (abstract and cheerful representation made from a frog whose size is determined by that day's activity amount), dice (abstract and reflective representation that can be stacked together to compare different users' data) and ring (reflective and public representation where the number of bubbles around the ring represent the number of active hours that day).

Printing their artifacts at home excited the participants initially; however, the excitement faded with time. The researchers required the participants to make the prints daily, of which two participants skipped several days. Some participants did not like the daily printing requirement and wanted more selective control over what and when to print. The frog visualizations caused additional motivation towards more physical activity since more activity meant bigger frogs, causing behavior change in participants. Some of the participants started to compare their frogs with each other.

The artifacts manufactured in this study are more ephemeral from the perspective of meaning and value generation than other data transformations. Two factors cause this difference. First, the artifacts are generated frequently, daily, which makes the participants less sensitive to the artifacts after some time. Second, the significance of heart rate data that has been collected in the study is not much different from any other ordinary day. Therefore, the data represented in the artifact becomes a reflection of that. Also, it does not involve user input other than the users' heart rate data.

Figure 2.19 Heart rate data on a plectrum (Karyda, Lucero & Mekler, 2021)

Contrary to this example, in Karyda, Lucero, & Mekler's study (2021), the heart rate data of a user that played bass guitar in a concert was collected for three hours. During the interviews with the user, they found out that the concert was significant for him. The resulting artifact, a plectrum (Figure 2.19), turned out to be as if he was given some part of himself (Karyda, Lucero & Mekler, 2021, p. 7). Therefore, the data connection with memories and what they symbolize for the data owner has significance in a meaning generation.

Figure 2.20 Meshu personal jewelry from flight patterns (top), the custom path created by a consumer, and her comments related to her travels (Hwang & Binx, 2015).

Data Type: Position over time

Meshu.io allows users to create jewelry from their travel data without prior knowledge of fabrication and data visualization (Dragicevic et al., 2014). The service has been created by the authors Hwang (Information designer) and Binx (data visualizer and mathematician) (Hwang & Binx, 2015). The online service was closed during the writing of this thesis. Therefore, including the user experience in the discussion is not possible. However, the main idea is to use a person's geospatial data as a material to create personalized jewelry. Meshu materializes the places that the user has been over the days, weeks, years, or even a lifetime. Therefore, the period for the data entirely depends on the user, and the visualization of time as a dimension is not present in the final physicalization. However, a timeline of the places the user has been residing in the mind of the data owner. Thus, looking at the final piece (a piece of jewelry), the user can reminisce about the places s/he has been to, represented by its form.

Dragicevic et al. (2014) argue that in Meshu's system, the user does not have much control over the form in the interface. The user can select jewelry material and the manufacturing method, such as 3D printing or laser cutting. The user can load the coordinates of places s/he has been to the interface. Then the final form is generated from those coordinates. This makes the system very deterministic and does not let much experimentation or personalization over the final form. However, the shape becomes an exact representation of where the user has been. So changing the shape would also mean changing places that have been traveled.

While beginning the project, the authors focused more on the technological side of using data in generative systems and making them tangible via laser cutters and 3D printers (Binx & Hwang, 2015, p. 291). However, as they explain in the *Encoding Memories* article, they understood the project is about people reminiscing, treasuring each other through gift-giving rituals, and honoring places they have visited together. They give examples from some users' stories, such as a boyfriend marking all the places they met with his girlfriend across their country, a wife marking all the places they have visited with her husband during their retirement trip, and others tracing routes, streets, honeymoons, and many other examples. So in this way, using only location data, a GPS location of a place can become a symbol and trigger for a treasured memory and contain an infinite amount of different meanings since each location would have a different meaning for everyone.

When gift-giving is considered, Meshu operates on a *shared memory domain* that can be explained as a memory that two or more people have in common. Thus, a single artifact made from the places that two or more people have visited together creates a shared meaning and can be *decoded* in different minds. The artifact's abstractness combined with the memory stored in the users' minds creates another special case for these artifacts: being able to hold a memory that is invisible to outsiders. In the beginning, the authors (Binx & Hwang, 2015) were also plotting the street grids and country lines which they later decided to remove. The grids and country lines provided too much information for a foreigner, and the creation of an abstract language enabled privacy for the users' data. This way, the users can give as much information as they like about the memories and even leave them entirely hidden from unwanted eyes.

Another aspect of the Meshu project relevant to this thesis is using personal memories and meaning as input data. In their internal tests, they used the places of restaurants they liked or places they visited on vacation. However, they feared that these memories and examples would remain too obscure. So they thought they needed some generic examples to illustrate how the service could be used. In order to establish the understandability of the service, the authors decided to use some symbolic premade example artifacts such as art museum places in the United States or neighborhoods in New York. As the authors explain, they learned from the founders of Nervous System (see 2.4.4 Product Personalization) that people were playing with their generative system but then purchasing a premade design rather than having their own manufactured. Inspired by this, the authors thought the premade examples would provide an entry point for the users. However, after the launch, they got pretty surprised:

> "Launching, however, surprised us. The initial wave of orders overwhelmed us, but what became immediately apparent was that people were using Meshu in a very different way than we had imagined. We had imagined most of our users to be excited about our work combining data visualization with rapid prototyping, but many of our customers knew about neither. Rather than a shiny new toy, people understood Meshu as a way to reflect on the places they had been, and the special moments they had shared with loved ones." (Binx & Hwang, 2015, p.289)

This case study from Meshu's launch illustrates the importance of memories as a meaning and value source from the users' perspective. Although the data can be straightforward, an x and y coordinates over the world, the meaning and value it can introduce in an artifact are unlimited. *So the way that value can be abstracted in form* *and its affordance to storytelling positively affect the value and meaning of the artifact.*

The representation of time in the artifacts of Meshu is quite different from the other examples presented in this section. The data that is used in Meshu, the geospatial location, can contain very different time frames. This is similar to the sound data of a song reminding a person of different memories from different periods of his/her life. Still, geospatial data, especially the way the Meshu users have utilized it, have the affordance to combine different memories into a single life story. Places from childhood, teenage years, and adulthood can be represented in a single artifact. Similar is valid when the user wants to combine memories with different people. The artifacts can combine different periods and scales, e.g., places in a city in a specific year and countries that have been visited in a lifetime.

Hanson (2010) argues that as people and artifacts change place through time, they pass through constant transformation, and these transformations become connected. It can be deduced that as the time spent with an artifact increases, the potential for the creation of meaning related to that artifact increases. So this work is doing this meaning transformation from the reverse. It gathers past experiences and manifests them into a single artifact through symbolic relationships.

From the perspective of meaning generation, the extent of the personality of data is significant in creating meaning and value in the resulting artifacts. Also, as the authors argue Binx & Hwang (2015) argue, the users do not care about the technological aspects of the system but rather to the extent they can create stories and meanings related to their memories and loved ones.

Figure 2.21 Waveform Keychain from “I love you” by Bizer (n.d.a)

Data Type: Sound intensity over time

In David Bizer’s work, an audio recording is transformed into an earring, pendant, or keychain by 3D printing and shipped back to the consumers through a 3D printing platform shapeways.com. The user sends him a custom request and the audio recording to be transformed into jewelry. Bizer creates the 3D model (no information about what techniques he uses) and uploads it to the Shapeways service. The user then purchases the artifact over a private link which is then manufactured and sent to the user’s address.

Bizer (n.d.b), in a dedicated website to this service, www.soundwave.love, states that this is a project he has been doing since 2008, originating from his thesis studies. Although no information is given about the conversion process, the waveform used in the figure tells us that the audio waveform of the recording revolves 360 degrees to create the earring form. The presented image is created out of the words "I love you," which can easily be connected to the form since the changes in the waveform are understandably connected to the resulting artifact.

The intensity of the sound volume versus time determines the overall shape of the resulting artifact so that certain emphasized words or tones can be visible throughout the form of the artifact. Although for the foreign eye, the shape of the artifact might mean nothing, for the owner of the artifact and the person who knows what the audio recording was about, it might act as a very personal memento. Also, since the form is only “readable” by the owner, it adds another private meaning dimension, thus increasing its value.

When thought from the perspective of individuals with a deceased relative or lover, such applications bring unprecedented value since a person can use a sound recording of that deceased person to materialize it in such a way that s/he has the chance to “touch” that deceased person again, but this time to his/her voice. Also, making the sound tangible introduces the permanence of the memory, typically connected to an ephemeral memory source, sound.

The artifact can easily connect to the waveform and spoken words in the example presented. For example, one can easily understand which part of the earring corresponds to the word "love." This legibility is possible because of the simplicity of the form. However, the presence of time as a dimension in the object establishes the connection between sound-time with space-time. Sound recordings are also the distribution of audio frequencies over time. Therefore the time dimension in the recording connects with the length dimension in the physical artifact. Thus, it creates a strong and meaningful transformation from sound to artifact. However, for longer recordings, understanding to form might be harder, causing some legibility problems in the artifact. Since the transformation process (the artist/designer does that process by himself without user participation) is not visible to the user, for more complex forms, the artifact might lose this strong connection to the audio and memory it represents. When this happens, involving the user in the artifact generation process might provide benefits in creating the connection between the data and the artifact.

2.9.3 Real-time Active Participation

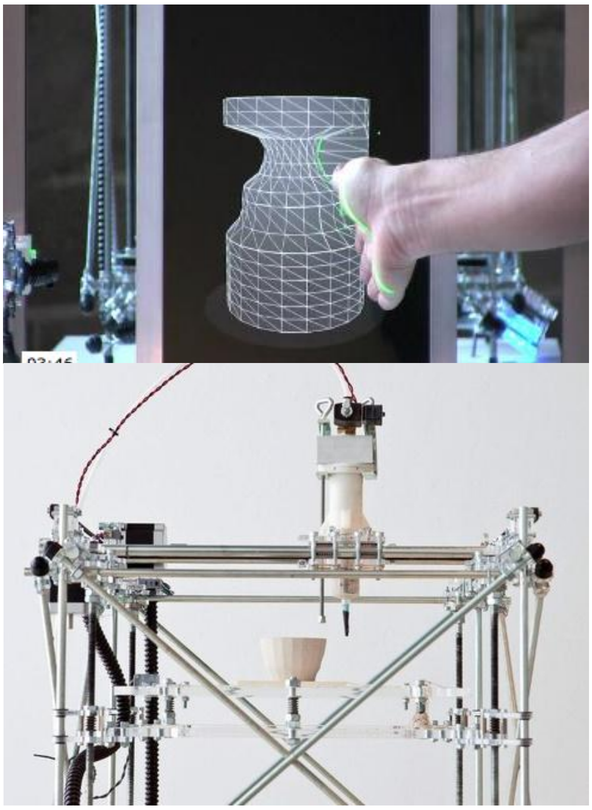


Figure 2.22 Unfold - Projects - L’Artisan Electronique (L'Artisan électronique 2010)

Data type: Position over time.

Unfold is a design studio founded in 2002 that investigates the role of the designer and shifting, blurring boundaries between the professional and amateur with the increasing digitization of manufacturing methods (Schillaci, 2018). In the L’artisan Electronique exhibition, the setup consists of a laser to detect the place and motion of a hand to deform a virtual clay model resembling traditional pottery techniques. After the user modifies the virtual clay using this apparatus, the resulting artifacts are saved and 3D printed in a specialized 3D printer that uses clay as the build material. This application transfers a traditional analog technique to a digital medium. It lets the user feel familiar with the interface rather than using complex CAD software with a mouse and keyboard. Body gestures are translated into first digital coordinates and then to a physical form. Although the designer ultimately designs the interface, and there certainly are some predetermined values (e.g., the deformation allowance of the form), the user experiences the process so that the resulting form/artifact seems to be made entirely by himself/herself.

The primary relevance of this example to this thesis is that the method designed in this project empowers an ordinary user with potter skills without any need for training. The system provides all the necessary translations, tools, and materials for the user's design intent to be materialized through data collection and translation into a three-dimensional artifact. The meaning is generated through the investment of the user’s lifetime (Czikszentmihalyi, 1991) and effort into the process combined with the realization of the user’s decisions on the final form of the artifact.

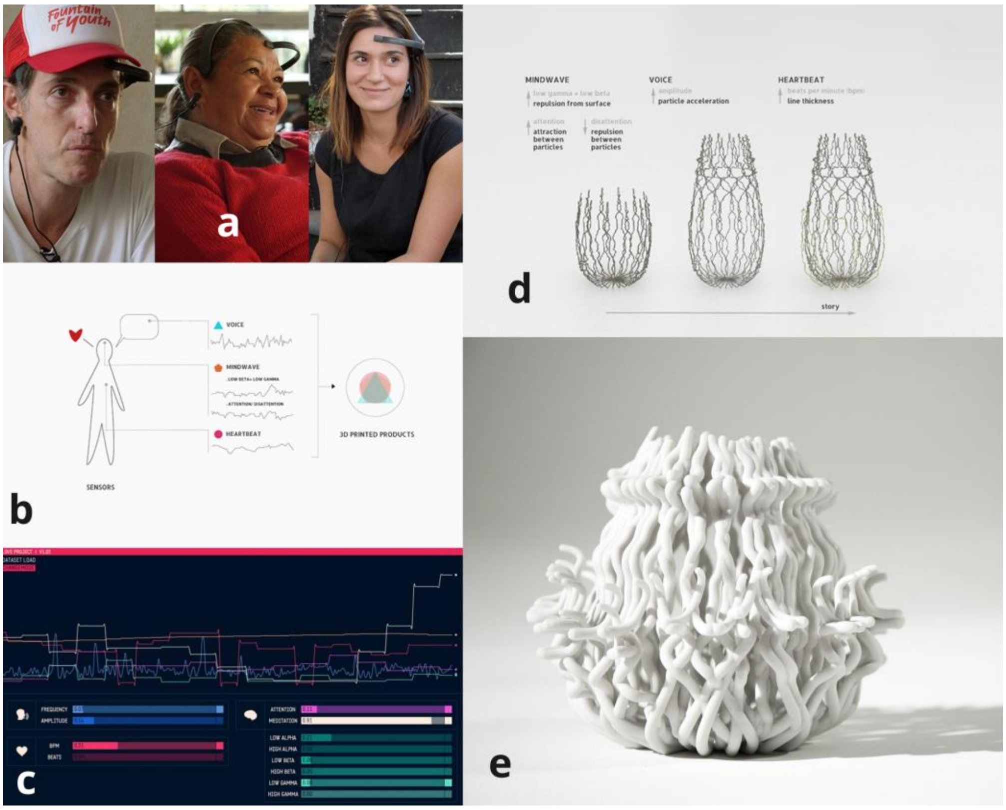


Figure 2.23 Love Project by Estudio Guto Requena (Requena, 2014a) a) participants with EEG sensors b) types of collected biometric data c) real-time screen showing the data flow d) generated forms and parameters used from the data set e) one of the resulting artifacts.

Data type: Biometric data and sound intensity over time.

Love Project (Requena, 2014a) is a social experiment by Estudio Guto Requena in which participants are invited to a session and attached to sensors that capture brain activity (Figure 2.23a), heart rate, and sound. In the project, an event is planned, and participants are invited. The participants are prompted to talk about someone they love and their story. While talking, the data collected from all the sensors are fed into a system that generates these vase forms, which are 3D printed as physical items (Figure 2.23e).

Although not much information is given about the tools used, the session's video recordings show a parametric design interface, Rhinoceros 3D (three-dimensional modeling and design software), and Grasshopper (node-based parametric design plugin for Rhinoceros 3D) is used to generate these forms from the data collected. The transformation into form happens in real-time; however, no information is given about whether the participants see these forms in real-time. The participants in the video seem to be more into telling the story of their love. The generated 3-D virtual forms are then manufactured through 3-D printing.

The data collected (Figure 2.23b) has three dimensions: voice, mind wave, and heartbeat. Mindwave and heartbeat dimensions can be seen in Figure 2.23c, which are varying values, and numbers over time. These values generate symmetrical forms, vase, bowl, or lampshade forms that begin from the ground and go upwards as time progresses. Although there is no exact information about the form generation procedure, Figure 2.23d provides information about the rules that generate the template form, thus explaining the connection between the data and the generated geometry. In the beginning, some particles are generated and start to move upwards, following an invisible vase form’s surface while leaving trails behind their path of motion. The brain waves and concentration amount determine how close or far these particles will be from each other and the imaginary vase surface as they move upwards with progressing time. The participant's voice controls the acceleration of those particles, while the heartbeat data controls how thick those trailing lines will be. Since all the participants will have different combinations of brainwaves and stories to tell, each vase generation creates a unique output from the system.

Inspired by the Love Project example discussed here, Bingham, Green & Porter (2017) discuss the depth of meaning that can be decoded from the represented data by comparing a poem's words written on letter wrapping paper to a DNA sequence that is coded with the letters of different enzymes. The meaning can be derived from the words of a poem at a deeper level. However, for the DNA sequence, it would be impossible to derive other than what it represents. This is connected to the *abstractness* attribute of the product that is to be personalized with meaningful data (Bingham, Green & Porter, 2017, p.9). The authors explain this by arguing that semantic interpretation is hard for some data. Without additional information, an outsider can decode the meaning from a poem but not from a DNA sequence. Similarly, they argue that the data used in the Love Project's artifact is "semantically and symbolically opaque to the uninformed viewer" (ibid., p.10). In other words, an outsider without accurate information cannot decode the connection between the variations of the artifact form with the participant data, thus, the artifact's meaning (ibid.). A viewer with information about the data and its connection to the form generation rules can interpret that a thicker part of the vase would mean a period with higher emotional activity. However, for Reify projects' artifacts (Figure 2.14), this is not possible since there is no information provided about the form generation process (ibid.).

Despite the analysis done in the paragraphs above, there is no information about the participants' responses to the outputs. Information on whether they wanted to control the vase form with their change in thought patterns or change their way of talking to change the speed of particles is not reachable. It can be anticipated that an almost ritualistic data collection process might have decreased participants' focus on how the form reacts to their behavior and thoughts. Moreover, the data collected involves the participant's attention evaluated by the brain waves. Therefore shifting their focus from their story to the vase form would contradict the aim of the experience. Also, it can be argued that the translation moment of the data collection and experience becomes a part of the artifact.

The translation of brain waves with heartbeat rate and voice ensures the uniqueness of the collected data and, thus, the form generated. However, the data and complexity of the method of its representation might make the form harder to interpret for meaning-making. The form represents the participant’s self while telling the love story. However, the words and their meanings are lost in translation, and the amount of variables makes connecting the input data to the output harder. This example focuses more on the unique form generation side of things and aims to create meaningful symbolic artifacts.

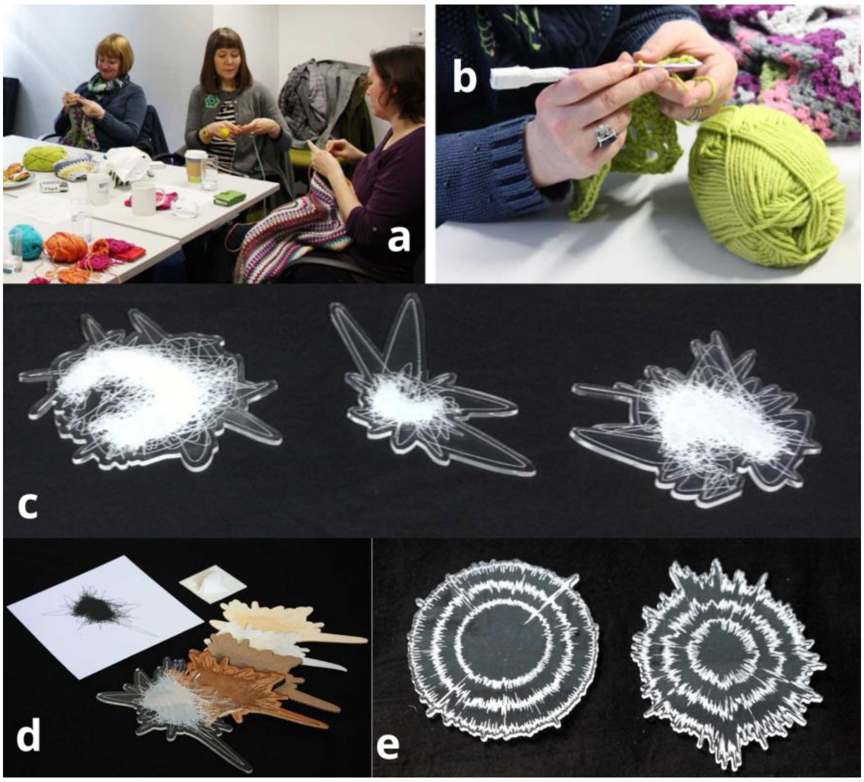


Figure 2.24 Craft movements translations in Data Things study process. a) initial discussion session with crochet practitioners b) wireless motion sensor used on the hooks c) initial abstract representations of the collected motion data d) data representations from the first workshop printed to paper and cut from different materials (Nissen & Bowers, 2015).

Data type: Position over time

In the *Data Things* article, Bowers & Nissen (2015) present two studies: first with the wearable clip artifact (discussed under the Deferred Active Participation section in this thesis) and second utilizing motion data of a group of crocheters. They designed a study involving crocheting and conducted a workshop with four to six local crochet practitioners with different experience levels (Figure 2.24a). Participants were given crochet hooks with motion sensors connected (Figure 2.24b) and expected to do crocheting. Then the motion data is translated into motion data representations by using Processing scripts that were etched and later laser-cut to create artifacts (Figure 2.24c).

The study started with discussions on the participants' experiences in crocheting. During the discussions, a test data collection was made to see how the data could be represented and if different participant data could be distinguished from each other. After the initial discussion sessions, two sessions of this study were conducted. The first was more of an exploratory phase, and the second involved an iterative method designed according to the feedback collected from the participants.

In the first workshop, the participant data was collected and translated into graph-like form, printed on paper, and cut from different materials with laser-etched plots (Figure 2.24d). Different materials aimed to probe participants' responses to them and spur some conversations among the participants. While evaluating participants' responses, one prominent request was to see the translation of their crochet hooks' movements into the generated forms live so that they could "see how it works" (Bowers & Nissen, 2015, p. 2471). Another concern of the participants was the aesthetic disconnect of the initial representations with crochet. The researchers developed a real-time version of the visualization system upon these concerns. Also, they changed the representations into a reorganized version, separating the x, y, and z coordinates of motion data into three concentric circles that start "to show the data more recognizably as stitches or rhythm" (ibid.).

Seeing the motion data translated into a form in real-time enabled participants to explore the connection between their movements and the resulting forms. One of the participants slowed down and even stopped to move the hook around just to understand generated form's response to his/her change in behavior. The authors argue that this showed participants' interest in how their movements' translations happen (Bowers & Nissen, 2015, p. 2473). Therefore it can be argued that real-time feedback allows one to understand how the translation from data to form occurs.

Involving the users or participants in the design and making processes creates a sense of meaning. This involvement elicited meaning generation from the resulting artifacts and their process. Also, as the authors argue, including the participants in the data translation process makes the resulting artifacts more familiar than alien objects created by some incomprehensible process (Bowers & Nissen, 2015, p. 2467). Also, it allows participants to understand which parts of the resulting artifacts are connected with which parts of the data, thus facilitating the meaning-making process. Therefore being part of the data translation process increases the legibility of the resulting artifact.

Concerning the legibility of the artifact, the authors compare two different studies they have conducted: One in which the participants were given the resulting artifacts (wearable clip artifacts that represent Twitter activity that is discussed previously) and the other (crochet example discussed here) that they were involved in the translation process being able to modify the outcomes of the translation process. Bowers & Nissen (2015) argue that the one in which the participants were involved required less explanation about the artifact's meaning.

The abstractness and ambiguity of the representations of data in physical artifacts enabled participants to show interest in the aesthetics of artifacts. Also, it enabled them to appropriate some near-future uses of the artifacts. Thus, rather than translating data into contextually connected forms, using abstractness and introducing some ambiguity to the process enables cognitive participation. The authors argue that not using familiar forms for the artifacts enabled associative freedom. The participants became able to associate the generated artifact with whatever they wanted. One of the participants defines the artifact as "written in crochet code" and sees it as a symbol for "Struggling... and succeeding to learn a skill" (Bowers & Nissen, 2015, p. 2472).

As the results of their studies, Bowers & Nissen (2015) argue that the translation activity of data creates opportunities for meaning-making and reflection. Connected to this, the data's "trajectory of use" (Bowers & Nissen, 2015, p. 2467) should be considered. They state that the data passes through multiple translations that can also predate the moment of the study or possible future translations. This openness to interpretation between translations requires "ambiguity and abstraction" that will allow "varied appropriation in use" (Bowers & Nissen, 2015, p. 2475). Also, they suggest seeing "personally relevant data" as an adaptable material that can be captured through the user's participation.

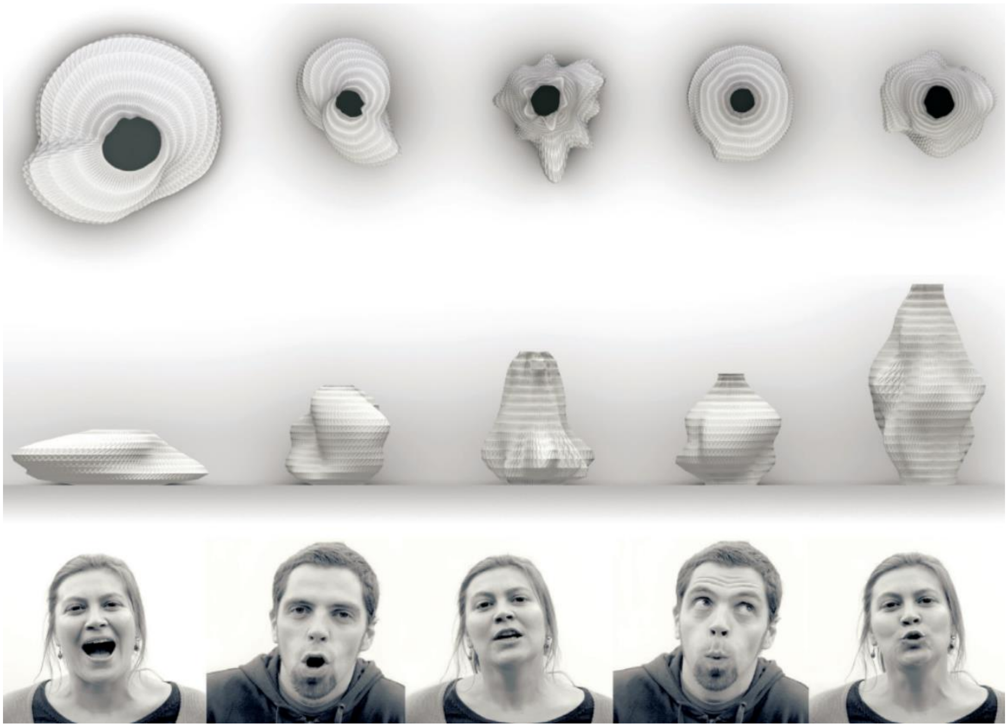


Figure 2.25 Vase #44 Project by In-Flexions (Schillaci, 2018)

Data Type: Sound frequencies over time

Figure 2.25 shows the vases generated in Vase #44 project created by a design studio named In-Flexions was founded by Sonia Laugier and François Brument back in 2009. Their aim in creating this project was to give their visitors "the most intuitive experience" possible (Schillaci, 2018, p. 75).

Vase #44 consists of a system allowing users to shape a virtual form by talking, whistling, and blowing into a microphone to modify a 3D model projected onto a wall. Users can modify a three-dimensional form with their data using an already familiar interface: their mouths. Because of the explorative aspect of the interface, the participants start experimenting with different sounds (Schillaci, 2018). The system generates wider vases for louder sounds and longer vases for longer talks. There is no information on whether the vase forms immediately give a response to the sound recordings (happens real-time) or generate the form after the recording is completed. It is also unknown whether sound parameters other than loudness and duration of the recording are used.

The designers of In-Flexion argue that the designers should also be focusing on the user experience rather than focusing only on "creating the best object" (Schillaci, 2018, p. 72). From the meaning generation perspective, the designers argue that when the users are involved in the creative process, their *history with the object* begins, and the artifact belongs to them before purchase.

Therefore, the interaction experience, from the beginning to the end, is expected to affect the resulting artifact's generated meaning, value, and sense of ownership.

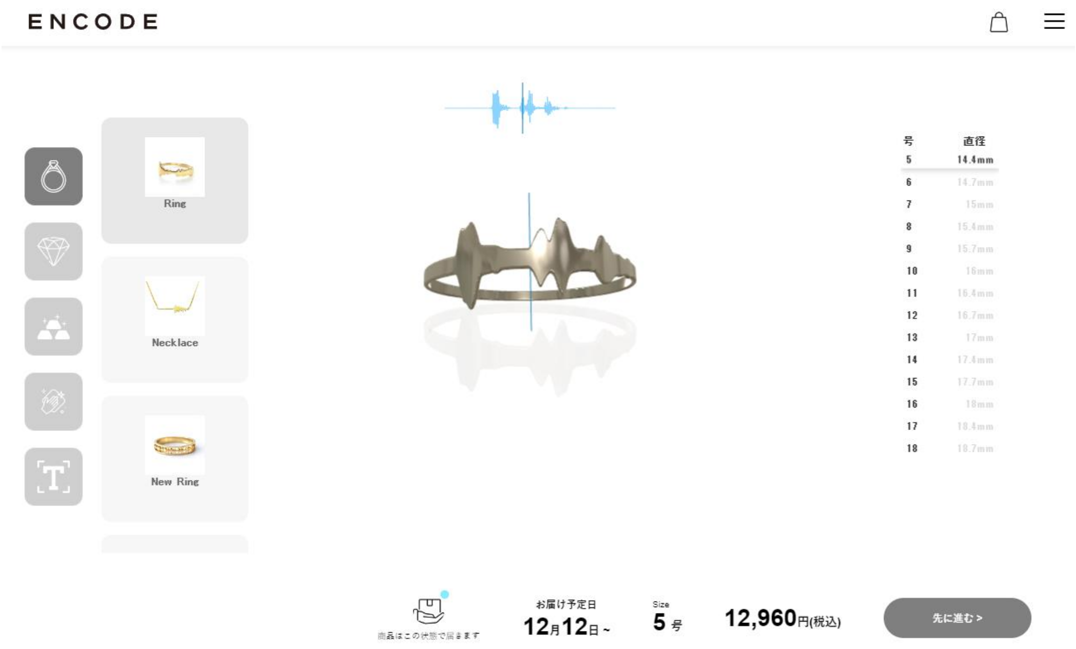


Figure 2.26 Encode Ring (n.d.) website interface

Data Type: Sound intensity over time.

Encode Ring website (n.d.) is a commercial application that lets users record their voices and see the resulting waveform and the artifact immediately after the recording (Figure 2.26). The interface lets the user record the voice, and as seen in Figure 18, a waveform of the recording is displayed with the generated ring. The user also can play the recording while a line scans over the ring form showing in sync with the playing sound. This facilitates the user to connect the form with the recording. New recordings can easily be done, and the results are shown immediately. This way, experimentation with the form and exploration of different sounds can be encouraged.

Figure 2.27 Encode Ring (n.d.) website promotional photo showing 3D printed jewelry.

The interface lets the user choose different forms, such as necklaces or ring designs. The chosen design is immediately visualized in the interface. The user can select materials such as gold and silver. After the user is satisfied with the resulting form, s/he can order the ring through the interface. The ring is manufactured via 3D printing and sent to the user (Figure 2.27). This experience allows meaning creation by involving the user in the process through his/her voice and lets further personalize the form with material options. However, the most critical aspect of Encode Ring among the presented examples is the establishment of a connection between the data (audio recording) and the resulting form through a real-time and in-sync playback of the recording with the generated form. This looks similar to Gilles Azzaro’s work in the Inactive Participation section, which also involves a scanning laser line over the generated artifact. However, this is done with personal data and the user's direct involvement in the form generation. Thus, it results in a much deeper and more meaningful connection with the artifact.

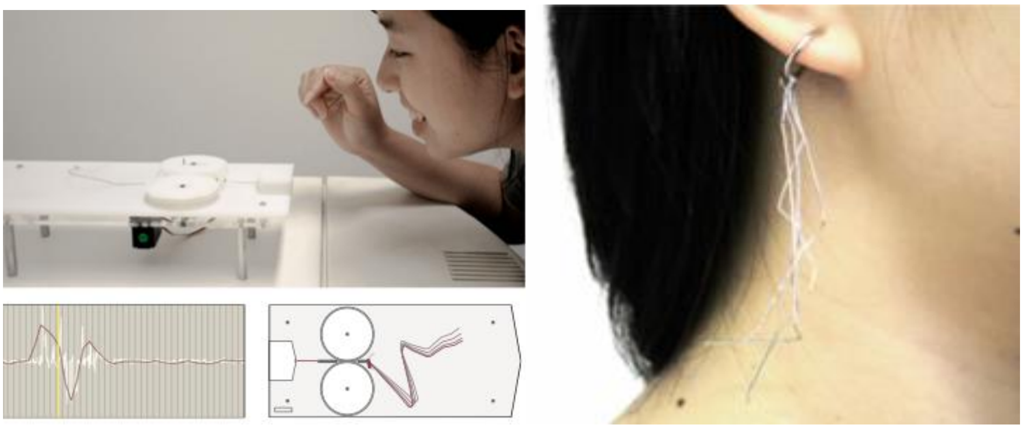


Figure 2.28 Wires bent in real-time according to users' voices (Willis et al., 2011)

Data Type: Sound intensity over time.

Willis et al. (2011) argue that with the increasing usage of digital tools in design and manufacturing, a gap appeared between the materials and the designer. With the authors' *Interactive Fabrication* research, they aim to close this gap by using real-time interfaces so that the results of actions can be immediately materialized in the final artifact. Coming out of this concern, they have designed a near real-time experience that translates sound frequencies captured by a microphone into bent wire artifacts.

In this way, the experience transforms digital interpretations of sound and empowers the user with a *quasi-tactile* tool that lets this translation from sound into a permanent artifact. They have developed the hardware and the necessary code that records a participant's voice, and after analyzing the waveform intensity, the machine bends a wire. It has two modes, echo and replay. In echo mode, the wire starts to be bent as the user speaks. The machine records a few seconds in replay mode and then starts bending the wire. The wire can be used as a personal accessory, such as an earring.

The authors (Willis et al., 2011) discuss a similar but different approach in the Sketch Furniture example. They also use embodied input and output that transform the user inputs into direct outputs. However, the problem with this approach is that the fabrication only starts after the design is completed (ibid.). According to the authors, a process that involves a real-time transformation of user input to physical output would close the gap between making processes that incorporate digital interfaces. This direct connection between the input (sound) and the output artifact (bent wire) creates a strong connection between the data used to create the artifact. The content of the recording is critical in creating and determining the value and meaning of the artifact. Since words can be recorded, the meaning and significance of the bent wire would be shaped by the meaning of those words. Also, the person who makes the recording determines the meaning and value of the generated artifact. For example, if the person who had created the wire with his/her voice is gone, it gains another meaning, most probably related to the concept of permanence and ephemerality.

From the users' perspective, the wire appears bent as they speak directly through the machine. So the distance between the input and output is very small. This small distance helps create a strong connection between participants' voices and the resulting artifacts. Thus, the wire becomes the physical manifestation of their words or recording literally. However, due to the immediate fabrication of the artifact, there is no chance for the participant to preview the resulting form. The inability to assess the form before manufacturing can cause many trials and errors, causing waste. On the other hand, it can be interpreted as capturing the moment as it is, like a polaroid photograph.

When the *Reify Project (2015)* example is considered, there is no chance to edit the data representation to represent personal preferences or how the participant feels about the recording. Thus, the usage scenarios might remain limited despite the strong connection between the artifact and data.

2.9.4 Discussions

From the examples explored in the previous sections, it is seen that many different kinds of data can be used in the creation of artifacts that have meaningful connections with the data content. However, the crucial part of the meaning generation is seen to be the *understandability of the process*. With this necessity in mind, the discussions below evaluate the examples from the perspective of personal meaning generation.

2.9.4.1 Understandability/Clarity of Translation

Azzaro's work on Voice Sculptures needs a laser that scans the artifact. However, since the data used in the generation of the artifact is a public speech, the resulting artifact can create a public meaning rather than having private meanings compared to the other examples presented here. The connection between the songs and the resulting forms in *Microsonic landscapes'* artifacts is not understandable. The designers have included frequency graphs under the artifact images (probably) to compensate for this disconnect. For the connection of sound and form, *Reify* provides an augmented reality app. However, the process is hidden from an ordinary user. Thus, the transformation of sound data to the artifact is not reachable and understandable.

Moreover, the app functions more like a way of reaching the song and overlaying some visual effects on the generated form rather than explaining how that form is shaped by sound. *Samba stool* does not have much information about the project. However, the real-time generation animation of the stool video helps connect the sound data to form. *Sound surfaces* vases also need explanations, so the artist created explanatory videos on how form generation takes place. From the visuals that the artist presents, the visual style of all the outputs (although generated by different sounds) looks very similar when the same surface generation method is used, even for different audio recordings. The data on the surface becomes like a texture rather than a dominant factor in shaping the overall form. When all the forms become similar, this similarity can negatively affect the meaning and value since it becomes harder to understand differences between different sounds or sections of recordings.

Waveform Keychain illustrates that when the sound data is used in a perceivable way, a recording with a short duration, it becomes straightforward to connect the features in the sound data (words I, love, and you in this case) to the form generated. Compared with the Sound Surfaces project, the effect of the audio recording's duration on the understandability of the artifact becomes much more evident. The Sound Surfaces project visualizes whole songs that are several minutes long, whereas the earring visualizes a very short recording, probably about several seconds. Therefore *the amount of data mapped onto an object plays an essential role in the understandability of the translation and the resulting artifact.*

Vase #44 project provides a very close interaction between the user, generated data (their voice), and the artifact since it allows the user to directly see the results of the sounds they make with their mouths. Therefore it allows experimentation with the tool immediately to see and compare the results of different voices. This interaction helps connect the input with the output since the user can directly manipulate the form with his/her actions.

Willis et al.'s study (2011) *provides the most direct connection between the data and the physical artifact. Thus, among the examples presented, this can provide the strongest connection between the data and the artifact*. Although in terms of creating a meaningful connection between data and artifact, *the resulting artifacts are aesthetically limited to certain forms since they are immediately manufactured*. Instant manufacturing forces the process to be straightforward and fast to manufacture, such as bending a wire.

Social data examples that have been translated into artifacts used statistical data. The translation can be regarded as straightforward since the resulting artifacts are like three-dimensional graphical representations of the data. Still, they need some reference points such as time periods, beginnings, and endings, as well as initial information about what that artifact is.

Love Project example uses multiple sources of data to generate the resulting artifacts. EEG data controls the strands' distance from each other while heartbeat controls the thickness of the strands, and at the same time, voice controls how fast those strand-generating particles move in space. These multiple data sources ensure unique form generation from the collected data. However, it can be argued that *with the increasing complexity of the data dimensions, it becomes harder for the user to grasp what they have been translated into in the final artifact*. Still, the real-time generation of the form allows experimenting with the process and directly seeing how different states of mind and speech can affect the generated form. Thus, the connection between user data and the resulting artifact can be established.

When the Aura application is considered, among the examples presented, the most hindered translation process makes it very hard for the user to connect the input data (heartbeat and voice) to the resulting symmetrical form. Two factors are causing this disconnect between the input and output. First, there is no explanation of how this form is generated. Second, after recording the voice and heartbeats, the form is generated in the background without the user seeing its generation, and then only the result is shown. When the other presented examples are considered, if the application allowed real-time visualization of the data's effect on the form, then the understandability, thus the meaning, of the artifact would increase.

The *Data Things* study is a good example of the effect of real-time form generation on the understandability of translation. The participants in the study desired to see how these representations are created in real-time, and the researchers modified the system to test a real-time iteration. This is discussed in the following paragraphs under the moment of translation section.

2.9.4.2 Moment of Translation

When the *Love Project* and *Meshu* projects are compared, the difference between the experiences through which the participants witness the translation becomes very significant. In the former, the participants have attached EEG sensors to their heads, heartbeat sensors to their ears, sit in a special place, and are expected to tell the love story of their lives. Similar guidance is continued in the *Aura* application the same design studio has developed. Of course, this ritualistic way of creating the artifact is also connected to the emotional aspect of the core idea, love. Also, since it was not academic research, the presentation of the process has a marketing side.

On the other hand, in *Meshu*, the translation happens on a screen where the user selects the places s/he has been, and the form is generated accordingly. All the processes required to create the artifact are realized through the screen interface of *Meshu* so it can become a private experience. While in *Love Project*, the experience or the memories are exposed to people other than the user. However, the designers' other application, *Aura Pendant App,* especially encourages the user to go to a quiet and calm place and record his/her voice and heartbeat while thinking about his/her message. Again, this creates a ritualistic experience that might become a part of the process in addition to the recorded data.

As described in the book (Schillaci, 2018), the users in the Vase #44 project immediately experiment with the interface to generate different forms by using their voices. Although there is no information about whether the forms are generated as they speak or after they stop speaking, the experience can be accepted as playful and exploratory regarding the immediate motivation to experiment with the interface.

In Willis et al.'s real-time wire bending apparatus (2011), the real-time nature of the moment of translation empowers the user to explore the possibilities and generate personal meaning through experimentation. *By decreasing the metaphorical and temporal distance between the input data (sound) and output artifact (bent wire), the connection between the two ends of the transformation process is strengthened.* An analogy to what happens in that process might be giving form to a material directly by hammering. The hammer is the sound in this case. Therefore, *closing the delay gap between the tool and the form that the tool shapes (the tool's effect) strengthen the connection between data and form.* Thus, what these transformations do, in essence, might be compared to what humankind is used to doing with tools used in craftsmanship for thousands of years. *Digital interfaces create an augmentation for the physical tool that can transform any type of data into any type of artifact.* In Willis et al.'s study, although everything seems physical and direct, there is an intermediary analysis and conversion step carried on by the processor and software embedded in the system. Because of the computation and manufacturing coming in between the input and output, these cause a delay in seeing the resulting artifact caused by sound data. This example is similar to *Encode Ring*, although *Encode Ring* makes the translation visualization of data in the digital domain first and then makes it tangible. The bent wires seem to be happening directly in the physical domain. However, there is no information on how instantaneous this happens, and the delay between the cognition of input and output would determine to what extent the latency affects the generated meaning.

In the *Sweat Atoms* study, the researchers do the data translation, but the users take part in the manufacturing via 3D printing. Witnessing the manufacturing phase attracted attention in the beginning. However, after some time, the participant interest in the study decreased. After realizing the effects of physical activity on the generated artifacts, some of the study participants increased their physical activity to get larger artifacts. They started to compare their artifacts with each other. Thus, although indirectly, they started to modify the process by adjusting their behavior.

Similarly, in the *Data Things* article by Bowers & Nissen (2015), the researchers develop a real-time form-generating iteration of the system they have developed upon requests from the participants. Then some participants tried to understand how the translation occurs by changing their crocheting speed, sometimes even stopping. Seeing the results of their actions immediately on the screen allowed them to understand how the forms are generated. Although not mentioned in the study, this understanding has two effects on the process. First, upon seeing that his/her movements have immediate effects on the generated form, *they trust that there is a direct connection between their data and the generated form*. Secondly, building upon this trust, the meaning of the resulting form is strengthened since the resulting form is a result of their immediate actions rather than an invisible process that *somehow* creates these shapes, as in the Aura application example.

Although a real-time interface helps construct the bridge between data, user actions, and artifacts, modifying the data in real-time might only sometimes be preferable. For example, the heart rate data of a user during a concert can be preferred to be left as it is, since it may give the impression of recording the moment as it is. However, if there are aesthetic concerns and the artifact is to be used or shared with other people or showcased in a place, then the data may need modifications to be used as a design material. There can be two cases for the usage; One is using the data as an inspiration or a starting point for design exploration. The other one is using the data as it is for the sake of representing the data. In the second case, personal meaning-making might be a byproduct of the process. However, in the first one, while modifying the form and data in real time, the user makes interpretations and makes decisions according to these interpretations.

The Samba Stool example includes a video on the project web page (Requena, 2014b). In that video, the song used to shape the form is being played while the form is generated in sync with that song. This enables the viewer to understand which song parts are responsible for the generated geometries. The video allows the viewer to witness the generation process, although s/he might not be physically present at the moment of the translation. *Therefore, a video illustrating the real-time generation of the form can create opportunities for communication of the form generated to foreign eyes.*

2.9.4.3 Multidimensionality of Data

Compared with the sound data examples, statistical data can be regarded as two-dimensional: intensity of a specific property over time. However, sound data can be three-dimensional: the intensity of a sound or a certain frequency, time, and the meaning of the things in the recording. For example, if the sound recording contains spoken words, it creates another meaning level that might come from the meaning of the words themselves.

Moreover, the person's significance can add another dimension to the interpretation of the meaning of the resulting artifact. Thus, the owner of that data, for example, the heartbeat data of a loved one and the meanings associated with him/her, becomes important while evaluating the importance and meaning of different dimensions in the data.

The *Love Project* increases the multidimensionality of data even further. Sound, heartbeat, EEG sensor data with eight dimensions, and time. In contrast, the *Meshu* project has only two dimensions, the x and y coordinates of the places a person has been. The time dimensions do not exist on the artifact but only in the mind of the data owner. Still, it can create many meanings upon different periods of a person through his/her lifetime.

Statistical data can also be multi-dimensional. In the *Fantibles* study by Andres et al. (2016), the researchers combined different data sets by creating a physical representation of the match scores and another physical representation of the tweets' emotional level over time. Since both representations share the same time domain, when stacked on top of each other, their combined interpretation creates the artifact's meaning: the intensity of the emotional response the person has given to a certain event in the match. Therefore, even if the data is one-dimensional statistical data, it can be combined with other synchronous or relevant data to create personal meaning.

2.9.4.4 Time as a Dimension on Artifact

Representation and presence of time as a dimension on the artifact affects the understanding and meaning-making process from the data-encoded artifacts. In *Sketch Furniture*, the forms take time to sketch and what is collected is the time versus position data of the designer's hand. However, the final result and the knowledge of how it has been done are enough. Because the result has a meaning as a whole, and the visual language is already familiar: a hand sketch of a chair but in three dimensions. However, if there is a translation between senses, as in the sound to form examples, then the presence of time as a dimension becomes more important to build trust that the data shapes the artifact. A practical example to illustrate the importance of this can is the Aura Pendant App. The app provides proof in the beginning that it can detect the user's heartbeat and visualize sound. However, after the user starts recording, no information about how the person's data generates or shapes the artifact form is given. After the recording is finished, a form pops on the screen. However, since the resulting form is a completely abstract geometrical form, which is the opposite of the Sketch Furniture example, it is tough to cognitively connect the form with the data. The only way of generating meaning is *to believe* that the system has *somehow* interpreted the user's data and created this form.

Another argument about the presence of time on the artifacts of the Aura App is related to the time the user spent creating the artifact. Before seeing the virtual artifact form, the user spends time narrating his/her emotions. Therefore, as discussed before, this experience might become part of the memory related to the artifact. Then the virtual form is displayed, and the virtual form (to become an artifact after manufacturing) becomes a three-dimensional anchor to both the memory of experience and memories connected to the things recorded. However, what is said might fade away from memory over time. Then a way of reaching the recording is needed. As mentioned in the previous examples sections, the app was planned to have a feature for playing the recordings back. However, due to the constraints of the project, that did not happen. Also, *Encode Ring* project claims that users can listen back to the original recordings by entering a serial code into an app. These two attempts show that being able to reach back to the data might be desirable to exploit the meaning-making potential of the artifact. Then the artifact can also become a tool for reminiscing.

Nearly all sound-related examples have a time dimension since they are representations of sound frequencies over time. However, in the case of Reify and Microsonic Landscapes examples, it is unknown how the time dimension progresses over the form, and there is no information on how the forms were generated. This makes them harder to understand for a foreign eye. Similarly, although *Love Project* uses time as a dimension in the artifacts, the complexity and density of data become so much that the connections with data become hard to understand.

Compared to Love Project, David Bizer's Waveform Keychain stands on the opposite. Since the duration of the recordings is very short (a few words like "I love you"), the density of the data is not as high as in the Love Project's data density. Therefore, the surface deformations caused by the sound data are easier to distinguish, leading to a clearer connection between the features of sound data to the form. Although it is beyond the scope of this thesis, it can be argued that there might be an optimum data density for a determined surface area of the artifact. Encode Ring is another similar example that lets the user record a short sound recording and immediately displays it as a three-dimensional visualization of the artifact. From experience with the interface on the project's website, it is observed that words spoken can easily be traced and connected to the form generated, especially when there are pauses between the words. Similarly, there are some moments in Sweat Atoms and Fantibles studies in which a dramatic change in the data can be observed, and they can be connected to a specific part of the data easily. It might be argued that the time range of the data should be normalized to each data so that the changes in the data used can be easily recognizable in the resulting form. Therefore, a qualitative description of this *optimum data density* might be can be argued as follows: *the amount of data over time dimension that is used to personalize the artifact needs to have distinguishing variances throughout the dataset while the density of the used data should not be increased when the distinguishing features over the artifact form starts to get unrecognizable.*

2.9.4.5 User Involvement and Personal Meaning

As mentioned in data physicalization examples, presented examples are grouped according to the involvement of the users in the translation process. The main reason behind this decision has been the effect of personal involvement in making these artifacts, either virtually or physically. The meaning is made in the participants' minds who own the memory (Andres et al., 2016). When the participant is not involved in making or designing, the potential for generating meaning cannot be fully used.

There are three different involvement categories in the present examples. While going from *inactive* to *real-time active* participation, the personal meaning generated from the process is argued to be increasing. Several factors might affect this variance in meaning generation.

The first one is the *nature of memories and data* used as material. If there is a public memory, such as in the example of Azzaro's voice sculpture, the translation of sound into an artifact will create meaning for the audience. However, since the memory is not personal, and the perceiver is not involved in the making process (but just observes), the connection with the artifact might be limited. For the artifact to have a significant meaning, that public memory should have a very significant personal meaning for the perceiver. Graduation rings people wear with their friends might constitute a good example. While creating a personal meaning, such shared memories and related artifacts create a sense of belonging to a specific group. As participants start to get involved in the generation of artifacts with their data, as in the *Deferred Active Participation* category, meaning-making evolves into the next step: self-reflection.

The second factor affecting the meaning generation is the *participants' distance from how translation occurs*. The distance is more significant in the first two categories (*inactive participation* and *deferred active participation)* as the participant is not witnessing how the translation occurs. When the distance is more significant, it becomes harder for participants to make sense of the data from the artifact. The artists or designers have created explanatory videos after the artifact is made to communicate the idea behind the artifacts. However, this thesis is concerned with how the user observes that artifact. Inactive participation does not include the participants in the generation phase, so they can only be involved as meaning makers, as mentioned before. However, the explanations the artists and designers give in their videos become an inseparable part of the meaning-making process if the concern is to connect the artifact and the thing it represents.

The third factor is the *level of control and involvement in the process*. In the first category, *inactive participation*, the participant is not involved in any data having any personal meaning. The only way of participation becomes the act of meaning-making in the participant's mind. Therefore, the participants in this category do not have agency in generating these artifacts but only in the meanings they generate in their minds. This situation improves in the following category, deferred active participation. Although not in real-time, the participants become part of the generated artifacts by providing data or actions. Still, they cannot be fully in charge of the artifacts generated since, in most of the processes, a designer or researcher is involved in generating the artifact. Thus, it prevents the participant from having an opinion on the generated artifact. Despite the limited agency, the participant behavior observed in some studies shows that the participants wanted to change the outcomes of the generated artifacts since they could not actively change the design. However, they can only do this in an indirect way that would cause a change in the collected data so that it affects the resulting artifact. Since they can do this in a limited fashion, creating a controlled meaning for the generated artifact is harder. This insufficient participant agency in the artifact generation process improves in the next participation method: Active Real-time participation. All the examples included in this category allow nearly instantaneous visualization of the participant's actions, transforming them into artifacts or virtual forms. In this way, the participants can understand the process and start to experiment with the outcomes. For the participant, this understanding and experimentation lead to an understanding of a connection between their data and the artifact while also building trust about their data becoming tangible as artifacts.

2.9.4.6 Summary

Following the insights obtained from the explored data physicalization examples, the primary research is presented in the next chapter. While designing the initial transformation method in the next chapter, these insights presented in the discussions provided the guidance needed to decide on the features of the process.

CHAPTER 3

PRIMARY RESEARCH

From the literature review conducted and the data physicalization examples explored, it is observed that involving the participants in the design process and using their personal and meaningful data in the creation of artifacts presents a huge opportunity for increasing the personal value and the meaning of artifacts. Thus, a co-design process is developed in this study stage that aims to personalize the form of a template artifact with personally meaningful and valuable data. This primary study aims to understand the possible implications of the participatory design approach using personally meaningful data.

The primary research studies were conducted with five participants during the 2015-2016 Winter-Spring season. Insights obtained from data physicalization examples presented in this thesis have been combined with the primary study's findings and used in developing an interactive personalization interface (CHAPTER 5) that is used in a design workshop (CHAPTER 6).

3.1 Research Framework: Co-design Approaches from the Perspective of Design

The concept of co-design has a history of decades, starting with the concept of participation. Participation in the design process first appeared in design research in the 1970s (Bjögvinsson, Ehn, & Hillgren, 2012; Cross, 1972). Throughout the development of participatory design practice, an evolution has occurred from manufacturing-driven design to technology-driven design to design for experiences (Sanders & Stappers, 2008).

The European participatory tradition strongly emphasized the democratization of the workplace. In contrast, US and UK traditions focused more on transferring "users' knowledge of work processes to improve the usability of end products" (Bjögvinsson et al., 2012; Lee, Popovic, Blackler, & Lee, 2009, p. 2094).

User-centered design, beginning in the early 1990s, has a research-oriented and expert mindset where participants were kept at a distance from the researcher to prevent interaction between them. However, this is argued to prevent a better understanding of users since it is impossible to interact with them from a distance. (Lee et al., 2009). This approach can be defined as designing *for* consumers (Sener & Van Rompuy, 2005).

Participatory design involves the active participation of the users in improving the usability of end-products in the United States, whereas in Europe and especially Scandinavia to democratize the workplace (Lee et al., 2009). Participatory design can be defined as *designing with (in the presence and with participation from) consumers* (Sener & Van Rompuy, 2005). Drain and Sanders (2019) mention the areas in which participatory design is widely used: information systems, *consumer products*, workplace layout, and humanitarian solutions.

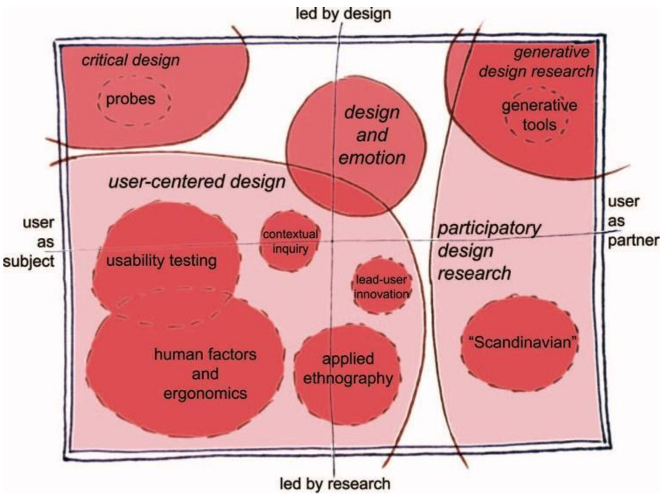


Figure 3.1 Participatory design research landscape (Sanders & Stappers, 2008)

Design for experiencing involved the users more in the design process through generative tools such as participatory prototyping methods and used these processes to extract users' latent needs (Lee et al., 2009). Design for experiencing later evolved to *co-design* and *co-creation* by Sanders and Steppers (2008). The authors define co-design as the "creativity of designers and people not trained in design working together in the design development process" (2008, p. 6). The authors present the participatory design research landscape as in 2008 in Figure 3.1.

Although having decades of history, Sanders & Stappers (2008) point out the reasons for the spreading of co-design taking so long :

Preexisting beliefs that not everybody is creative
Existing hierarchy of experts and expert designers
In new generations, it is easier because the internet gives a voice to everyone.
Internet Facilitates idea-sharing.
Participatory thinking is incompatible with consumerism, in which new needs are invented, but the participatory approach only designs things for actual needs.
Participatory design has been only seen as an academic endeavor with little relevance to the marketplace.
Companies only soon realized they needed more than adding new features, so they are now more eager to create budgets for different ways of designing and researching.

Involving users in the design process or empowering them to create their personalized suits of clothes has been a long-held dream that was even present in books written five decades ago (Piller, et al., 2004). This transforming design landscape changes "what we design, how we design and who designs" (Sanders& Stappers, 2008, p.11).

Among participatory design and codesign literature, what is meant by participation and the degree of participation varies from one method to another (Saad-Sulonen, Eriksson, Halskov, Karasti, & Vines, 2018). Participatory design (PD) is defined most recently as *a collaborative design approach in which technical experts work together with representatives of impacted communities to design suitable solutions for their problems* (Drain & Sanders, 2019). The process of making has become an activity that can engage both designers and co-designers throughout the co-design process (Sanders & Stappers, 2014). According to Bjögvinsson et al. (2012, participatory designing is designing together around things.

Involving the users in the product development process in the early stages has been an important factor in product improvement and innovation. Although a successful outcome is not granted, by this involvement, the latent needs of the users can be accessed, which is not possible with other methods (Lee et al., 2009, p. 2091). Understanding these latent needs in full potential lies in understanding the collaboration between the user and the designer (McDonagh-Philp & Lebbon, 2000). However, to successfully involve the user in the design process, only following guidelines or incorporating design tools is insufficient. In order to ensure the successful involvement of the user in the process, it should be understood that the knowledge coming from him/her is localized, "embedded and invested in their daily lives" (Lee et al., 2009, p. 2093). As a result of this type of knowledge, it is hard to communicate with the designers.

Similarly, Sanders & Stappers (2008) point to a communication gap between different disciplines and argue that new co-design languages addressing cross-cultural or interdisciplinary communication will gain importance. Lee et al. define user-designer collaboration as "coordinated and joint problem-solving activities where two parties can learn about each other through an iterative process of constructing and rebuilding mutual identities" (2009, p. 2092). Sanders & Stappers argue that in building/making, "people can bring their insights to the surface" (2014, p. 6). Lee et al. (2009) argue that to facilitate user-designer collaboration, mechanisms for "encouraging, empowering, and challenging the users to bring their own contexts for our gate generation during the early stage of the development process" are needed (2009). This collaborative experience of the design process enables the designers to better understand the concepts emerging from user needs. Moreover, it helps designers convert these understandings into innovative design concepts (Lee et al., 2009).

3.1.1 Effects of Co-design on Value

The users' involvement in co-design processes not only increases product value but also creates a value realized just by the user's participation in the process (Thenral & Suganthi, 2018). However, some participants might avoid personalized products just because they fear regretting their choices. Still, when the participants are more confident or capable of co-design or personalizing a design, the chance of them giving more value to a customized product increases (ibid.) Inspired by this additional value creation and fear of choices because of insecurity with design skills, an opportunity of creating a *safe zone* that exploits value creation can be created. In this safe zone, an ordinary person can be placed in a controlled design environment created by the designer so that the person using that system would feel the guidance of the design discipline while still making his/her own decisions.

A significant example discussed in this thesis's previous sections is the Nervous System's Kinematics generative system (Rosenkrantz & Rosenberg, 2014b). In the system, the user can personalize the form, change the dimensions, or even the overall shape of the necklace. Still, whatever the user does, the generative system ensures that it is within the boundaries of 3D printable geometry, and the forms are generated according to the design intent and visual style of the designed product. However, as the authors argue, when the choices in a personalization system are too high, the sheer number of choices can become overwhelming because of the increasing effort the user has to put into the process. Similar findings can be observed in the explanation of the Meshu project, which is also discussed in the *Data Physicalization Examples* section. The founders of Meshu state they know most of the Nervous System users use the system to personalize the form, and then instead of purchasing the one they have personalized, they go for a readily made one. However, when they used the system of Meshu, which allowed them to pin the places they had been to on a map, and the software connected those points to create a mesh, the users immediately started narrating their own lives. Comparing these two examples provides insights into the effect of personal data in such personalization systems. Although the software designed in Nervous System's Kinematics application provides infinite options and aesthetically pleasing outcomes, people still prefer ready-made designs. *Therefore, although generative systems let a person create their own designs, personal data and the meaning-generation potential of the system play an important role in the adoption of the system developed.*

3.1.2 Real-time Visualization Approach in Co-design

Digital realization tools are increasingly used in the fast-moving consumer goods sector. Real-time systems are expected to provide improved communication of user needs and criticisms about the new products. They provide direct communication between the designer and the user since no intermediary researcher is needed (Sener & Van Rompuy, 2005). The authors' preferred haptic touch system benefits are quick idea visualization, quick form modification, real-time visualization of surface deformations, and realistic imaging. The real-time visualization of the model makes it easy to communicate the end product to the end-user so that no further visualizations are needed. Also, the participant can take action according to the final appearance of the form rather than trying to imagine what it will be like when it is finished. From the participant/consumer's perspective, s/he feels more valued and becomes more active compared to interviewing methods (Sener & Van Rompuy, 2005).

Figure 3.2 From co-design study of Sener & Van Rompuy (2005).

Sener and Rompuy’s study (2005) uses a co-design method involving a CAD environment. The participants were asked for their opinions and ideas about an on-screen 3D model of a consumer item, and the designer/researcher made any necessary changes to the model through a haptic interface. The participants immediately see the outcomes of the changes they requested from a photorealistic visualization of the consumer item they are designing. The results of the study evaluate the outcomes from various perspectives. From the designer’s perspective, the form creation process is public and open to feedback, strengthening communication between the designer and the consumer. The real-time generation of 3D models on the screen eliminates the need for time-consuming 3D renderings. On the other side, from the consumer’s perspective, the high interactivity of the process brings empowerment, resulting in consumers’ feeling valued rather than being subjects being examined. This interactivity leads to more consumer engagement, who can also directly “judge, accept or revise their suggestions” (Sener & Van Rompuy, 2005, p. 23). However, when the consumers were given the digital tools that the researcher/designer uses, most felt uncomfortable with the system's complexity or refused since taking the designer's role was not their purpose. The study concludes that unless the systems used in such design methods “become immediately usable by non-experts, a designer will always be required to act as an intermediary” (ibid.).

3.1.3 Co-design and Perceived Value

Co-design and personalization are converging with each other because, day by day, the users start to be more empowered with the tools that they can become their designers through the systems that enable the users to customize the form of a product or artifact according to their needs (H. Zhao et al., 2018). Alizon et al. (2010) have developed a five-dimension model that evaluates the perceived value of products that consumers customize from a consumer viewpoint. The dimensions are *utilitarian/functional value, uniqueness value, self-expressiveness value, hedonic value,* and *creative achievement value* (Alizon et al., 2010). Utilitarian/functional value is defined as the value emerging from the proximity of individual preferences and product characteristics (ibid.). *Uniqueness value* comes from the chance to assert personal uniqueness while using the customized product. *Self-expressiveness value* is defined as the value coming from the chance of being able to reflect one's identity through the use of a product. According to the authors (Alizon et al., 2010), the first three values (functional, uniqueness, and self-expressiveness) relate to the consumer's expectations of using a personalized product. However, the last two values (hedonic and creative achievement) come from the co-design process. Hedonic value comes from aligning the consumer's enjoyment, fun, or pleasure needs with the experience's capacity to match those needs. Creative achievement value comes from the feeling of accomplishing a creative task of codesigning (Alizon et al., 2010, p. 506).

This model is adopted by Thenral & Suganthi (2018) to explain the perceived value construct of the product involvement processes. The first three values, function, uniqueness, and self-expressiveness, are related to the participant's expectations of the outcome. On the other hand, the hedonic and creative achievement values are related to the co-design process. Thenral and Suganthi (2018) argue that this might be because of the investment of time and thinking of participants into the final product. According to the authors, this investment might create value for the participants irrespective of the outcoming product. To test their hypothesis, they designed a structured questionnaire among 1052 respondents selected with convenience sampling. The sample was mainly undergraduate and postgraduate students but also included “university teachers, research scholars, government employees, lawyers, etc.” (Thenral & Suganthi, 2018, p. 23). The questionnaire consisted of a hypothetical situation where the respondents would have the chance to co-design any product of their choice. Every decision they make will be included in the final product and delivered to them.

In their study, the authors Thenral and Suganthi hypothesize that the value of the co-design process is mediated by the participant's self-efficacy in the process. However, involvement in the process has more impact on the perceived value of a product than the effect of self-efficacy. Still, more involvement means becoming more informed about a product and increasing self-efficacy. Increased self-efficacy increases the consumer's belief in co-designing a product which finally increases the perceived value of the co-designed product. The results of the authors’ study show that *as involvement increases, the perceived value of the codesigned product increases*.

Co-design through real-time interaction creates a *common history* with the artifact since the design process takes time. This common history creates attachment no matter the resulting aesthetics of the outcome, as Raz argues (2001). Moreover, because of the common history, the attachment becomes unique, thus irreplaceable.

To map the emerging landscape of design research and practice, Sanders & Stappers introduce time-frame into the equation concerning the world as it is now, the near future, and speculative futures (2014, p. 13). Core in Figure 6 represents the traditional design practice. The inner ring is the world as it is, the middle ring is the near future, and the outer ring is the speculative future. Newly emerging fields illustrated in the Figure 3.3 are design fiction and service design. At the intersection of future studies and design, design fiction lies.

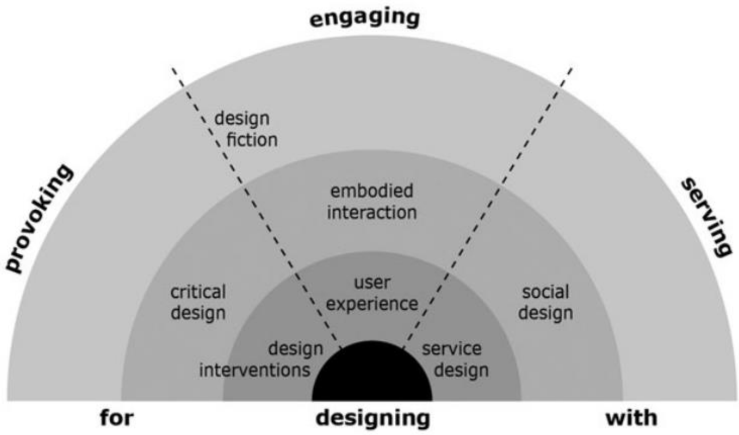


Figure 3.3 Emerging design movements across time scales (Sanders & Stappers, 2014, p. 13)

When this study is considered with the emerging movements in Figure 6, it can be placed in two intersection axis: between serving and engaging slices and between provoking and engaging slices as *data-driven emotional design*. It is between serving and engaging slices because the transformation method works as an interactive experience that involves the user in the experience of making through embodied interactions while serving the user by empowering him/her with design skills to create a three-dimensional form from personal data. It is between provoking and engaging on the critical design and embodied interaction levels since the resulting artifacts can initiate self-reflection through interaction with tangible artifacts that allow the perception of data with multiple senses.

3.1.4 The Role of the Designer: Shift in Agency

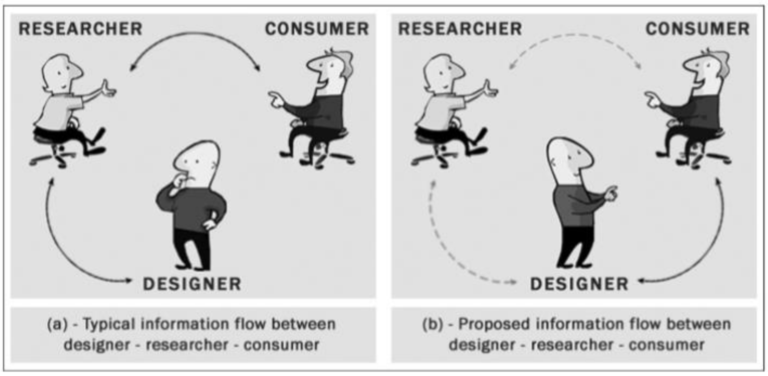


Figure 3.4 Comparison of traditional information flow between designer researcher and consumer with the proposed method (Sener & Van Rompuy, 2005).

The transformation from the user-centered design approach to co-design brought some shifts in the roles of participants in the process (Pierri, 2017; Saad-Sulonen et al., 2018; Sanders & Stappers, 2008). In traditional user-centered design, the users are mainly passive objects of study. Researchers bring knowledge from theory and generate more knowledge through observation and interviews. They then pass this knowledge to the designers, who passively receive it and “add an understanding of technology and the creative thinking needed to generate ideas, concepts, etc.” (Sanders & Stappers, 2008, p. 12).

Contrary to this discrete separation between the roles in traditional user-centered design, the boundaries between the roles start to get blurred in co-design approaches. The artifact of study in the previous approach, the user, has been given the position of the *expert of his/her experience* and undertakes a vital role in the knowledge development, idea generation, and concept development phases. The designer, meanwhile, supports the user in generating insights by providing tools for ideation and expression (Sanders & Stappers, 2008).

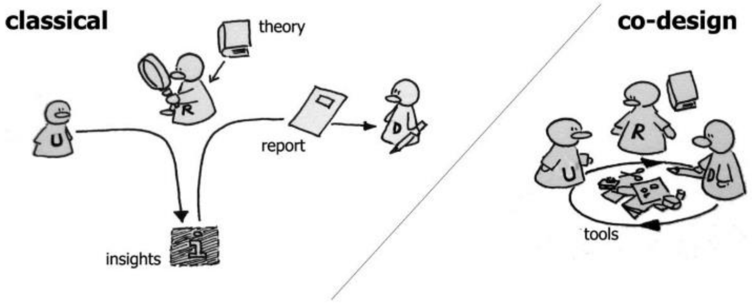


Figure 3.5 The designer, user, and researcher roles in classical and co-design approaches (Sanders & Stappers, 2008).

According to Sanders & Stappers (2008), whether a user becomes a co-designer depends on his/her level of expertise, passion, and creativity. For the users to become co-designers, however, they need to be provided with the right set of tools. The researchers become the facilitators who might also be the designers simultaneously. The need for designers will be felt in more areas. The specialized skills of designers, such as design thinking, visual thinking, conducting creative processes, finding missing information, and making important decisions in the absence of information, will be necessary as the design profession's field of application will extend to the design of systems and environments. Sanders & Stappers argue that the designers will soon be designing tools for non-designers to use to express their creativity. A more recent article validated the authors' predictions in 2008 about the changing of design as we knew it (Pierri, 2017).

The design in the last century, as Manzini and Coad (2017) argue, was 'the act of particularly gifted individuals capable of imprinting their personal stamp on artifacts and environments" (p. 66). On the opposite end of the spectrum is 'post-it designers,' as the authors call it, where the role of design experts is reduced to leading actors without any specific contribution to the design process other than facilitating the process. As the empowerment and involvement of users in the codesign practices increased, the danger of disappearing the designer from the equation by dissolving his/her skills to the other participants (*diffused design capabilities)* started to appear

(Manzini & Coad, 2015). Clive Dilnot (as cited in Pierri, 2017) argues that this risk has to be taken while "expanding into other disciplines".

Similarly, Yelavich and Adams (2014) argue that design is treated as a 'panacea' for every problem. This perception of design as a universal solution to everything oversimplifies the role of design and designer while threatening its criticality and preventing its ability to initiate agency (ibid.). Since the agency does not always bring design as a result (Pierri, 2017), only providing the tools and skills to people does not automatically provide a novel design solution. Pierri's argument parallels Yelavich and Adams' concerns about treating *design* as a solution to every problem while overlooking critical thinking abilities and oversimplifying the skills of designers. Combined with Manzini & Coad's (2015), it can be argued that treating designers only as facilitators of a collective design session or thinking some kind of design (without the critical part) would be a solution to every problem is not working. Therefore, the design profession's skillset in generating novel solutions to problems through critical thinking needs to be considered while suggesting new ways of collective designing.

The agency of designers is changing, and it is becoming harder to define a designer's role since new approaches have become inevitable (Pierri, 2017). The scope of the designers has expanded beyond traditional or high-end product design into not only the design of "systems, narratives, debates" but also "conditions for the social, emerging publics and alternative futures" (Bjögvinsson et al., 2012). This thesis primarily focuses on the designer being the system designer that empowers the user to create their version of the system's outcome.

Inspired by all the literature explored on meaning, value, attachment, emotional durability, personalization, data physicalization, co-design, and benefits brought by them in increasing the lifespan of products by creating additional value and meaning, this research proposes a transformation method that empowers the user to create meaningful and valuable artifacts through the usage of personally meaningful sound data. The role of the designer/researcher in this transformation method becomes the designer of the system and the experience that allows this transformation to happen. The next chapter presents the primary study conducted in which the designer/researcher and the user co-designs and personalizes a form with personally meaningful sound data. This primary study is then analyzed with thematic analysis that guides the next version of this transformation method, which is then tested in a remote workshop setting at the 2020 UTAK conference.

3.2 Research Methodology

Research through design, emerging from action research, involves generating knowledge through the cycles of individual reflections. This study uses *research through co-designing* (Bakırlıoğlu, 2017) within the *participatory design* approach that adopts generative design methods and tools and uses *qualitative research* methods for knowledge generation. The reason for adopting *research through a co-designing approach* has been the need to understand the transformation process rather than only exploring its outcomes (ibid.). By collecting and analyzing non-numerical data, such as words, images, and sounds, qualitative research aims to acquire a deeper understanding of a particular phenomenon (Glaser & Strauss, 1967). This type of research is often used in the social sciences and is particularly useful for exploring complex phenomena that cannot be easily quantified or measured. Some of the advantages of qualitative research include the ability to generate rich and detailed data that provides insight into people's experiences, perspectives, and motivations, to explore complex and dynamic phenomena, to uncover underlying patterns and trends, and to provide a more holistic and nuanced understanding of a particular phenomenon. Additionally, qualitative research allows researchers to explore complex and dynamic phenomena that are difficult to measure or quantify using more traditional research methods. This can provide a more holistic and nuanced understanding of the phenomenon being studied and help researchers develop more focused and detailed research hypotheses (Bailey et al., 2020; Braun & Clarke, 2017; Saldaña, 2010; Williams & Moser, 2019). For this, semi-structured interviews and participant observations are used to collect qualitative data through video and audio recordings. To document different decisions and the progression of research, a continuously updated Ph.D. journal is kept during the research phases. Figure 3.6 shows all the entries of the journal until today.

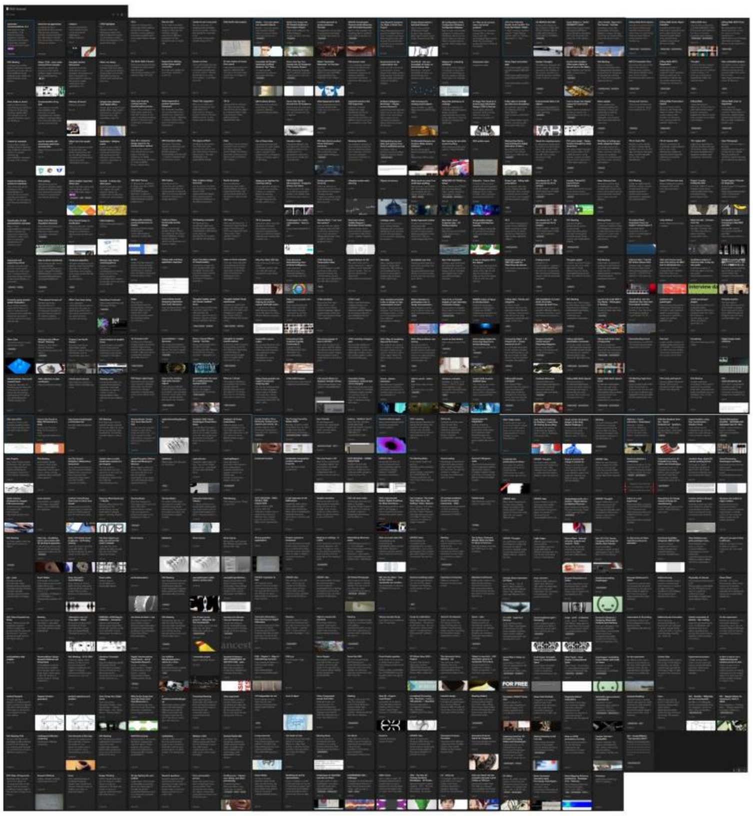


Figure 3.6 473 entries added to the Ph.D. journal between 11.2012-.12.2022.

As seen in Figure 3.7, the journal has logs and records of ideas, insights, examples from the internet, people related to the field, meeting notes, concerns, and keywords.

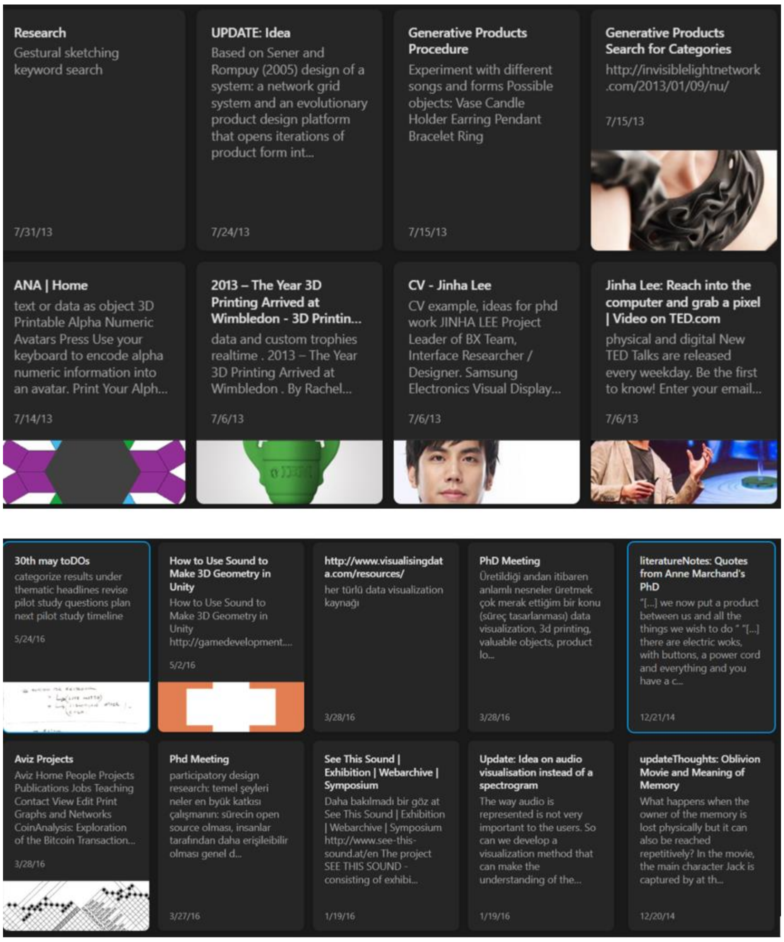


Figure 3.7 Selected entries from the Ph.D. journal.

All the entries have a date of creation and rich text content supported with visuals, links to video content, and online presentations. Over the years, it has been seen that some of the websites visited are no longer available. Thus, newer entries for websites are also included with screenshots from the website and links to the page.

3.3 Phases of the Primary Study

The primary study consisted of five phases. I followed an interview protocol at each phase that involved instructions and questions about the designed transformation method. The detailed interview protocol can be found in Appendix A: Exploratory

Research Interview Protocol. The contents of the phases are explained in the paragraphs below.

Phase One: Introduction.

In this phase, the study participant is asked to find a meaningful audio recording that is to be transformed into a tangible artifact. The maximum length of the recording requested is 10 seconds, and it is mentioned that it has to *remind the participant of someone or something that evokes emotions when it is listened to*. It is mentioned that the recording can be a person's voice, a melody, an ambient sound, or a recording from the past or today. The participant is also informed that if the recording they bring is longer and they cannot adjust the timing of that recording, it can be cropped during the study. Thus, it can also be a video recording, and its audio can be extracted during this study.

After the general introduction and requesting the audio files for the next meeting, the participant is presented with examples before and after the transformation process they will use in the study.

Phase Two: Audio analysis and Artifact Generation

This phase is where all the personalization and form-generation processes take place. In this stage, the participants are asked questions about their selection of the audio files they bring. Then if needed, these audio files are cropped according to the participants' preferences. One of the participants wanted to record her voice, so that process is done in this stage. After the audio files are ready, phase two of the study continues with the following steps:

Exploration of selected recordings and transformation from sound to image
Exploration of transformation from image to three-dimensional artifact

Stage A, the exploration of the selected recording, starts with exploring the meaning and value of the sound recording for the participant. The audio file is cropped and opened in Sonic Visualizer software if needed. This software generates a spectrogram image (a duotone image that plots different frequencies in the audio signal versus time) of the audio. One of the features of the software is that it can play the audio in real-time while scanning the spectrogram image with a line representing time. This stage's primary aim is to understand the audio file and its representation as a spectrogram image, together with the connections between them. During this stage, the participant is continuously asked questions about the connections between the sound s/he hears and the visuals that s/he sees. Explanations about what the bright and dark areas in the spectrogram image also mean, the representation of high and low-pitched sounds and the existence of time dimension in the spectrogram image are made. Then the participants are asked whether they see any connections between the sound and the image generated.

Stage B, exploration of transformation from image to three-dimensional artifact, involves understanding how the image is translated into a 3D object. In this stage, what happens to the bright areas in the spectrogram image is explained as they are converted into bumps on the artifact's surface. The dark areas in the recording correspond to flat areas on the artifact's surface. The interview protocol explains it as "the sounds in the recording will transform into hills, and the silent parts will remain flat" (Appendix A). Also, it is mentioned that the spectrogram image obtained from the sound recording of different people's voices, even if they say the same thing in the same tone, will be different and unique to that person.

During the explanations, because of the physical limitations of the FDM 3D printing method, the participants are warned about very sharp points in the artifact surface. Furthermore, they are directed toward smoothing the surface to make the artifact manufacturable.

During this process of 3D form generation from the spectrogram image, the participants are continuously asked about their preferences. For example, "Is this surface bump amount enough?", "Do you prefer changes on the surface?", "Do you need more bumps, or do you prefer a smoother surface"? During these questions, the participants were asked about their decisions' reasons.

After the changes on the generated form are completed, and participants are happy with the result, they are asked about the connections between the image they have seen in the previous stage and the generated object. The same question is asked about the connection between the sound they brought and the artifact they saw on the screen. After the questions are completed, the final form is saved and exported as an STL file and opened in a slicing program to prepare it for 3D printing.

Phase Three: Preparation for Manufacturing

In this phase, the prepared file is exported for 3D printing, and the artifact is manufactured in a 3D printer. Only two participants, P1 and P2, could attend this manufacturing phase.

Phase Four: 3D Printing

The phase where the manufactured artifact is handed to the participants, and they see the physical artifact for the first time. Questions about the relationship between the sound they brought and the artifact they are getting now are asked. Also, they are asked about anything they would want to be different if they could change the process. The session ended with questions related to any suggestions they might have.

Phase Five: Follow-up Interview

This phase consists of a follow-up interview with the participants who were given the artifacts. Questions related to where the artifact is stored now and whether they handled the artifact since the last meeting are asked. The details about the questions asked can be found in Appendix a.

Duration of the phases

The duration of the phases with two different sessions is outlined in the following table:

Table 3.1 Durations of study phases with participants

Participant:	Duration in min:sec					
	Phase 1 Duration:	**Phase 2 Duration:**	**Phase 3 Duration:**	**Phase 4 Duration:**	**Phase 5 Duration:**	**Total:**
1	4:47	35:22	2:00	23:20	10:31	**76:00**
2	2:46	32:45	4:53	13:05	12:13	**65:00**
3	3:44	26:05	-	24:20	13:05	**67:14**
4	9:01	36:55	-	38:04	12:45	**96:45**
5	3:10	31:51	-	20:37	16:59	**72:37**

The total time difference between the five studies has been 31 minutes, with varying differences between the study phases.

3.4 Recruitment of Participants

I have selected five participants using the convenience sampling method from people who have computer literacy and do not know CAD modeling. Three participants were from the company I worked in, and two were among the people I worked with. I also wanted to have age variance to collect possible feedback related to different age groups. Thus, the demographics of the participants selected for the study are as follows:

Table 3.2 Demographics of the primary study participants

Participant	**Gender**	**Age Range**	**Occupation**	**Total interview time (min:sec)**	**Date Range of Interviews**
P1	Female	50-60	Interior designer	**76:00**	12.27.2015 - 1.1.2016
P2	Female	30-40	Finance / Accounting	**65:00**	1.4.2016 - 1.14.2016
P3	Female	30-40	Biologist	**67:14**	6.15.2016 - 8.10.2016
P4	Male	70-80	Professor (Public Administration), traveler	**96:45**	1.29.2016 - 6.16.2017
P5	Male	20-30	Graphic Designer	**72:37**	6.16.2016 - 8.10.2016

My reason for choosing people who do not know CAD modeling was to eliminate biases of the people that might come from previous experience with 3D software packages.

3.5 Research Setup

I have used my notebook computer with a webcam and audio recording capabilities in all the studies. I used Adobe Audition for *audio editing*, Sonic Visualizer for *audio analysis*, Adobe Photoshop for *image processing*, The Foundry Modo for *3D modeling*, and Voxelizer for *slicing the generated model for 3D printing*.

The two studies conducted were in two different places because of the time constraints of the participants and me. I have visited P1's home and conducted phases 1, 2, 4, and 5 at her home. For phase 3, I took the participant to the office that has the 3D printer for the manufacturing session.

I conducted the primary study with P2 during a lunch break in an office environment. All of the phases with P2 have been conducted in the same environment. The study with P3 is again conducted in an office environment after work hours. However, due to the time constraints of the participant, she could not be involved in the manufacturing process. P4 preferred to conduct the study at his home, so all the stages were conducted there. However, he could not attend the manufacturing session due to his time constraints and inability to carry the 3D printer to his home. The study with P5 was conducted in his work environment during breaks and after work hours in a nearby cafe. Due to his time constraints, P5 could not attend the manufacturing phase.

All participant phases were recorded with a computer camera used in the transformation process. In phases one and two, the participant was recorded while facing the computer screen with a synchronized screen capture of what I was showing him/her on the screen. I recorded the participant and me together around the 3D printer in phase three. In the last two phases, I recorded the participant by placing the computer camera facing the participant, myself, and the artifact manufactured in the 3D printer.

3.6 Tools Selected in the Stages of the Study

This study uses tools in audio analysis, image processing, and 3D CAD modeling tools. The procedure consists of six stages:

Audio editing
Audio Analysis and Visualization
Image processing
3D CAD Modelling
Slicing the model for 3D printing
3D printing

In this section, I present and explain the tools I have used in the preliminary user studies.

3.6.1 Audio Editing

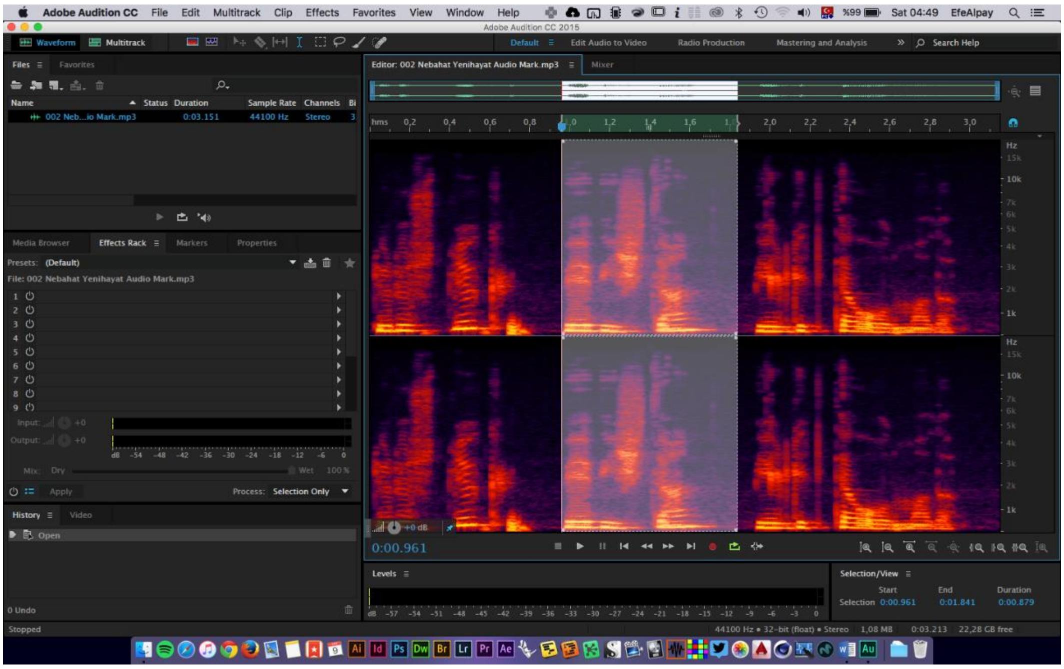


Figure 3.8 Adobe Audition Interface Screenshot

In order to process the files requested from the users, I needed an editing program for audio files. I chose *Adobe Audition* for this need. The reason behind my decision was my familiarity with the software and the built-in functionality of the software of showing audio spectrogram images of the recorded or opened sound files.

3.6.2 Audio Analysis and Visualization

The main requirement for me in this process is to extract visually detailed information from the audio so that it can be converted into rich visualizations that can give results unique to each sound recording. In the following paragraphs, the reasoning for my decision process is explained.

For the analysis of the audio stage, I determined some requirements. First, the way the audio is analyzed should lead to unique results that would make every sound recording different from the others. Audio waveform visualization is a widely known method that we come across in our everyday lives (Figure 3.9). However, from this study's perspective, the problem with this type of visualization is that it only shows the combined waveform, which is very hard to be recognized by human perception as unique. This recognition difficulty makes it visually generic because of the indistinguishable patterns.

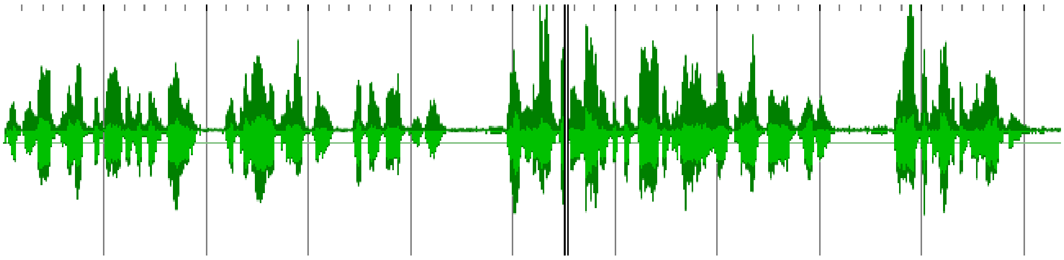


Figure 3.9 Audio waveform visualization

The problem I mentioned above becomes more apparent when two people speak the exact words with a similar accentuation. When the audio waveform is analyzed, two representational waveforms look very similar. Thus, such a representation does not fulfill the need to provide unique visual representations.

As software, I have used an open-source audio analysis tool called Sonic Visualizer (https://www.sonicvisualiser.org), which uses the Fast Fourier Transform method to separate the combined audio waveform into a spectrogram image consisting of discrete frequencies (Cannam et al., 2010). This image visualizes the frequency versus time function of the waveform while also visualizing the intensity of each frequency over time. With spectrogram analysis, the sounds are much more distinguishable from each other. Figure 50 shows the place of different sounds existing in the same recording. Y-axis shows the frequency of the sound, whereas X-axis represents time. Because of the tonal differences between adult and child speech (or yelling, for this example), the two voices can easily be distinguished.

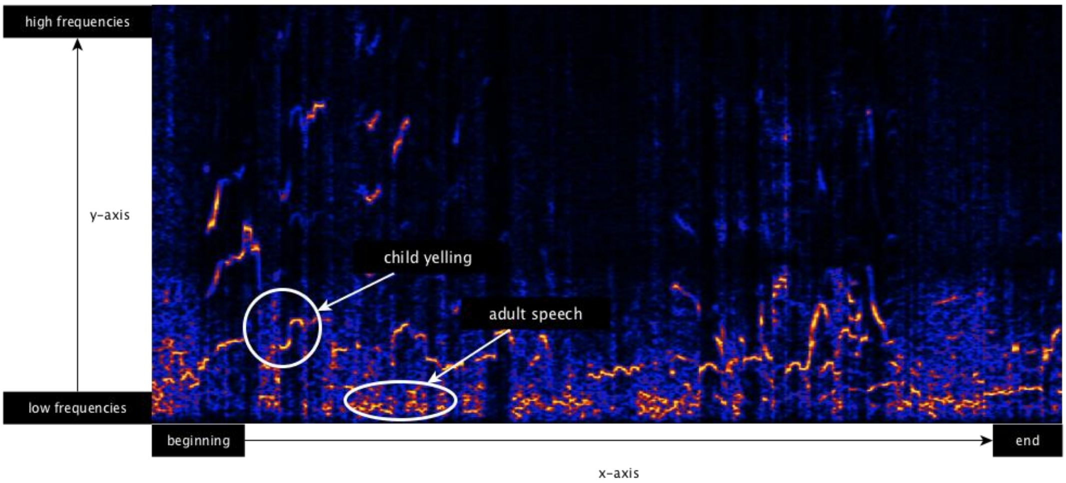


Figure 3.10 Distinguishing different sounds in spectrogram images generated by Sonic Visualizer software.

Another reason for selecting spectrogram imagery as a visualization method is the dimensionality of the resulting representation when converted onto the surface of an artifact. The audio waveform only has two visually recognizable dimensions, time and intensity (while combined in a single waveform). On the other hand, spectrogram images have three dimensions: time, intensity, and frequency. This character provides a stronger, easier, and more distinguishable connection between different sounds and their representations. Figure 3.11 shows two ways of audio visualization of the same audio file: spectrogram image on the top and audio waveform at the bottom.

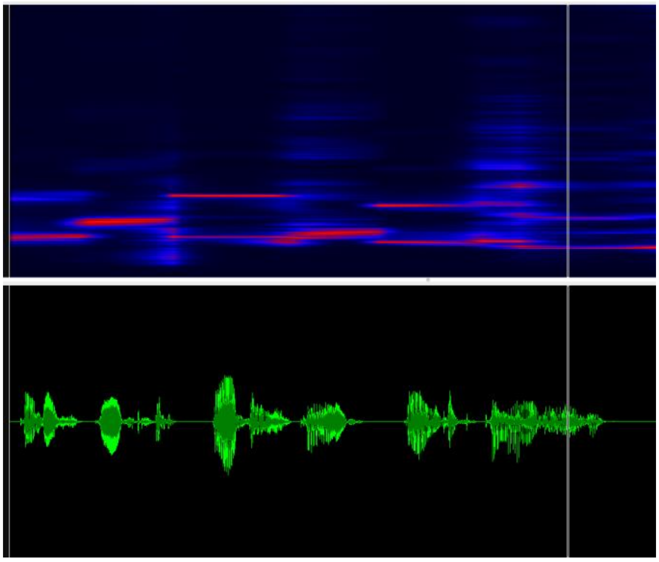


Figure 3.11 Spectrogram image (top) versus audio waveform (bottom)

Although the spectrogram image provides much more detailed visual information than the audio waveform, it requires some conceptual learning on the frequency of sounds and their corresponding examples from real-life situations. For this, different sounds or users' sounds can be played in real-time, and how the spectrogram image works is explained.

3.6.3 Image Processing

I used the images produced by Sonic Visualizer (Cannam et al., 2010) as topographical maps that would define the surface height of the artifact to be personalized. However, the generated images in Sonic Visualizer usually create sharp or thin edges that might easily break when manufactured. Thus, I had to further process the image in a way that would smoothen these edges. I used the Gaussian Blur effect in Adobe Photoshop to smooth the sharp parts.

I developed this stage by going back and forth between the 3D modeling stage explained in the following section and this stage. Also, when I used the image generated by Sonic Visualizer as it is to modify the 3D artifact, the modeling program produced some faulty geometries that made it impossible to export as a solid

3D model for 3D printing. Later, I understood the problem was very sharp surface displacements that led to the breaking of polygons. Figure 3.12 shows the original spectrogram image of a speech without any modifications.

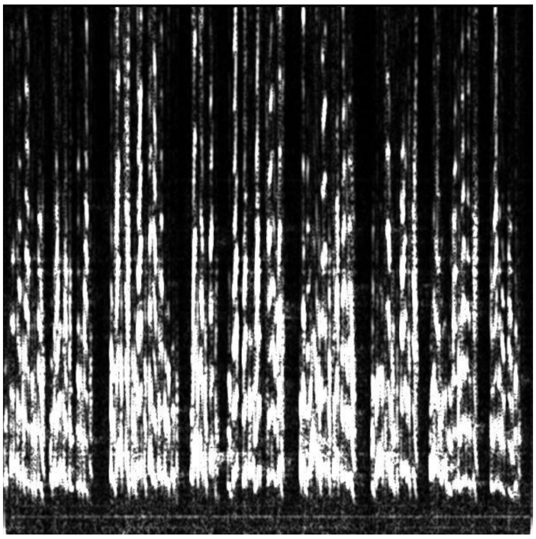


Figure 3.12 Original spectrogram image

In order to smooth the surface displacement, I used Gaussian Blur and vertical Motion Blur effects in Adobe Photoshop.

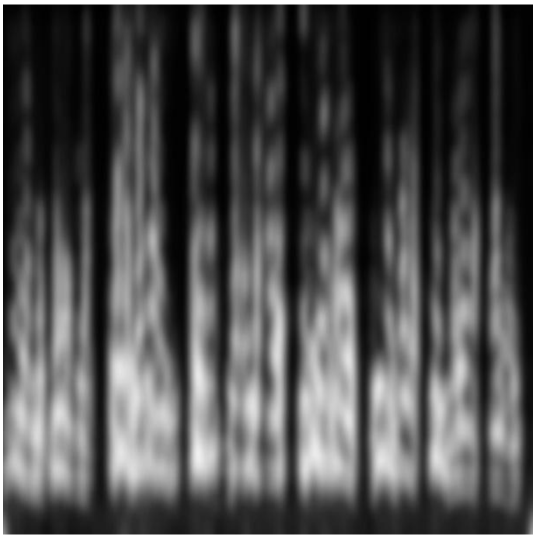


Figure 3.13 Smoothed spectrogram image

In the 3D CAD Modelling stage, the image's light areas displace the initial model's surface. The whiter the area in the image, the bumpier the corresponding place becomes in the model. The dark areas do not cause any deviation from the original model. Sometimes, the image may have light areas very close to the image’s borders that can cause displacements on the edges of the 3D model. Displacements close to edges cause some triangulation problems in the 3D model. Thus, the smoothed image then needs further processing, such as darkening the border of the image in order to prevent these problematic displacements and to act as a border that holds the outer proportions of the original model in place. After I finished the processing, I saved the image as a PNG (Portable Network Graphics) to use as a displacement map in the next stage.

3.6.4 3D CAD Modeling

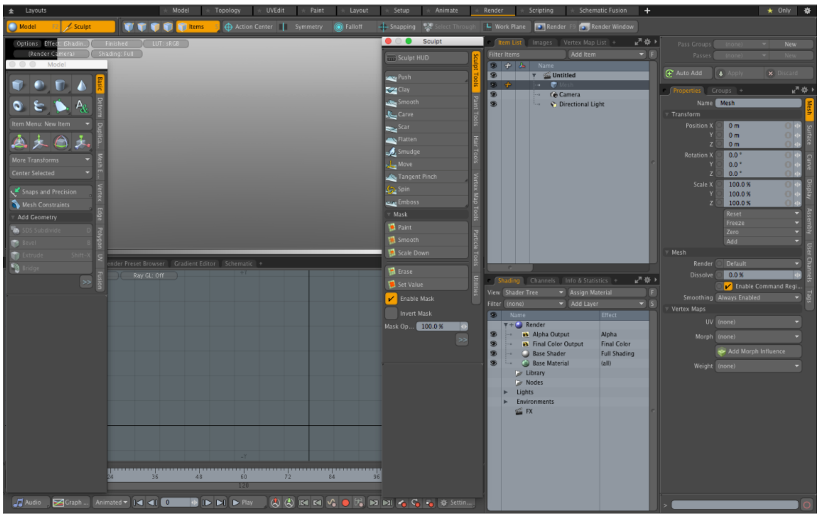


Figure 3.14 Screenshot of Modo interface

For the generation of the customized surface, I used the image that I processed in Adobe Photoshop. The transformation from a 2D image to a 3D model would be established in this stage. For this process, I used CAD modeling software called The Foundry Modo 901. My reasons for choosing Modo for this process were my familiarity with the software, its capability to export STL files for 3D printing, sculpting capabilities, layer-based material editor, and real-time rendering capabilities of the software. Figure 3.14 shows the interface of Modo software.

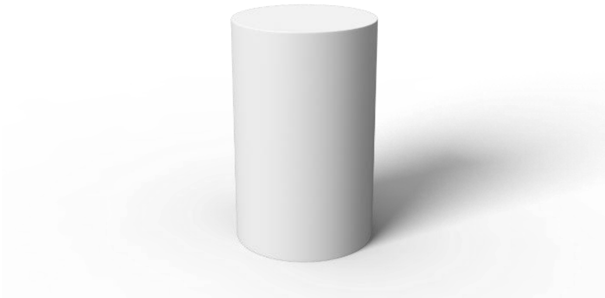


Figure 3.15 Empty cylinder model

I created an empty cylinder with a diameter of 40 mm and height of 60 mm as the artifact to be customized with sound (Figure 3.15). Then I assigned the processed file of the spectrogram image as a displacement map material onto the surface of the cylinder. After this assignment, I mapped the Y-axis of (the frequency range) of the spectrogram image from the bottom of the cylinder (lower frequencies) to the top (higher frequencies). I also mapped the X-axis in the image that represents time onto the cylinder's circumference (Figure 3.16).

Figure 3.16 Spectrogram image and its application as a displacement map onto the cylinder

After the initial assignment of the displacement map onto the cylinder, some further adjustments are done, such as the displacement distance amount and surface polygon subdivision. Suppose feedback from the participants mentioned a change in surface smoothness. In that case, the map texture is modified in Adobe Photoshop to increase or decrease blur amount in the image.

3.6.5 Preparation for Manufacturing

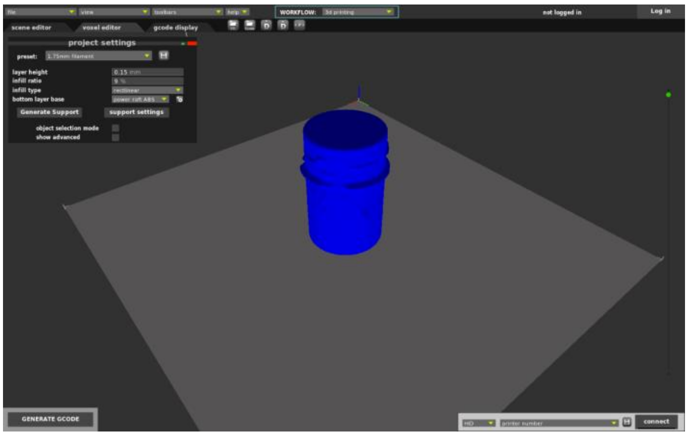


Figure 3.17 Screenshot of Voxelizer interface

After exporting the model as an STL file from 3D CAD software (Modo), I opened it in “Voxelizer,” the proprietary software of the 3D printer I used (Zmorph). In this stage, the parameters like layer height, build speed, and infill amount were the most important ones to me since they affected the details on the surface, the time it takes to manufacture the artifact, and the weight of the artifact, respectively. I used the layer thickness of 0,15 mm with 80mm/s build speed and 9% infill amount in both of the builds I made. After completing the necessary settings, I exported the GCODE file that would drive the 3D printer to build the CAD model exported from Modo.

3.6.6 3D Printing

For manufacturing, I chose the Zmorph 3D printer available in the office I am working at METU Technopolis (Reo-tek Co.). The reason for choosing Zmorph over Zortrax (also available in the office) is that Zmorph is an open-source printer that lets me control many more parameters than Zortrax. Thus, I would have more control over how to manufacture the artifact. First, I was thinking about printing a hollow cylinder since I could make it much quicker (about 30 minutes) than a closed one with an infill. However, if the artifact is left empty, it might be used as a container of small stuff. The primary focus is on the sound's meaning and value as a physical 3D artifact without any function. Thus, I decided to close it to prevent any referral to functional usage and confuse the participants.

Figure 3.18 Zmorph 3D Printer used for manufacturing

The closed artifact takes about three to four hours to be manufactured, even with a 9% infill amount. This period would make it hard to carry it on with the participants, so I decided to invite the participant only to a portion of the manufacturing session.

As the build material, I used white ABS plastic. I did not want to use any other material than plastic since it has become a very likely material and lacks any additional meanings or tactile feelings that may be present in other materials like clay, wood, metals, etc. Also, it is one of the most cost-efficient materials for low-cost 3D printers. For the material color, I chose white because I did not want the user to be affected by the color of the artifact. Instead, I wanted it to be like a blank page that would only reflect the form and meanings if there were any.

3.7 Variables Caused by the Tools Used

The tools used introduce many variables into the transformation process. They are explained and discussed in the following sections.

3.7.1 Audio analysis and editing

As I mentioned in the "Tools" section, finding a way to represent the given audio file was a unique challenge. Although the audio spectrogram image analysis creates images unique to that sound recording, several parameters can dramatically change the image's composition. For example, in Figure 3.19, I selected a linear frequency scale marked with a red arrow. White areas showing sound frequencies appear at the bottom of the generated image. However, when I selected the logarithmic frequency scale, as shown in Figure 3.20, the white areas in the image would shift upwards. This change would also cause dramatic changes in the model I generated according to this image. Linear scale images cause artifacts that have displaced bottoms, whereas logarithmic scale images cause artifacts that have displaced tops. Of course, this is valid mainly for audio files with human speech. Other kinds of recordings will cause a different distribution of the displaced surfaces, some more evenly distributed and some not.

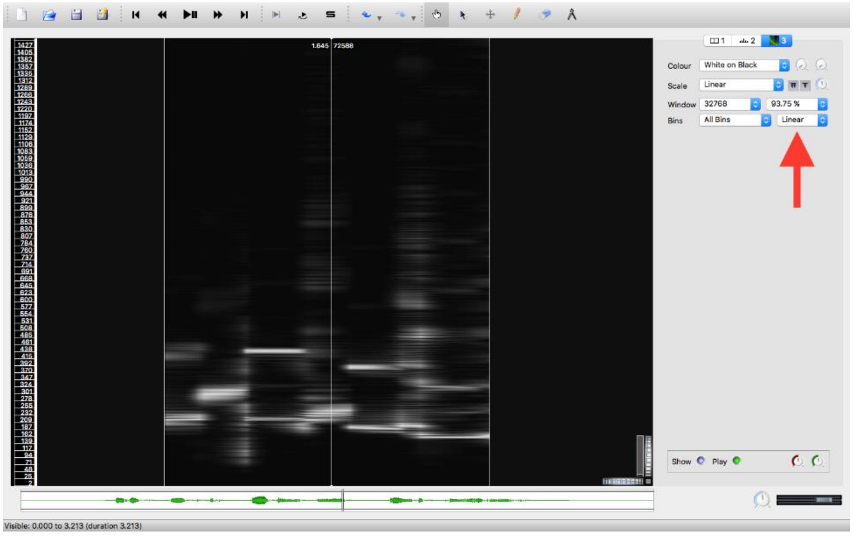


Figure 3.19 Audio spectrogram image with linear frequency scale

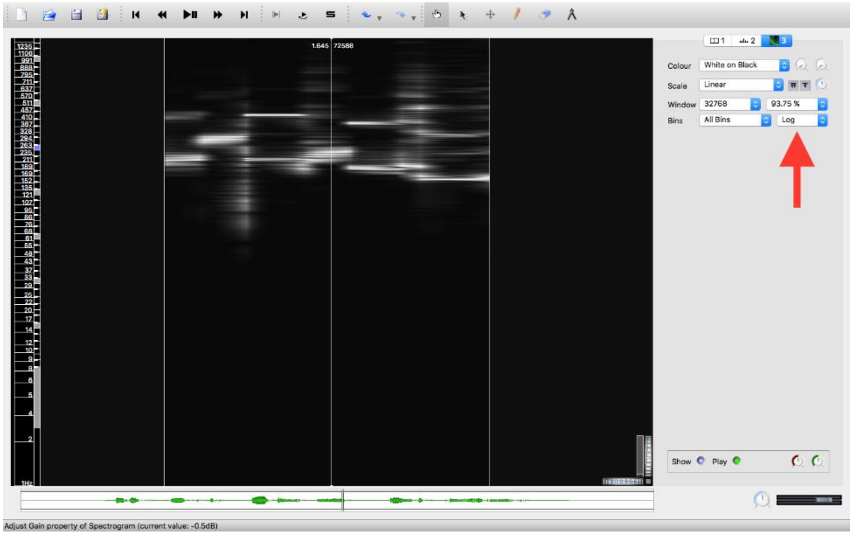


Figure 3.20 Audio spectrogram image with the logarithmic frequency scale

Apart from the *linear* and *logarithmic* frequency scales, another scale parameter changes the appearance dramatically. This parameter affects the brightness of the overall image. Previously invisible lines appear when the mode is changed to “meter” instead of linear. They are also recorded, but we cannot hear them since they are either too high frequency and/or very low intensity. Those might be background noises that were not intended to be recorded or the sounds we usually cannot hear. However, this does not change the fact that they are part of the original recording.

Thus, discarding or including them in the final image creates another variable. Figure 3.21 shows the amplified image I generated using the “meter” scale.

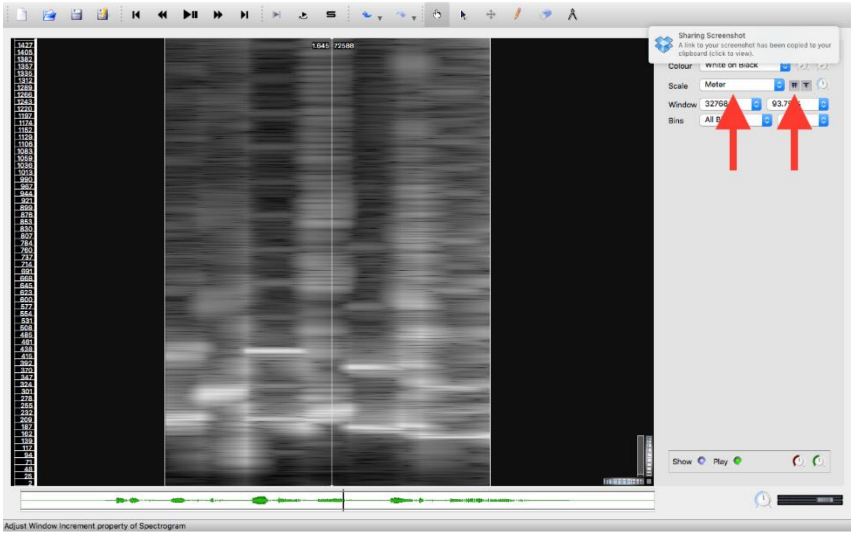


Figure 3.21 Meter scale audio spectrogram image

Compared with Figure 3.19, the image in Figure 3.21 shows many other frequencies that could not be seen in the previous image. The meter scale functions like a brightness dial for this spectrogram image. Since they are very dark in the original image, they are probably inaudible noises in the recording. Thus, increasing the meter dial is like increasing background audio noise. Increasing the meter value creates a visual noise that makes the *meaningful part of the sound* hard to distinguish from the background.

3.7.2 Image processing

The tool for image processing introduced more variables into the process. The variables I determined are as follows: the smoothness of the image, the borders of the image, and the stretching amount of the original image to fit the texture map of the artifact.

The original image exported from Sonic Visualizer is sharp to be used as a displacement map on the artifact. When I used the exported image directly as a displacement map in Modo, some polygons started to break apart, as I mentioned in section 3.6. Thus, I needed to modify the original image, such as adding a Gaussian Blur filter in Adobe Photoshop. Moreover, I also added a motion blur effect to smooth the surface vertically. The problem with these steps was that the blur amount was entirely up to the user and me. So each time this process was repeated for a different user, a different amount of blur would be needed since the image has different sharp and smooth areas.

The generated image from the Sonic Visualizer can sometimes have bright parts that are too close to the edges of the composition. When this happens, the bumps on the artifact's surface come so close to the edges of the artifact that it can lead to problems with the model's topology, causing broken geometry and uncontrollable features on the model's edges. I decided to put a dark border around the image so that it could return the geometry to the original when coming toward the edges to prevent any problematic deformations. This process, to me, is similar to taking a photo of something and then adjusting the composition. Whatever is inside the photo is there, but the photographer can crop it in a way s/he wants to correct some errors or strengthen an impression. The participant responses during the studies include comments related to modifying the sound data and spectrogram images, thus will be discussed in the next chapter.

Another variable related to image processing is the stretching of the original image exported from Sonic Visualizer. The duration of the audio recording directly affects the width of the image generated. Since the frequency range in the software is constant, varying the duration of recordings causes images with different ratios. For standardization, each image is stretched or compressed into a square ratio of 1/1, 2048 pixels by 2048 pixels.

Implications

The implications of the variables in the image processing stage are similar to the ones in the audio analysis stage. Both of them directly affect the final appearance of the resulting artifact. This effect can even change how the manufactured artifact evokes emotions since the tactile properties of the artifact change when the surface becomes rough or smooth. I do not change the frequency distribution of the image by, for example, distorting, cutting, and pasting. Thus do not theoretically alter the content of the image. However, other processes like smoothing and darkening the edges make some parts of the artifact more visible than others. Thus, I thought an alteration from the original exported image might cause issues similar to the ones in the audio analysis part. However, as I mentioned in the paragraph above, that did not seem to be an issue in the studies. Moreover, I had the observation that being able to change some properties would be necessary for the user to appreciate the final form of the artifact to be formed.

Apart from these visual changes, the resolution of the data also changes. I needed to stretch or compress the images to fit a square format. When longer recordings are used, they lose some details when their sizes are reduced to fit the square format. When shorter recordings are used, their resolutions are up-sampled (or stretched) to fill the square.

3.7.3 Artifact Selection

As discussed in *section 2.7, Translating Data into Artifacts*, a form was needed to map the data. Thus, I needed to decide on the form of the initial artifact to be modified. I thought of the necessity of the artifact becoming invisible and only the forms created by the sound to be visible. Also, I wanted the form to allow the observation of the time and frequency dimensions. Thus, the parameters that I mapped onto the artifact should be readable from the properties of the artifact. Cylinder’s bottom, for example, represents the lower frequencies, the top represents higher frequencies, and the circle's circumference represents time. Although I mapped audio data to artifact surface like this, the reverse would also be possible. Such as mapping frequency dimension to circumference and starting the recording data at the bottom, progressing towards the top.

Concerning the connection between the artifact and the data, the *embodiment concept* discussed in section 2.7.2 presents three association types: indexical, iconic, and symbolic relationships. In that section, I argue that using a *symbolic relationship* would allow this method to be applied to a broader range of artifacts since if the method successfully creates value and meaning even in a generic artifact, it can be applied to any artifact. *The only problem with symbolic relationships is that they need explanation. Involving the user in the process tries to solve that problem. The user's involvement in the process empowers him/her with an understanding of the process.* According to the literature, this understanding creates two types of meaning: one coming from the user's participation in the process (discussed in co-design literature) and two, the meaning coming from the usage of personal data (discussed in data physicalization in sections 2.3 and 2.4).

As I mentioned in the 3.6.6 3D Printing section, the artifact to be manufactured should remain functionless (to prevent any meaning and value that might come from function) other than carrying the sound visualization. Thus, instead of making the cylinder hollow, I closed it so that nothing could be put inside.

Concerning the decisions I made here, this process could be tested with a wide variety of artifacts that might introduce potential values and meanings into the artifact. However, to maintain this study's focus, I designed the studies only with the cylinder form. By selecting the cylinder as the artifact to be customized, I tried to eliminate additional value and meaning that could be present in other functional artifacts. In this way, I wanted the participants to focus on the value and meaning of the surface itself and the memory it connotes.

3.7.4 3D CAD Modeling

In 3D modeling, the form of the artifact is shaped by the image processed in Adobe Photoshop. Thus, the primary variable is the image coming from the post-processing stage. However, there still is a variable in the material properties of the model in

Modo. The displacement amount directly affects the height of the bumps caused by the white areas in the image. Therefore, it acts as an additional parameter in the artifact's appearance.

Another variable is the dimensions of the cylinder. I wanted the participant to be able to hold the artifact with a single hand. Based on the literature survey, it is known that physicalizations with different sizes can lead to different ways of interpretations of the data represented. Thus, I have selected the initial dimensions accordingly. The aim was to keep the artifact small so that it could be carried easily but not so small that the features on the surface became hard to distinguish. Because of these reasons, I considered its relationship with the human hand while dimensioning the artifact. The diameter of the cylinder is 40 mm, and the height is 60 mm. Although these are the dimensions of the cylinder initially, the displacement map differentiates the diameter throughout the surface. Thus, every cylinder being manufactured has deviations from the initial value and the dimensions of each other.

3.7.5 Manufacturing Method

Among many manufacturing technologies, I selected 3D printing to produce personalized artifacts. The main reasons for this preference are the following:

Scalability of Artifact

When the digital file is created, the final artifact can even be a statue made of concrete due to the many different techniques and materials used in 3D printing. Even nanoscale forms can be manufactured. *Thus, the meaning and value domain can also expand according to the artifact's medium.*

Distribution of Digital Files and Standardization

3D printers and their applications are spreading into various places that cover industries, end users, and consumers. This spread also means that the files generated have more and more potential for their materialization places. Compared to other computer-controlled manufacturing methods like CNC milling, laser cutting, and similar subtractive methods, 3D printers require less specialized knowledge (when consumer-type printers are concerned) and fewer materials since they do not waste material like the subtractive processes aforementioned.

Material Selection & Applicability to Various Materials

Among many materials present for 3D printing, I have selected ABS plastic for building the models. I have made this choice in order to eliminate any kinaesthetic values and meanings that could be associated with other materials. Of course, plastic also has such properties; however, it has become a material that we have become so used to that most of the time, it does not make a difference. Also, I wanted to see whether even an artifact made of simple plastic could gain a strong meaning and value when manufactured.

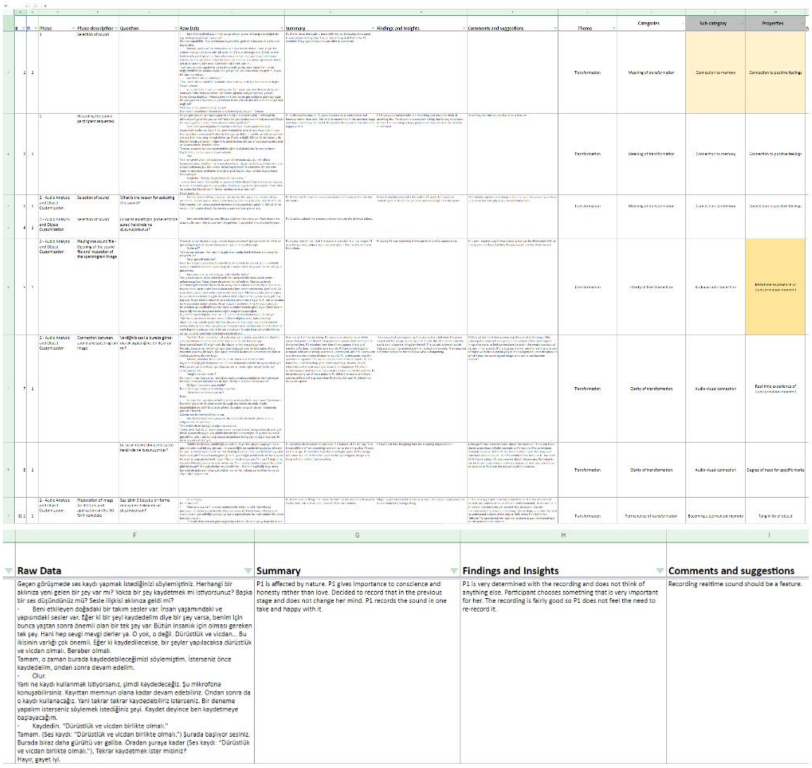
The materials of 3D printing are getting more and more diverse. Some examples available for 3D printing are titanium, steel, silver, gold, ABS, PLA, polyamide, aluminum, chocolate, concrete, living tissue, UV polymers, clay, glass, etc. Thus, with each material option, the applicability field of the method, their possible value, and meaning domains expand. Although 3D printing as a manufacturing method has the future potential of use with different materials, the experience of users with materials is beyond the scope of this thesis. Still, in the next iteration of the transformation method, different material properties are probed with the developed interface (see Design Workshop chapter).

Form Complexity

Although many complex forms can be manufactured by adding separately manufactured artifacts to each other, 3D printing allows otherwise impossible forms to be manufactured in a single piece. Also, when a CNC machine is considered, there needs to be a separate way to calculate the tool head movements for each type of complex shape. These limitations can also introduce some limitations to the form of the resulting artifact. Thus, these barriers are overcome by using 3D printing methods, letting the form free of these constraints.

3.8 Thematic Analysis and Coding Process

After completing the interviews, I transcribed and compiled all the data in a Google Sheets document with separate sheets for each participant session. I labeled all the data according to which phase of the study they were coming from, together with the description of phases, and parsed it into chunks, responding to different questions in the protocol (Figure 3.22).



Raw Data	Summary	Findings and Insights	Comments and suggestions
Geçen görüşmede ses kaydı yapmak istediğinizi söylemiştiniz. Herhangi bir aklınıza yeni gelen bir şey var mı? Yoksa bir şey kaydetmek mi istiyorsunuz? Başka bir ses düşündünüz mü? Sesle ilişkisi aklınıza geldi mi? - Beni etkileyen doğadaki bir takım sesler var. İnsan yaşamındaki ve yapısındaki sesler var. Eğer ki bir şeyi kaydedelim diye bir şey varsa, benim için bunca yaştan sonra önemli olan bir tek şey var. Bütün insanlık için olması gereken tek şey. Hani hep sevgi mevgi derler ya. O yok, o değil. Dürüstlük ve vicdan... Bu ikisinin varlığı çok önemli. Eğer ki kaydedilecekse, bir şeyler yapılacaksa dürüstlük ve vicdan olmalı. Beraber olmalı. Tamam, o zaman burada kaydedebileceğimizi söylemiştim. İsterseniz önce kaydedelim, ondan sonra devam edelim. - Olur. Yani ne kaydı kullanmak istiyorsanız, şimdi kaydedeceğiz. Şu mikrofona konuşabilirsiniz. Kayıttan memnun olana kadar devam edebiliriz. Ondan sonra da o kaydı kullanacağız. Yani tekrar tekrar kaydedebiliriz isterseniz. Bir deneme yapalım isterseniz söylemek istediğiniz şeyi. Kaydet deyince ben kaydetmeye başlayacağım. - Kaydedin. "Dürüstlük ve vicdan birlikte olmalı." Tamam. (Ses kaydı: "Dürüstlük ve vicdan birlikte olmalı.") Şurada başlıyor sesiniz. Burada biraz daha gürültü var galiba. Oradan şuraya kadar (Ses kaydı: "Dürüstlük ve vicdan birlikte olmalı."). Tekrar kaydetmek ister misiniz? Hayır, gayet iyi.	P1 is affected by nature. P1 gives importance to conscience and honesty rather than love. Decided to record that in the previous stage and does not change her mind. P1 records the sound in one take and happy with it.	P1 is very determined with the recording and does not think of anything else. Participant chooses something that is very important for her. The recording is fairly good so P1 does not feel the need to re-record it.	Recording realtime sound should be a feature.

Figure 3.22 Google Sheets Document showing participant 1’s responses (top) and the analysis columns (bottom)

While conducting the thematic analysis, I kept a coding journal using Evernote (Figure 3.23) besides the Ph.D. Journal that is kept during the study. I have included the decision-making process while labeling data in the coding journal. I have noted emergent themes, categories, labels, and reasons for the decisions taken with their dates in this journal. Also, I have noted when I felt that the categorization of the labels needs to change.

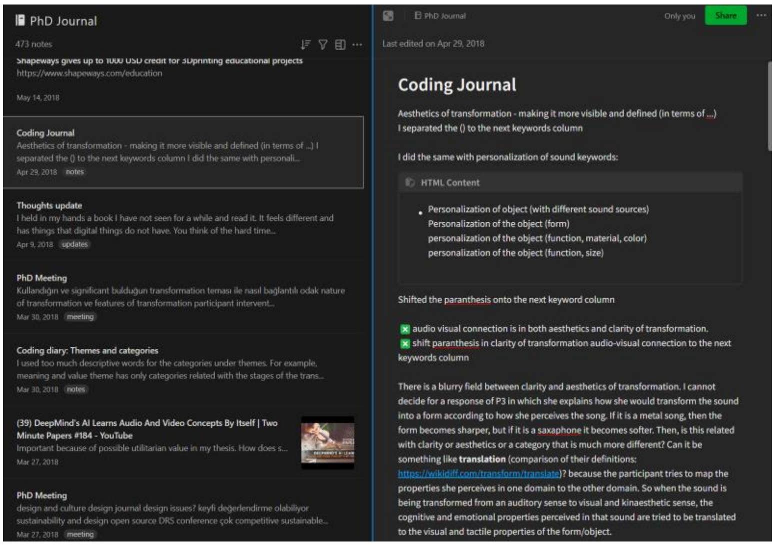


Figure 3.23 A screenshot from the decision-making log during the thematic coding process.

In the first coding round, I divided the conversation chunks into too many parts, and the coding resulted in a very granular scheme. Then, I had to repeat the process since, in the first round, the codes turned out to be too descriptive (Figure 3.24).

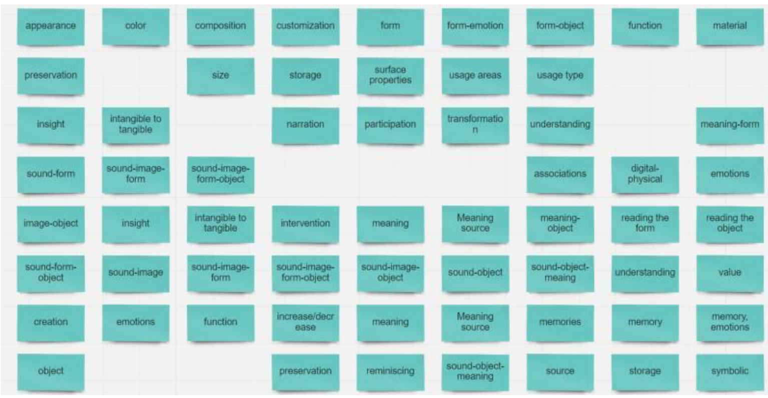


Figure 3.24 First round of coding resulted in very descriptive categories.

Qualitative analysis and coding processes are cyclical by nature (Saldana, 2010; Bailey, Hennink & Hutter, 2020). Thus, during labeling the data with properties and categories, I used a *dynamic labeling system* by using Google Sheets' Named Ranges function. Following the initial coding and the emergence of several properties and categories, I used the emergent labels and created a separate sheet that defined those labels as *Named Ranges*. For instance, the *"Functionalization of the object"* property (Figure 3.25) is represented by the label *"pFunc"* (Figure 3.25Then, while defining the data labels in the participant responses sheet (Figure 3.7), I entered the label *"=pFunc"* into the cell. This way, if there are changes in the label defined in the other sheet (Figure 3.6), all the data coded with the *"pFunc"* label would automatically update. This proved to be an efficient method since it saved me time by automatically updating all the data sheets instantly when I changed some minor definitions in the cyclical process of thematic coding and analysis by adopting an inductive approach.

pFunc | fx | Functionalization of the object

	A	B	C
1	**Cat**	**SubCAt**	**Prop**
2	Accessibility of transformation	Flow of process	Duration and progression of the process
3	Aesthetics of transformation	Unattended realization of transformation	Familiarity of the programs used
4	Clarity of transformation	Personalization of object	Low-cost alternative for the attended version
5	Meaning of transformation	Audio-visual connection	Stronger connection with the object
6	Permanence of transformation	Connection to memory	Functionalization of the object
7	Social clarity of transformation	Becoming a permanent memory	Sound distribution across object surface
8		Connecting people	Stylistic preferences
9		Sound-object connection comprehension	Surface enhancement

Figure 3.25 Dynamic labeling system created in Google Sheets by defining labels with Named Ranges function.

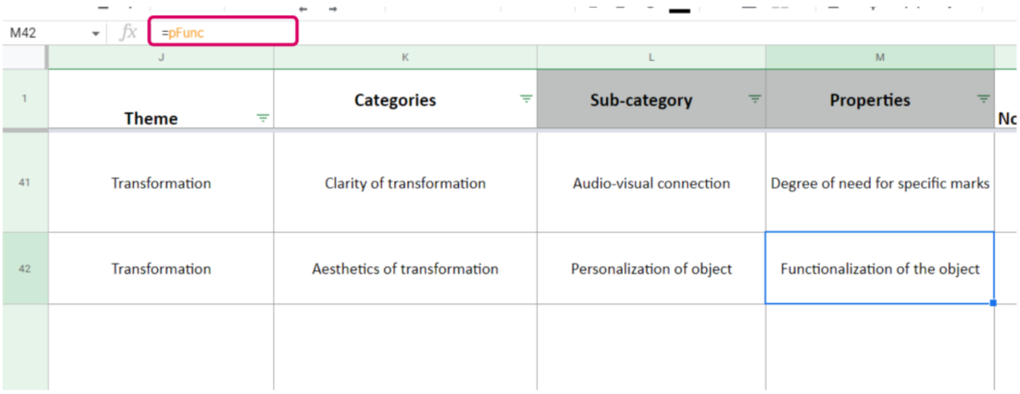


Figure 3.26 Using dynamic labels as a formula in coding the interview data.

As Braun & Clarke (2017, p. 79) argue, themes are used to find "patterns (themes) within data," and these patterns reside in the mind of the researcher who thinks about the data from his/her perspective. Therefore, I believe that there is a need to explain how these themes emerged in this study. All participant analyses were done from the *meaning-making perspective* and with concerns for transferring the meaning from the audio recording onto the final artifact. Thus, the emerging themes have been interpreted from that perspective. In addition to meaning-making, ways of improving the interaction of the participants with the developed transformation method are considered.

In the next chapter, the results of this analysis are presented as the dimensions of the transformation method. After their descriptions, the insights related to these dimensions are used as considerations for developing the next version of the transformation method.

CHAPTER 4

RESEARCH FINDINGS AND INSIGHTS INTO THE NATURE AND DIMENSIONS OF THE TRANSFORMATION METHOD

This chapter presents an approach that adopts qualitative research to interpret primary studies. The thematic coding and analysis (Saldana, 2010) is used to derive insights from the primary study, and they are used to design a second iteration of the transformation method.

Categories, sub-categories, and their properties that emerged from the data collected in the primary study are presented in Table 4.1. Appendix C illustrates example participant responses, insights extracted from the data, and their corresponding category labeling in thematic analysis.

The properties and suggestions that emerge from the data obtained from semi-structured interviews are presented as suggestions for improving the transformation method from the perspective of meaning and value generation in the next chapter.

Table 4.1 Thematic analysis results and categories

Categories	Description	Sub Category	Description	Properties	Description
Accessibility of transformation	This category covers participant comments about the transformation process itself, such as the length of the process, the ease of the transformation process, and their implications.	**Flow of process**	How the transformation process progresses from the perspective of the participant? Is it boring? Does something unpleasant happen? Are there any issues with the flow?	**Duration and progression of the process**	The overall experience of the transformation process concerning length and the way of its progression
		Unattended realization of transformation	The possibility of the participant doing the transformation all by himself/herself and its benefits. What would happen if the participant could do this transformation without outside intervention?	**Familiarity with the programs used**	Participants' interpretation of the apps used in the transformation process
				Unattended as a low-cost alternative	Being able to realize the process unattended would make the process cheaper and quicker
				Unattended as an engaging alternative	Making the transformation unattended establishes e stronger connection between the object created and the participant.
Aesthetics of transformation	This category covers participant comments that are related to the personalization of the object in an aesthetic manner.	**Personalization of object**	The ways participant uses to personalize the form of an object, such as function, appearance, and composition.	**Functional Attributes**	Participant's trying to find use cases for the resulting object offering different materials, form choices, use cases
				Sound distribution across the object surface	Participants' preferences and comments about the placement of spectrogram image (and in connection: sound data) on the object surface
				Stylistic attributes	Participants' preferences that are connected with the visual appearance of the artifact, such as color and style (when "style" is specifically used)
				Surface enhancement	Participants' preferences about the surface smoothness and bump amount of the resulting form

Table 4.1 (Continued)

				Use of different sound sources	Participants who want to customize the form by trying other sound sources quickly and see what comes out of it
Clarity of transformation	This category covers participant comments that include to what extent the transformation process is understandable by the participants and possible ways to understand the process better, making the object more meaningful and valuable.	**Audio-visual connection**	The ways participants connect an audible source (sound) to a visible source (image or form).	**Marking the beginning and end**	The importance of being able to recognize the beginning and end of the sound recording
				Interpretation of surface bumps	The importance of recognizability of certain bumps representing specific moments in the audio recording.
				Real-time experience of transformation moment	The participants' comments about the connection between spectrogram image and sound, also about the realtime playback of the sound file together with the participant and its importance in understanding the process and establishing the audio-visual connection
				Returning back to sound	The participants' comments about being able to play the sound they brought through the object and its importance in keeping the audio-visual connection while making the object more understandable
				Role of rhythmic sounds for recognizing patterns	The participants' comments about specific patterned sound recordings with repeating pauses like pauses between words or rhythms such as drums, bass, or words, etc.
				Translating perceived properties of sound to object form	The participants' effort to modify the surface of the form according to the audial qualities of the sound to the visual qualities of the surface.
Meaning of transformation	This category includes participant comments related to the meaning of the sound file they brought and its connection with the memory they have.	**Connection to memory**	The relationship between the sound participant brings and his/her memories about it.	**Audio sample part as a representation of the whole memory**	The participants' comments about the meaning of part of a long recording and to what extent it represents the memory as a whole.
				Connection to positive feelings	The participant's comments related to the reasons behind his/her choice of audio recording.

Table 4.1 (Continued)

Permanence of transformation	This category covers comments about how the transformation process makes the memory-connected sound more permanent.	**Becoming a permanent memory**	Transformation of sound, considered an ephemeral memory, into a physical object and becoming permanent.	**Tangibility of object**	The participants' comments about the transformation of the sound into a solid object and its connection with the concept of permanence, how an ephemeral sound can transform into a tangible and solid object, becoming a permanent memory
				Translation between senses	The participants' interpretations of the changes happening when something that can only be heard is transformed into something that can be seen and the way it adds to the memory's permanence
				Multisensoriality	Participants' comments about how the experience becomes a multisensory one and how that makes the experience more memorable
Social clarity of transformation	This category covers participants' comments related to their ideas about how the resulting object would be interpreted by a stranger who has not seen the process.	**Connecting people**	Objects becoming a connection between people that share the same memory.	**Sharing a common memory**	The Participants' comments about the object becoming a symbolizer or something that is shared between more than one person.
		Comprehending sound-artifact connection	Strangers being able to interpret a connection between the sound and the artifact	**Interpreting the connection by audience**	The participant's comments, concerns and solutions about how the object's understandability by strangers and how it can become understandable by a stranger

4.1 Primary Study Findings: Themes and Categories

The categories presented in Table 4.1 are explained in more detail in the following sections. Participant responses, followed by related discussions, exemplify each category and property.

The audio file preferences are presented in Table 4.2 below, together with their sources, importance, and associated feelings.

Table 4.2 Summary of participant audio types and their significance for participants

P#	Audio type	Significance for the participant	Meaning coming from the content	Feelings
1	Voice: participant's own voice saying a certain phrase	her life motto	Yes, it is the phrase "Honesty and conscience should be together."	No specific feeling was mentioned (Determination?)
2	Voice: daughter's voice (first clearly said words)	her life's most important thing, her first excitement with her child	Partially: the words said by her daughter herself, rather than with a family member's prompt	Happiness
3	Music: Zaz "je voux"	song played at her wedding, positive feelings and happiness when listened, has memories connected with it	None She does not know French	Energetic, happy, optimistic
4	Music: Bach "L'offrande Musicale"	story of the composition of the piece, the symbolic meaning of volunteer activity in a non-profit activity)	Yes, the story of the composition	No specific feeling mentioned
5	Music: Outlaws "The last gunfight" Game theme music	happiness brought by achieving a challenging task	None	Accomplishment, being envied

4.1.1 Meaning of Transformation

This category covers participant comments related to the meaning of the sound file they brought and its connection with the memory they have. The evaluation of the responses is presented under "Suggestions for the improvement of the transformation process" subtitles at the end of each property. The sub-categories and related properties are outlined in the following table:

Table 4.3 Follow-up hierarchy table showing the mentioned category in the hierarchy.

Category	Subcategory	Properties
Meaning of Transformation	Connection to memory	Audio sample representing the whole memory
		Connection to positive feelings

4.1.1.1 Connection to Memory

This subcategory refers to the relationship between the sound participant brings and his/her related memories.

4.1.1.1.1 Audio Sample Representing Whole Memory

This property covers participant comments about the meaning of part of a long recording and to what extent it represents the memory as a whole. P3, who selected her wedding song for the sound recording, thinks shorter periods of sound are enough to represent the connection to the memory. Although she thinks that the whole song is important, a ten-second portion of the song, which includes the chorus, is enough since she thinks that is the part that attracts the listener.

Suggestions for the improvement of the transformation process

The length of the audio sample does not need to be very long, according to P3. But when other participants were also considered, none of them expressed a need for a long section of a song or an audio recording. From P3's comments, it can be deduced that the most recognizable part of the audio file might be enough to represent the memory. However, different types of audio might have different requirements from the participants' perspective. For example, a speech with a special meaning might not be cut off and reduced to several seconds if the whole speech is important to the participant. That considered, there is no evidence in the interviews to show the importance of such a need.

When the sound recording is kept long, the visual representation of the audio data becomes too condensed in the artifact form. This makes it harder to recognize the patterns that connect the sound and artifact.

From P3's comments and when the overall interviews are considered, keeping the audio recordings around 10 seconds seems to be the best option. However, allowing the participant to cut the desired part should be an essential feature of the audio selection process.

4.1.1.1.2 Connection to Positive Feelings

This subcategory covers participant comments about the reasons behind participants' choice of audio recording. All the participants choose an audio recording that has some kind of importance to them. Generally, they choose an audio recording connected to positive feelings. P1 chooses an audio recording of her life motto with the words "Conscience and honesty should be together," thinking that this is important for everyone in life. She wants to transform something that she thinks is valuable and meaningful for the world. She states that since the transformation process is done with her participation, the sound should be something from her. She is very determined with the words that she records and does not want to change them or think of anything else. In Figure 4.1, a screenshot from the audio recording phase is presented.

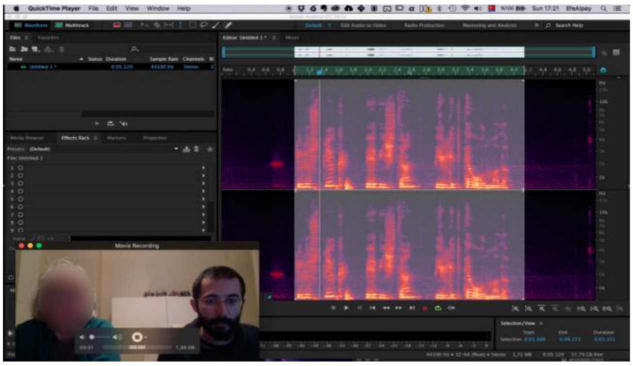


Figure 4.1 Screenshot from P1's audio recording phase.

P2 chooses her daughter's first words from a video recording. In that video (Figure 4.2), her daughter says, "what is the name of this" by herself without any exterior intervention or prompts. This makes her happy whenever she watches the video. She states that when she sees the 3D-printed artifact, it makes her happy too. When she looks at the artifact, she remembers that moment and speech.

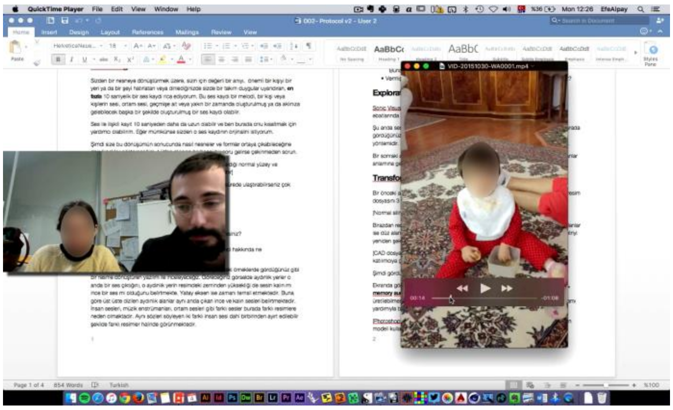


Figure 4.2 A screenshot from P2's decision-making phase about which part of the video she wants to be transformed.

P3 chooses a song that they used in her wedding. The song "Je Veux" makes her happy and evokes energetic and good emotions whenever she listens to it. P3 especially mentions that she prefers memories connected with positive feelings to motivate her and give her energy. She compares this song she brought with another one and reveals the song she brought is her wedding song, and she prefers it because it is more optimistic and especially it has beautiful memories associated with it. She defines the manufactured artifact as "a toy from your childhood that you cannot throw away” because it makes you feel good and remember past times when you look at it.

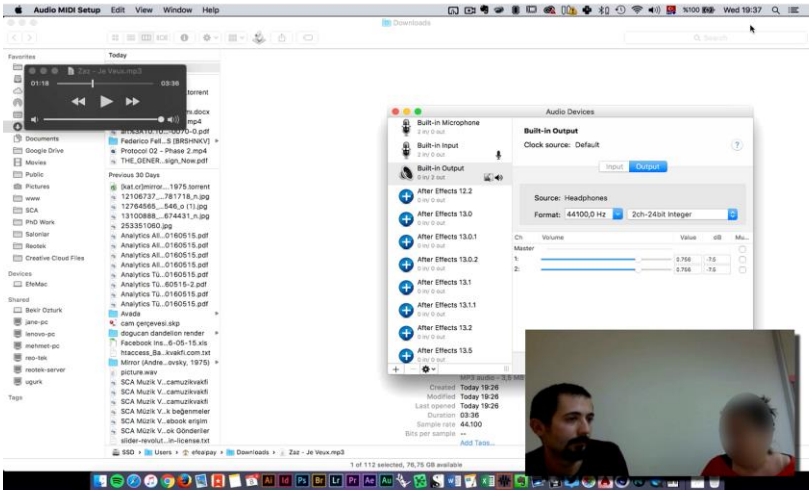


Figure 4.3 A screenshot from P3’s audio selection playback

P4 defines the reasoning behind his choice of the music piece, L’offrande Musicale, as melody, theme, historical context, and the use of the notes of the piece on the awards they give in a music foundation. This music becomes the symbol of the foundation. They only use notes rather than mentioning the name of the composer. He does not explicitly connect his choice to positive feelings. However, when the use context is considered (an engraving on awards given to nominees by the music foundation), it can be evaluated as a connection to positive feelings such as success.

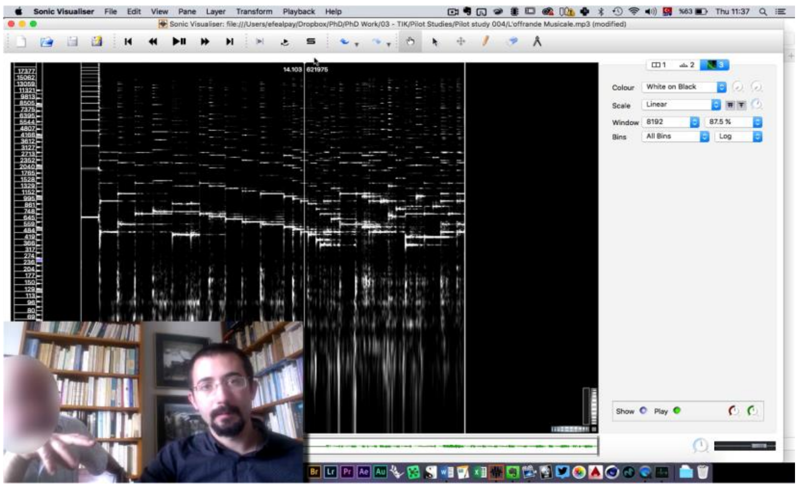


Figure 4.4 A screenshot from P4’s spectrogram image and its real-time playback.

P5 chooses a final theme song that plays after finishing a computer game called Outlaws (developed by Lucasarts). Figure 4.5 shows the last scene from the game, and Figure 4.6 is a screenshot from the study. He chose this song because that is a game that he played a long time ago when he was around the age of 10, and after a long period of playing, this was the last song that played after killing the last bad character in the game. P5 states that finishing such a game for a small kid was not easy. His completion of the game made his friends envy him. He finished this on a snowy day, so whenever it snows, he remembers this song and the game.

Figure 4.5 A screenshot from the last scenes of Outlaws game (by Lucas Arts) played by P5.

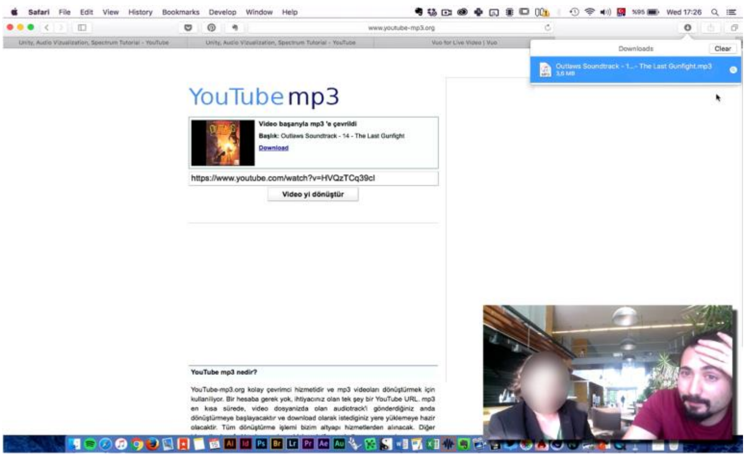


Figure 4.6 A screenshot from the study of P5 while downloading the theme song from the youtube video.

Suggestions for the improvement of the transformation process

All the recordings are related to positive feelings. Nevertheless, some are more personal and some less (P4). When the explanation of P4 about the meaning of the sound he brought is examined, it appears that he has the least personal connection with the sound among the five participants. As argued in the literature (Karyda, Mekler & Lucero, 2021) and mentioned back in *2.8 Personal Data as Design Material* section, weak connections between the data and the person can prevent the physicalization process from working. Another detail about P4's sound selection is the time frame he made the decision. While all other participants had a few days to select the recording they wanted to bring, P4 decided during the study's first phase. Thus, this quick selection might affect the assessment of his personal meaning of sound. Because of these reasons, it is decided to request that participants be guided before the study to select both meaningful and personally significant sounds while also ensuring enough time is allocated for the participant to make the selection.

4.1.2 Clarity of Transformation

This category covers participant comments related to what extent the transformation process is understandable by the participants and possible ways to understand the process better, making the object more meaningful and valuable. Response evaluations are presented under the "Suggestions for the improvement of the transformation process" titles. The sub-categories and related properties are outlined in the following table:

Table 4.4 Follow-up hierarchy table showing the mentioned category in the hierarchy.

Category	Subcategory	Properties
Clarity of transformation	Audio-visual connection	Marking beginning and end
		Interpretation of surface bumps
		Real-time experience of image and sound

	Returning back to the source of sound
	Role of rhythm for recognizing patterns
	Translating sound's perceived properties into form

4.1.2.1 Audio-Visual Connection

This subcategory covers participant comments concerning how participants connect an audible source (sound) to a visible source (image or form). The participants' experience is then evaluated by their contribution to the *clarity of transformation* category.

4.1.2.1.1 Degree of Need for Specific Marks

This property covers participant comments about the importance of recognizing certain moments from the artifact surface, such as the beginning and ending of the sound recording and certain moments or words in the sound recording. The spectrogram image used in the transformation process guides the participants to understand the bumps on the artifact surface and make the connections between the audio features and the artifact. However, some audio recordings, especially the ones that create a dense composition when transformed into an artifact, need further guidance to be understood. Just like in the *Reify* example discussed in the Data Physicalization examples section, after some point, the representation of the data over the artifact surface becomes very hard to distinguish and understand. Although participants did not directly comment about the density of the data over the surface, P1 commented about sound being stretched over the artifact surface, and P3 argued that more crowded voices would result in a more crowded artifact surface.

Apart from the artifact's surface complexity, the audio recordings' beginning and end were another areas in the comments. P3 thinks knowing the beginning and end of the recording is not very important since loved songs are already played repeatedly.

However, if it were a speech of Atatürk, she states that it changes. P3 connects playing the songs again and again with the looping form of the cylinder. For songs, knowing the beginning and end is not essential, but if it is an important speech, then it matters.

Contrarily, P4 prefers the artifact to tell clearly where the recording starts and ends. For this, he suggests using a rectangular prism since the beginning and end of the recording will be understandable in whatever orientation it might be placed.

Suggestions for improving the transformation process

P3 is probably looking for the general mood in the songs she likes rather than certain moments or phrases. This uncertainty may also cause 10 seconds of recording to represent the whole song for her. However, for speeches, the beginning and the end gain importance, which will probably influence her selection of the time duration and section, since she might want to see which bump corresponds to which word or part of the speech. The difference between the two recording types might be pointing to a dominant interpretation of the memory: a song as a whole (for P3) represents positive feelings and memories so that a part of it would represent the same for her. On the other hand, different speech sections might represent different feelings and memories; thus, a section might not represent the whole. Therefore, *the selection of the audio section might become more critical in the meaning of transformation.*

Although no direct comments are made about the interpretation of the beginning and end of the recording, two very different approaches to the representation of sound on the artifact's surface provide clues about the importance of observability of the beginning and end of the recording on the artifact surface. P3 interprets a song as a looping thing, whereas P4 states that it has a beginning and an end. This variance of opinion might relate to the types of songs they have brought. P3's audio has repeating choruses, so that might be causing her to interpret the song as a looping thing. On the other hand, P4's audio is a classical piece that has discrete sections and does not have any repeating parts.

Since the audio types and their interpretations by the participants are much more likely to be unpredictable, the transformation process should consider these differences. Bump marks can be used to specify the beginning or end of the recording. Also, a circular form can be used for participants who interpret the sound as looping. Marking of the beginning and end can be a feature but optional depending on the types of audio recordings.

4.1.2.1.2 Interpretation of Surface Bumps

This property refers to the importance of recognizing individual bumps representing specific moments in the audio recording. During the primary study, all participants successfully interpreted the final artifact through the spectrogram image. P1 looks at the surface of the virtual artifact on the screen and states that they usually are only bumps on the artifact's surface. However for her, she states that it is not like that. She *sees her voice there and recognizes the loudest part of her voice while saying those words*. The artifact does not resemble sound for her. They are bumps and dents on the surface, but P1 does not look at them like that. Instead, one of the bumps is the loudest part of her voice recording. P1 does not think the sound, image, or form should overlap completely. P1 knows that the sound and image also depend on the recording setup. Despite these differences in the technical aspects of the recording, she states that the result will be more or less similar. For P1 seeing the sound recording and the transformed 3D version is enough for her to connect the two. P1 thinks the form she sees is as she expects. P1 relates bright areas to bumps and thinks they have a connection. P1 does not need to look back at the image since she remembers the visual details. She wonders how the very bright spots on the image will come out in the final artifact. P1 defines her voice in the spectrogram image as a thing in the middle of two parallels (see Figure 4.13, c, and d on page 200).

As soon as P1 gets the manufactured artifact, she reads the bumps on the surface and connects them to the recording. It is a strange feeling for her to be able to see the spectrogram image on this artifact. P1 says, in fascination, these are the things she said and asks whether all kinds of sound-related things can be done like this. P1 immediately recognized the recording's beginning and end and said, "This place should be the beginning of the word ‘conscience’**."**

P2 can see the waves on the artifact's surface. She can feel the emptiness in the silent places. She tries to connect the sound to form by comparing the sound to bumps and silence to emptiness. That way, she can connect them but cannot think of another way. When she thinks about the connection with her daughter’s voice, she can distinguish her words like saying “what,” “is,” “the,” “name,” “of,” “this.” This connection makes her happy. However, she cannot understand the simultaneous sounds accompanying her daughter's words. She likens them to an echo. She is informed about the human voice’s composition of different frequencies. Then she connects these simultaneous bumps as a part of her daughter’s voice. She wonders if it was an older person, whether there would be more frequencies. She also asks what would happen if it was a song and predicts that there will not be any empty spaces. This extrapolation of her on the representation of a song over the surface provides evidence that she has cognitively acquired the transformation method.

In contrast with the previous two participants, P3 does not try to read specific details of the song on the artifact surface. Rather than that, she is interested in the general appearance of the artifact. She assumes that, in the future, a device will be reading this artifact to her. She believes the form is shaped by sound. Then, whether all the details of the sound can be perceived on the artifact's surface or not loses its importance.

P4 thinks that the output artifact can be talked about when asked.

> P4: "I find it interesting. Of course, we have made a relatively simple -monophonic- piece’s mold here. I do not know what it would be like when made from a symphony. I wonder if it would be as talkative as this is. It's more talkative. The other is vaguer."

When P4 is asked what he means by “talkative,” he explains that it means the expression is strong. He speculates that if it were made from a symphony, there would be many different sound heights, and it would be too complex to be understandable. The comments of P4 also signify that he can extrapolate his current experience with the transformation method into other scenarios with different sound recordings, thus providing evidence that he has understood the process.

After the manufactured artifact is handed to P5, he can track the bump that represents the bell in the song and the gradual rising of the song. He thinks we lose the initial image through the process; however, they transform into peaks on the artifact, and in that sense, we keep the connection. He is sure the form would be much different if it were a song from Slayer (a thrash metal band). P5 sees the "guidelines" of the song on the artifact as he describes more pronounced bumps on the surface. He traces the beginning and ending parts of the song. He thinks there might be parts he spots wrongly, but it is more important and enough for him to understand where the ringing of the bell starts and how the trumpet progresses.

Suggestions for the improvement of the transformation process

Understanding the method brings curiosity about the result of other sound sources like songs and crowd voices. All participants wondered what the artifact's surface would be like if another audio were used. They have predictions based on their experiences in the step-by-step transformation process. However, enabling them to experiment with other types of audio recordings, such as songs, symphonies and voices, would increase the clarity of the transformation process by letting them interpret specific marks more confidently and construct a stronger audio-visual connection.

P1's mentioning of seeing the spectrogram image before telling about sound, shows that it is the connector that comes to mind before the sound and the memory itself. Spectrogram image is not a problem for the participants; however, this creates an intermediary step and requires extra cognitive processing to connect this image to the form again. A way to directly create the specific marks on the surface without needing a spectrogram image would facilitate its interpretation since one step will be removed from the process.

After the connection between sound and its representation is constructed in participants' minds, the representation and recognizability of each feature in the audio recording start losing importance. Specific marks ("guidelines," as P5 defines them) can be enough to preserve the connection. Then, the participants are more concerned about dealing with the visual appearance of the artifact. In the current process, the participants are only given the parameters to change the surface smoothness and bumps on the surface. However, material, color, artifact form, and orientation can also be provided for them to explore.

The process can have different pre-determined lengths for different sound types. For example, songs would be recorded in shorter clips since there will be more data for a given time regarding beats, sounds, etc. Given that the artifact has a finite surface, this data should be cropped more than a single person's voice recording. This way, the general composition of the sound around the form can be more even and satisfactory for the participant.

4.1.2.1.3 Real-time Experience of Image and Sound

Participant comments on real-time sound playback, sound transforming to an artifact, transformation's importance for process understanding, and establishing an audio-visual connection are presented in this section. In some parts of the recording, P1 sees some simultaneous white areas that point to different frequencies of sounds that are heard at the same time. She wonders how these lines appear and she states that she has not recorded such sounds. P1 tries to understand the origin of these darker white lines; however, she lacks the knowledge to compare the method to other representations of sound. After P1 listens and sees the representation of another sound, she understands that the system can separate the sound into its most intricate points. At first, P1 has difficulty connecting the sound with the image. After listening to the sound and seeing real-time playback of the spectrogram image, she starts to find connections between empty spaces and pauses in her speech. P1 talks in certain pauses, and she sees that the spectrogram visual represents a similar pattern. She discovers that every word has a pattern. P1 thinks that the result would be less meaningful if she were not told about the initial stages throughout the study. P1 can literally read the words that she recorded from the artifact's surface since P1 knows what corresponds to what. Because of that, this is much more impressive for her.

Figure 4.7 Spectrogram image of P1's audio recording.

P2 tries to understand the spectrogram image and how the transformation occurs. P2 uses words such as "scattered," "high pitched," "tone difference" and mentions in the end that she has not heard the voice this clearly while watching the video. The real-time experience of sound makes her observe the sound more focused, and she states that she has not listened to her daughter's voice with such attention before. She connects the white parts in the image to the bumped parts in the 3D form. She realizes that the software "detects" the pauses between the words. However, P2 states that she cannot connect the sound to the 3D form without the spectrogram image.

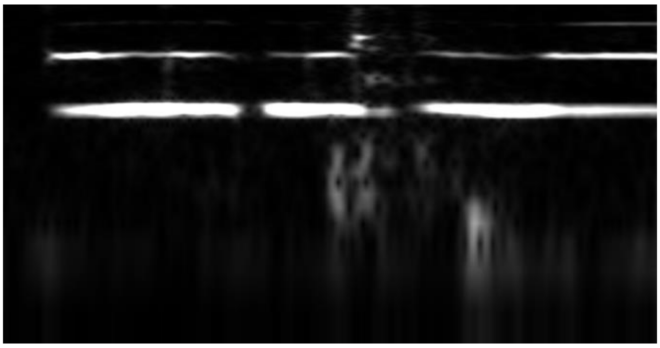


Figure 4.8 Spectrogram image of P2's audio recording.

Like P1 and P2, P3 cannot directly connect the 3D form with the sound. She mentions that she can see the visual “one-to-one transformation" of sound waves. She mentions that since she had already seen another participant’s artifact, her artifact came out as expected. However, she states that the exciting part is when she has seen the “one-to-one transformation” phase in which the sound is transformed into the spectrogram image.

P4 reflects upon the transformation of sound into 3D artifacts and thinks of this process as an exciting and “magical” process. He thinks he will like the resulting artifact after completing the transformation process. He states that we usually only listen to or read the music in two dimensions. The norm is reading or listening to sound/music. In this process, the sound becomes physical and interpreted that way.

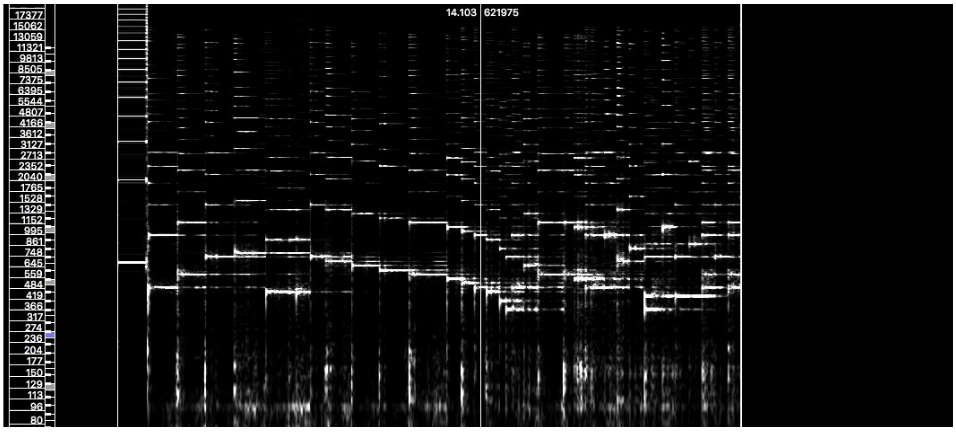


Figure 4.9 Spectrogram visualization of P4's audio recording in Sonic Visualizer software.

P4 examines the spectrogram image as the researcher opens the sound file, explaining the meaning of bright and dark spots and their relationships between sound frequency and time. He repeats things explained to him as a sign of his understanding of the process, such as "treble and bass" and "high and low." The participant mentions that the moment he hears something, he sees a stain on the screen. P4 understands that the cursor points to the moment of the sound in real-time. He also mentions that he can see the bass sounds go toward the bottom and high-frequency sounds appear towards the top. After the participant believes the real-time transformation, he spends less time trying to match visuals and sound but more on discovering new parts that exactly match (the gesture on his face changes to smiling).

The more complicated parts (multiple layers of lines along the x-axis in Figure 4.9) in the spectrogram image make it hard for the participant to evaluate sound and visuals simultaneously. After simplifying the image by increasing the contrast and eliminating not-so-audible parts in the recording (Figure 4.10), the participant interprets the representation as “real-time.”

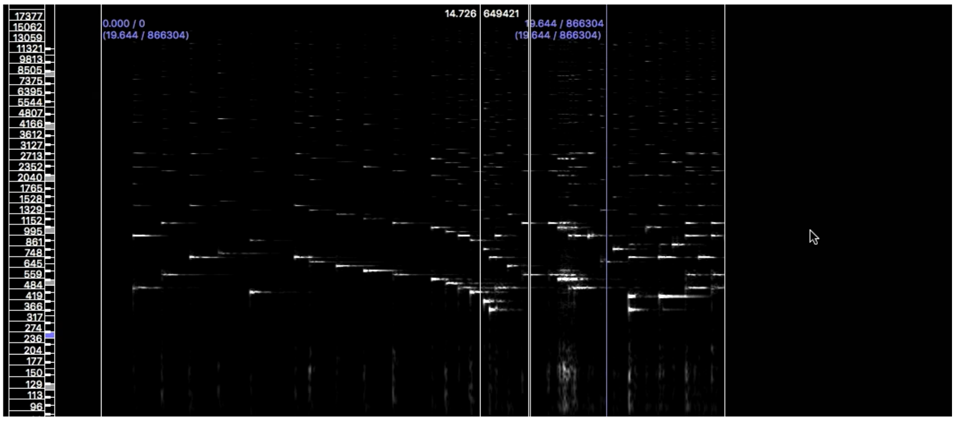


Figure 4.10 P4’s audio recording spectrogram in Sonic Visualizer software after a different visualization method is selected and peak frequencies are normalized.

P5 thinks that the person participating in that process enables the participant to see the modifications instantly. He thinks of an application idea that lets the person modify the shape and send it to manufacturing. *He remembers the sound when he looks at the artifact because he was there in the process and mentions that it is tough to forget*. However, the artifact reminds him of the song itself rather than the moment of its manufacturing.

It is hard to discuss an original representation of sound in this stage since many variables exist. However, the primary studies showed the importance of the participant’s knowledge of the process. For the audio analysis stage, two variables can affect the study's implications: The first one is the shifting of the image upwards or downwards. The second is the image's brightness, which makes previously invisible parts visible.

Suggestions for the improvement of the transformation process

The pauses between words help participants (P1, P2) to understand the method more easily. They become reference points for participants to follow what is happening.

When the participants can see the real-time playback of the sound with the visuals generated, this experience lets them understand how the transformation takes place and create an experience-based ground that materializes the connection in the participants' minds. The initial generation of the image forms the foundation of the "original" representation of sound, and it sticks with the user. What the participant sees first when the sound transforms into a visual representation is very important. Thus, *the sound should be directly transformed onto the artifact's surface in real-time.*

If the process lets participants see the real-time creation of the artifact with the sound playing in the background, then the phase in which I play the spectrogram image with sound can become obsolete. Getting rid of the spectrogram image phase would also decrease the cognitive processing required by the participants to transfer meaning coming from sound to the artifact surface.

The spectrogram image is an essential part of the transformation process, which, when played synchronously with the audio, helps create the connection between sound and the resulting artifact. However, that synchronized playback was only possible with the spectrogram image during the study. Thus, the spectrogram image becomes the center of the visual connection between sound and form. Since the initial connection is made between the image and sound, the participants later translate that image onto the artifact and mentally translate those visuals into 3D structures.

In P4's case, the audio recording has many simultaneous frequencies that must be understood to be accepted as a real-time representation of sound. Then, the visual complexity (meaning multiple frequencies heard simultaneously) becomes a limiting factor since the participant can not filter through the visual noise in the spectrogram representation. Decreasing the visual complexity by filtering not-so-audible sounds and pronouncing the peak frequencies solves the problem for P4. However, there might be more complex recordings that would require further processing of the recording, and none of the participants' studies provides clues about what would happen to the perception of real-time transformation when there are no visually and audibly recognizable patterns.

P5's comments about the difficulty of forgetting the transformation process point out an essential aspect of the participant being there when the transformation happens. Throughout the process, the participants see the visual representation of the audio file and make connections between the audio, visuals, and the artifact. However, more important than seeing the transformation process, the experience of being *in the process* and being able to direct it maybe creates another type of connection between the audio, the symbolic meaning of the audio, the artifact, and the participant. Thus, more than form, being involved in the process and the time spent making the artifact can be a stronger reminder of the audio recording itself. The process was initially designed to use an audio recording connected with a memory to create an artifact expected to carry the meaning and value of the initial audio. In the process, the participant's involvement is a crucial part of the study. However, in the final artifact, although there can be a way to reach the sound's original by integrating online links onto the artifact, the process of transformation and participant's involvement are completely lost since there is no recording of it. Concerning the importance of the participant's experience during the transformation process, using a way of recording and reaching back to the participant's experience can significantly enhance the meaning and value of the process and the final artifact. This situation resembles going to a touristic place where a person tries pottery for the first time, and while trying to form the clay on a potter's wheel, s/he is recorded on a film for future reminiscence. This transformation method differs from that. Rather than being very amateur with the material and technique, it provides familiar tools: memories and personal sound, thus increasing self-efficacy. The creation of meaning and value becomes inevitable through the participant's involvement in the transformation process as guided by the arguments from co-design, meaning, value, and attachment literature. Also, as it will be argued in the following sections under the *social clarity of transformation* theme, this recording can help the communication of the meaning of the personal experience to someone who has not seen the process and has no information about the resulting artifact. For example, participant interactions with the software can be video captured and become a documentation of the final artifact. The recorded video then can relate to the sound in a way that after reaching the sound recording through the artifact, the participant or an outsider can also reach the recorded video of its making.

4.1.2.1.4 Returning Back to the Source of Sound

This property refers to participants' comments about being able to play the sound they brought through the artifact and its importance in keeping the audio-visual connection while making the artifact more understandable. Most of the participants (P1, P2, P3, P5) stated a need for a way to reach the audio recording. For P1, the artifact must have some explanation because P1 thinks it must be known since it is a memory for her and must be evaluated with its content. P1 wants an explanation on the artifact surface that is clearly visible so it can tell about itself. She talks about a music device that plays according to the bumps on a cylinder and thinks of a device that provides a way to play the song when the artifact is put into it.

P3 is interested in listening to the artifact. She suggests that the artifact could play the sound with the press of a button. She suggests an artifact like a speaker and plays the sound when touched. Similarly, P5 thinks of a player device that enables it to return to the sound by “releasing the sound locked inside the artifact.” He gives an example from Disney’s Infinity game in which a figurine is bought, and when plugged into a device, the owner can start to play the game with those figurines.

Artifact playing the song would be a third relationship with the artifact. The artifact and sound should have connections to have a meaning, according to P3. When this artifact is given to a stranger, s/he cannot guess that the form is coming from that sound. Otherwise, it is not different from geological fossils. For P3, for a stranger to understand the artifact, an explanation of how that form is generated is needed. Similar comments and concerns are gathered under the *social clarity of transformation* theme in section 5.5.

Suggestions for the improvement of the transformation process

The connection between sound and artifact is essential for it to be a meaningful artifact. This connection is established through the explanation of how that artifact is formed. Being able to return to the sound increases the chance of a stranger's understanding of the artifact, while it may also enhance the meaning and value for the possessor of the sound. When combined with the concept of permanence, something ephemeral can become permanent in that artifact because that artifact lets us return to that sound repeatedly—also giving us a clue about where that memory exists in physical space. The transformation process does not currently host a method to listen to the original sound through the artifact. However, participants' comments point to the importance of such a mechanism. Since methods like putting the artifact into a reader and playing back the sound can require integrating physical components and electronic devices, a more practical method is suggested. QR codes that can link the artifact with its sound can be integrated into the artifact so that a participant or someone can scan the QR code and see the original sound/video of the related memory.

4.1.2.1.5 Role of Rhythm in Recognizing Patterns

This property refers to participants' comments about specific patterned sound recordings with repeating pauses like pauses between words or rhythms such as drums, bass, or words, etc. Among the audio selections of the participants, P3's song -Je Veux- can be defined as the most rhythmic song. P3 relates the rise and falls in saxophones with the bumps on the form's surface. After understanding that those bumps are more related to the rhythms, she mentions that further investigation is unnecessary since how the peak sounds are related can be understood. For P3, the concept of rhythm is very suitable for the definition of the song and the artifact surface generated from that. However, P1's motto recording and P2's daughter's voice also have rhythmic properties in which silences follow words. This progression of sound is also recognized as rhythm by the participants. After they realize the same rhythm is in the generated spectrogram images, they cease questioning the connection between the audio and the visuals.

Suggestions for improving the transformation process

Rises and falls in sound are related to bumps on the surface. However, after understanding the connection of the sound with surface bumps, the participants do not try to investigate intricate details. When the participant understands a connection between the sound-image-form, then s/he sees it unnecessary to search for every detail in the sound and find their corresponding shapes. After this point, the transformation process might enter a *pre-justified personalization space. Here, the connection between the audio and the artifact is already established. However, the participant is going further not to justify the connection but to satisfy his/her aesthetic and personal expression needs related to the artifact.* P3 and P5 establish this by increasing the bump amount, while P2 tries to match the surface to her interpretation of her daughter's voice. For P3, this stage is like making covers of the songs, and for P5, it detaches sound from the artifact by aestheticizing it. *Since the artifact-sound connection is made in participants' minds during the real-time transformation experience, playing with the form further does not appear to be destroying this connection.* Thus, *the transformation process should allow more formal deformation and changes related to the artifact's appearance, such as different materials, dimensions, and form changes.*

4.1.2.1.6 Translating Sound's Perceived Properties into Form

This property refers to participants' effort to match his/her perception of sound with his/her perception of generated form. For example, P2 tries transforming the concept of "Pureness" into soft surfaces and loud parts into higher bumps. P2 initially thinks of voice tone as a constant entity, but later she says it is not like that after seeing the spectrogram images. She defines her daughter's voice spectrum image as flat/straight. Her daughter neither shouted nor spoke silently. She thinks the visual and sound relates to each other. She states that the system puts silences in between the words by itself. She likens the image to a river, and nothing else comes to her mind. She likens the 3D form to a space shuttle (Figure 4.17, a), whereas it is more like a flowing river as a 2D image for her (Figure 4.8). She states that the form with a lower bump amount was "purer." If she is to connect the artifact with the image, she prefers the less bumped one, but the more bumped version is more pleasing for her. When she thinks of the 3D form with her daughter, high bumps become frightening since they are like another person's thicker voice. The less bumped version is more suitable for her daughter and more "elegant." She does not want to decrease the bumps too much since it signifies almost no voice. She states that if it was a male voice, then the depth of the bump could be more. However, smoothness is more suitable for a kid's voice (Figure 4.17d). P2 related the visual properties of the form with the visual properties of her daughter with these words and made an interesting suggestion about the form of artifacts:

> "If it was on a small baby form it would be more suitable with my daughter... We could have shown the bumps on the dress of the baby. That would be more suitable to a child's voice I think, not a cylinder. A car sound might be more suitable for this cylinder… I think it would be more beautiful if we choose the artifacts according to the sounds that we select… But this is also beautiful"

Vande, Moere & Patel (2009) classify this type of connection between the data source and its physicalization as a *symbolic representation* (p. 8). P2 thinks a form related to the source of sound would have a different meaning for her.

For P2, the artifact itself does not mean anything if there is no sound. The artifact gains meaning from its connection with sound and her understanding of the sound-form transformation process. She connects the form with her daughter’s voice tone, the smallness of her child’s voice tone, and the appearance of the form as small and elegant.

Like P2, while evaluating the surface properties of the artifact, P3 connects the surface characteristics with the feeling the song gives her. Although the song has downs and ups, she states it is not exhausting, so she thinks the surface can be softer. For her, if it was a metal song, it could be sharper, but if there is a saxophone, it can be softer. Rather than using the spectrogram image as it is, the participant prefers to modify the surface properties according to how P3 perceives the song. P3 thinks the interventions and modifications done after transferring the spectrogram image onto the artifact surface as making covers to songs.

P5 talks about the essence of the song. He states that the visual representation of the sound on the artifact does not make him feel how he usually feels when he listens to music. Instead, his perception of the song's progression reminds him of the song. The form or representation does not immediately remind him of the feelings and emotions the song evokes. In other words, he connects the rising melodies with the surface details while establishing a connection between them.

Suggestions for improving the transformation process

P2 treats the artifact as if it is a representation of her daughter. P2 connects gender with bump amount. P2 transfers meaning from her daughter to the form, and while interpreting the form, she reflects the properties of the form back to her daughter. If they do not fit together in her mind, it becomes disturbing. P2 might be trying to connect other features, such as cuteness and facial properties. The sound source features, sound characteristics, and the resulting form are connected. So, the participant tries to reflect auditory experience in visual preferences. After the participant records or sees the effect of sound on the artifact surface, instead of using definitions about visual properties such as bump amount and smoothness, different definitions can be used, such as noisy, silent, calm, crazy, creative, etc. In addition, new parameters can be added to visualize other emotions and adjectives.

The sound prepares the initial personalization of the form. Later the participant wants to customize it further according to her aesthetic preferences. After the sound and source are connected in the participant's mind, a continuous editing process goes along to make them fit together. The participant asks the researcher to change parameters, sees the result, and asks to change something different. Then the researcher asks for another parameter, and so on. Thus, the interaction process should facilitate this kind of editing. However, the current process has the researcher's intervention between each statement of preference.

4.1.3 Accessibility of Transformation

This category covers participant comments about the transformation process itself, such as the length of the process, ease of transformation, participants' experience with the processes used in transformation, and their experience throughout the stages of the study. The sub-categories and related properties are outlined in the following table:

Table 4.5 Follow-up hierarchy table showing the mentioned category in the hierarchy.

Category	Subcategory	Properties
Accessibility of transformation	Flow of process	Duration and progression of the process
	Unattended realization of transformation	Familiarity of apps
		Unattended version as an engaging alternative
		Unattended version as a low-cost alternative

Flow of process subcategory focuses on participant responses, their experiences concerning the duration and progression of the study and their interpretation of the study. *Unattended realization of transformation* subcategory focuses on to what extent participants interpret the transformation process as a self-conductible experience and outlines the possible outcomes of this ability.

In the following sections, the sub-categories for the *Accessibility of Transformation* category are presented, followed by an evaluation of the category's contribution to the value and meaning of the transformation process used in the user studies.

4.1.3.1 Flow of Process

This subcategory covers participant comments concerning how the transformation process progresses from the participant's perspective. The participants' experience is then evaluated by their contribution to the *accessibility of transformation* category.

4.1.3.1.1 Duration and Progression of the Process

This property refers to the transformation process's overall experience concerning length and its progression. The transformation process is understood well by all the participants. The step-by-step progression is easy to follow by the participants. They can follow the steps easily, although they do not have any experience with the programs (P1) or understand what is going on in the background (P2). P1's lack of understanding and inexperience in the software makes it hard for her to suggest any improvements to the flow of the personalization process.

The process is interpreted to be smooth. However, the duration of the manufacturing phase prevents participants from seeing their artifacts being materialized from start to finish. None of the participants were eager to wait for the artifact to be 3D printed, which takes around three to five hours of printing time. The participants want to see this phase (P1, P2, P4). Still, being able to manufacture an artifact that is completely customized to the participants' preferences in such a relatively short time (from the beginning of the form creation until the artifact is completed) fascinates P1:

> It is extraordinary that this artifact is given to me without any difficulty. I had no difficulties and did nothing. You recorded the sound, showed me the graphic, 3D-printed it out, showed me the printing process, and it was handed to me. This period is very short for me.

Since P1 is an interior designer, she has experience in manufacturing artifacts and products. Thus, she might be comparing the transformation process to conventional manufacturing techniques, and she might perceive the process as short.

The manufacturing length makes P4 think that the manufacturing phase is expensive. He reaches this judgment by assuming that using a 3D printer for that period of time must be costly. P4 also mentions that actively participating in the manufacturing process is important for him. After the manufactured artifact is handed to P4 and the video of the 3D printing process is shown to him upon his suggestion (Figure 4.11). His interest in the manufacturing process increases as the participant starts to ask questions about the maintenance and cleaning of the artifact while using it.

Figure 4.11 A still from the short manufacturing video shown to P4.

P4 is interested in the manufacturing phase, but he is concerned about his available time and his daily schedule. Consequently, he prefers a video of the manufacturing phase. He does not expect a 4-hour manufacturing time which appears to be a long period for him. Although the participant cannot attend the manufacturing phase because of his unavailability of time, he wants to see the artifact being manufactured from a video upon the researcher's suggestion. Concerning the overall process, P4 has doubts about the practical value of the artifact but is still interested in the experience as the researcher is involved in it:

> This has been an important process for me. Such things can be done. You are doing this, and that is important too. You [referring to the researcher] are busy with things like this. That is part of life too. Maybe I can show them to a couple of enthusiasts if they ask. Put it on the TV or on the table.

P4 also gives clues about how the artifact might play a role in his daily life by mentioning a possible use case, which might be a conversation artifact if people ask about it. If somebody asks about the artifact, he says that he would explain that there is a researcher that transforms sound into artifacts, and this is made from a recording of a song.

Suggestions for the improvement of the transformation process

During the form personalization process, the continuous intervention of the researcher to materialize the participant preferences might decrease the *accessibility of transformation* by causing the participant to disengage from the process. In order to make the transformation process more accessible, the role of the researcher in the process can be rethought. *Decreasing the researcher intervention in the process or even eliminating the need for the researcher intervention can potentially increase the accessibility of the transformation.*

From the ideas that come into P1's mind, it can be deduced that the length and ease of the process make her feel empowered, so she can put forward many ideas and think they can be realized easily. Thus, the software interface can let the participant experiment with other artifact forms other than plain cylinders.

All of the participants wanted to see the manufacturing; however, due to the duration of the 3D printing phase, none could see the whole process. The production period of a completely personalized artifact is practically long to participate in when the manufacturing phase is considered. Although participants 1,2, and 4 want to see the manufacturing of the artifact, three to five hours of printing takes too much time for them to participate and experience. Thus, as P4 suggests, a time-lapse video of the manufacturing phase can be integrated into the overall experience to strengthen the perception of involvement in the manufacturing phase.

P4's comments about the process mentioning the researcher being part of the process, give clues about the importance of the participant experience. Although the study's focus is on the process of transforming sound into an artifact, the participant's experience with the involvement of the researcher and how the process progresses with the intervention of the researcher -as well as the researcher's background- start to become part of the participant's experience. This unplanned experience through the study might create a story that describes the features of transformation to an audience and can be used to enrich the experience in the next iteration of the transformation process.

After the manufactured artifact is handed to the participants, talking about the process and how it's made appears to be increasing the value and meaning of the artifact. There is no direct question to evaluate the effect of the process on the value and meaning of the artifact, but this can be probed in future studies.

4.1.3.2 Unattended Realization of Transformation

This subcategory covers participant comments concerning to what extent the transformation process can participants realize unattended and its potential outcomes. Participants' comments also include the effect of participants' familiarity with the programs used in the transformation process.

4.1.3.2.1 Familiarity with Applications

This property covers participant comments related to participants' interpretation of the apps used in the transformation process. P1 mentions that since she is not familiar with the programs used in the process, she cannot make any recommendations about the process. She thinks that being able to use these programs is the most important factor in being able to offer any suggestions:

> I don't think there is something under the name of suggestion because you've shown it so step-by-step that it feels like I'm capable of doing all these by myself. But the most important factor here is to be able to really use these programs. I mean, I don't know. That's why I can't find it [can't provide any suggestions].

Although she does not know the programs being used, the step-by-step nature of the process makes her feel as if she could also follow the same steps by herself.

P2 is generally curious about what comes next in the process. Since she has no experience with the programs used, she finds it hard to guess. In contrast, P3 has some past sound editing experience from her radio programs. But she does not have any prior 3D modeling and CAD experience. For both participants, no suggestions regarding the modeling phases are made.

Suggestions for the improvement of the transformation process

The participants without experience with 3D modeling programs or tools are purposefully selected in the study. Thus, the unfamiliarity of participants with the apps used might have kept the focus of the study more on what the form and process meant for them rather than "what if the app was like this" suggestions.

Despite the difficulty in getting any suggestions about the modeling process, the step-by-step progression of the study appeared to have an essential role in helping the participants catch up with what was happening in the transformation process. Thus, guiding the user during this increases the *accessibility of the transformation*, and the next iteration of the process should provide step-by-step guidance, helping participants see what to do next. For example, a progress bar can be integrated into the interface that shows at what stage the participant is and what is coming next.

4.1.3.2.2 Unattended Version as an Engaging Alternative

This property includes the participants' comments on the implications of the unattended version for generating a stronger artifact-participant relationship. When

P1 is asked what she would do if this process were widespread, she starts to introduce many ideas that she would create, from personalized gifts to artifacts created from family-related memories. She gives examples of making artifacts from the performances of actors throughout their plays.

P3 wants to be able to make this process by herself because of being faster and unbound by another person:

> I want to do something, and if you are dependent on someone, it would take more time, but if I do it myself, I'll do it faster…. I think it's a lot cheaper for me to make it faster. If I can do it myself, and do not need someone else, I can handle it more appropriately [cost effectively].

During the transformation phase, P3 continuously wants to make the bumps on the surface higher. P3 gives clues about this unsatisfied desire for a higher bumped surface of the artifact when she sees another participant's artifact that is more bumped and tells that it is more beautiful than her artifact.

After providing some initial input by sharing his preferences, P4 leaves the decision on further modification of the surface properties to the researcher and asks what the researcher would suggest. After mentioning everything is up to his taste, he asks whether his taste is being evaluated. When asked whether he would prefer a tool that would let him realize the transformation process by himself or not, P4 mentions that he does not see a practical benefit that this transformation process would provide for him:

> To be honest I do not need a tool that lets me make this transformation by myself. Because I cannot see what utility this artifact would provide me yet. I cannot see the benefit. Besides being a curious ornament artifact, I cannot see a direct practical benefit. But, for example, I like to combine music on my own computer and make a CD and listen to it in my car. That is something I have done with the technology I use but it also serves my purpose.

P5 states that he liked the idea of making sound into a tangible artifact that you can touch and play with very much. Participants being a part of that process and being able to see the modifications instantly is a good thing for P5. He suggests an application idea that lets the person modify the shape and send it for manufacturing.

Being part of the form generation process has a significant impact on the overall experience from his perspective.

P5 does not want to change anything in the process since he describes it, and the researcher does the modifications. He states that it wouldn't change anything if he were the one touching the mouse. He thinks it might be better for people to do this process by themselves in an application that would let them think better and completely tweak the artifact as they want. He does not want this for himself but for the people or participants involved in that type of process. He gives an example from the Sims game, in which players create their own characters and control their daily activities, and says people love it. Something that can be personalized is always more valuable for him since it creates a sense of identity. When asked whether he would be satisfied if the artifact was adapted according to the sound without asking him, he clearly stated that he would not accept such an artifact.

Suggestions for the improvement of the transformation process

P1's comments about what she would do if the transformation method was widespread (meaning that if this method were accessible in daily life, like printing or gift shops), might be pointing to an increase in the participant's engagement if the transformation process was more interactive and easier to do for the participant by herself. The flow of ideas about the things she would do if the transformation process was widespread shows that there could be many things that she would have tried if the process could let her do the transformation by herself. Initially, the participants were asked to bring the audio recording with them. However, P1 decides to record her voice during the interview. In order to tackle such situations, a sound recording feature should be integrated into the transformation process. Thus, creating an interactive transformation process and interface might create a more engaging experience for the participant. Such an interface, at the same time, would probably allow the participant to try new things that do not come to the researcher's mind.

Concerning P3's comments, it seems that because of the researcher's intervention, she does not get her desired height on the surface, although she initially seems to be satisfied with the form. Her reaction after seeing someone else's artifact implies that some of her preferences were lost in the transformation process. This is probably because, after some point, she might have thought this was the maximum possible bump amount. If she had the chance to experiment with the form by herself, then she might have come up with a different form that would make her more satisfied with the resulting artifact. Thus, the process should empower P3 to do this transformation by herself and allow experimentation.

P4 might be concerned about being judged, so he might have given limited feedback or input during the process. This might imply that the presence of an outsider in the process might be preventing the participant from stating his/her preferences. *Thus, enabling the participant to realize this transformation process all by himself might create a more engaging alternative to the current process.* For instance, the interface that the researcher uses can be re-designed to let the participant modify specific parameters by himself and see the results immediately. Thus, without any conversation between the researcher and the participant, he can interact in real-time with the prepared interface and see the results instantaneously. Although he does not see a practical benefit in using such a tool, providing him with such a tool that enables him to make artifacts as he wishes might change his perception of the process. He mentions that he prepares CDs on his computer for his personal use by himself, and such a tool can resemble this process, letting him experiment with the tool and provide additional insights. This can also be used to compare his before and after reactions to the process.

P5's suggestion of an application that lets someone realize this process by himself/herself might imply that although the researcher has done everything he wanted, something is missing. This missing piece might be the continuous disruption of the process flow by the researcher that gets in between the participant and the artifact. P5's "think better" comment might mean the ability or freedom for the participants to experiment and explore by themselves. Thus, it might be argued that letting a participant realize the transformation process by himself/herself can increase the *sense of identity transferred onto the artifact*. This, in return, might increase the meaning and value of the final artifact. Without an intervener in the process, being done something "all by themselves" can strengthen the sense of identity and belonging.

None of the participants, except P2, brought the source of audio with them. P1 recorded the sound during the study. P3, P4, and P5's choices required finding the song from the internet and downloading it as an mp3 file which is then transferred to the software for the extraction of the selected audio section. In order to extract the audio required by the participant choices, a web browser, YouTube mp3 downloader service, and QuickTime Player software were used. Therefore, if the flow of the transformation process is to be developed to favor participant use, the next version of the transformation process should let participants select different audio sources by themselves. For example, instead of using different software to extract the audio from the video, the participant can select the video file and easily choose the audio section that s/he prefers to use in the transformation process.

4.1.3.2.3 Unattended Version as a Low-cost and More Accessible Alternative

This property covers participant comments about lowering the perceived cost of the transformation process by enabling the unattended realization of the transformation process. P3 thinks that the process would probably be faster since there would be no need to communicate her preferences to another person to make the changes when she does this entirely by herself. She thinks that it might be cheaper. The transformation process involving the researcher implies to the participant that the process can be expensive and dependent on another person.

Suggestions for the improvement of the transformation process

P3's comments imply that designing an interface that lets the participant do the transformation process by herself would increase the accessibility of the process by decreasing the dependency on an outsider. Concerning her comments, the interface design should let the participant conduct the transformation process from beginning to end without any attending researcher. For instance, the sound recording or selection can also be done by modifying some parameters in the interface. Also, through a parametric interface, the user can modify the bump amount, surface smoothness, and orientation of the sound along the surface by using a slider interface. Then the user can save the form as a file or continue to work on the artifact if s/he wants. When satisfied with the final form, s/he can complete the process and save it for manufacturing.

4.1.4 Aesthetics of Transformation

This category covers participant comments about the form and function of the resulting artifact, such as the functional attributes of the artifact, the distribution of sound data across the artifact form, its stylistic attributes, and the connection of surface smoothness and bumps with the participant interpretation. The evaluation of the responses is presented under the “Suggestions for the improvement of the transformation process” titles at the end of each property. The sub-categories and related properties are outlined in the following table:

Table 4.6 Follow-up hierarchy table showing the mentioned category in the hierarchy.

Category	Subcategory	Properties
Aesthetics of transformation	Personalization of artifact	Functional attributes
		Sound distribution on surface
		Stylistics attributes
		Surface smoothness and bumps
		Using diverse sound sources

Personalization of artifact subcategory focuses on the ways the participants use for personalizing the form of an artifact through function, appearance, sound data composition, surface properties (smoothness and bumps), and sound sources. The following sections present the sub-categories of *Aesthetics of Transformation* category, followed by their related properties.

4.1.4.1 Personalization of artifact

This subcategory refers to the ways participants use to personalize the form of an artifact, such as function, appearance, and composition.

4.1.4.1.1 Functional Attributes

This property covers participant comments about the participants trying to find use cases for the resulting artifact offering different materials and form choices. All the participants search for functional use cases of emerging artifacts throughout the transformation process. Still, some participants (P1, P2, P5) mention that the artifact is also valuable because of the data source used in the transformation process.

Table 4.7 below sums up the practical use cases proposed by the participants for the resulting artifacts and their current perception of the artifact's function.

Table 4.7 Functional use case proposals by the participants

P	Current function	Potential function
1	Transforming ephemeral to permanent	Teacups, decorative panels, awards, pepper shakers saying bon appetit, a testament to children, Orhun monuments, decorative table ornaments, constitution
2	Decoration, heirloom	Decoration, pencil holder
3	Decoration	Pencil holder, jewelry, bracelets, pendants, watch, picture frame, computer case, flowerpot, speaker, bibelot
4	Talkative, curious artifacts	Musical notes, "curious artifacts", Talkative artifacts,

5	Decoration, collectible	Wall panels, decoration, table surface, child's moments saying "dad"

P1 gives many examples of the possible use cases of the transformation method. Some of them are teacups, decorative table ornaments made from her message, wall panels made from Brahms pieces or Deep Purple's Perfect Strangers song, and pepper shakers made from a voice recording saying "Bon Appetit". She adds that the use cases for the transformation method are related to the character of the person using it. P1 suggests that the form or function of the artifact and the content/meaning of the sound can be connected. For example, if the sound is about someone saying "Bon Appetit", then the artifact can be pepper shakers. When asked whether anything has changed after her sound has transformed into a physical artifact, she responds that it has become a physical artifact.

P2 cannot find a functional use for the artifact that is manufactured. Because of that, she thinks that she can use the artifact for decorative purposes. But this time, she is not sure about the quality of the visual appearance of the artifact for decoration. She thinks that the plastic's appearance is not very suitable to use as a decorative artifact.

P3 prefers the size according to usage type. If used on a table, it should be portable and small. But if used as a decorating artifact, bigger. She wants to keep the artifact. Because it is an artifact made especially for her, and it really is special, coded, and a beautiful artifact that can stand on her table and an artifact that she can talk about when asked. In terms of function, she wants to make it a pencil holder. Other than that, she is thinking of jewelry, bracelets, pendants, a picture frame, a computer case, a bookcase, a flowerpot, a speaker, watch. She thinks it would also be a beautiful cup made from porcelain. She thinks glass will make it harder to be seen. If it is made from glass, it would be more like a bibelot.

P3 suggests that the process can be made easier and let people realize the transformation themselves. Instead of using cylindrical artifacts, the participants can use different artifacts. She suggests using artifacts that can be more functional. Also, she states that spherical artifact forms can be used. She adds that this can be sold as a product.

P4 does not see any functional use of the artifact. He tries to find a functional use of the artifact as musical notes to read the piece from, but that seems complicated, if not impossible, for him. The process is "interesting" for him but lacks function and utilitarian value for P4. He sees the artifact as a replacement medium for listening to music or sounds. For him, the only functional use could be if the artifact could provide an *easier way of reaching the original sound that no other medium or method provides.* For P4, this transformation method can be used to create exciting artifacts. He defines the resulting artifact as a “curious artifact.”

For P5, size seems important for the artifact's functional use since he generally thinks of larger artifacts than manufactured ones. For general use, he suggests that many people would want wall panels made from their children’s moments of saying “dad” and mentions that his mother would be a target demographic for this transformation process. For his usage, he is thinking of making a decorative tabletop from the sound data. He later adds that this might be coming to his mind since he is looking for a table to purchase for his home.

Suggestions for the improvement of the transformation process

When P1’s pepper shaker example is considered, instead of providing a premade and meaningless base form to personalize, the participants can be presented with various artifact forms to use for modification with sound. This way, the process can be enriched to capture differences that may result in participants having different characters. P1 states that her sound has become a physical artifact when she is asked about any meaning-wise transformation. Although not mentioned directly, this transformation from an intangible audio file to a tangible artifact can have additional benefits from the participant's perspective, such as gratification coming from the artifact's kinesthetic properties, such as the permanence of the artifact and being able to touch it. One functional use of the transformation process can be converting an intangible and ephemeral sound recording into a permanent physical artifact. This core function of *transforming intangible and ephemeral into tangible and permanent* can be emphasized in the transformation process or the interface.

P2 finds it hard to use the artifact as a decorative ornament because of the material qualities of the plastic material. Thus, presenting material options for the manufactured artifact can facilitate the use of the final artifact in daily life. Also, it can be deduced that the material properties of the manufactured artifact should be in line with the intended use case. Thus, function-specific material selection in the transformation process can be integrated into the interface.

Concerning P3's comments, the size of the artifact directly affects the participant's relationship with the artifact during the day. The size of the artifact should be customizable according to the intended function. Different sizes of the artifact will probably lead to different connections with the artifact. If it is portable, s/he can interact very often. If not, the interaction cycles with the artifact can vary.

P4 does not see a direct functional value in the resulting artifact. However, he gives some clues about the possible functions of the artifact when in a social context. This context might be the communication of the artifact to another person by the owner of the artifact. Thus, it might be possible to make a discussion on the *social function of the artifact*. When talking about the artifact is considered, only talking about the final artifact may not be enough. Thus, the process of its making can be incorporated into the final artifact. This is discussed further in the *social clarity of transformation* section.

The symbolic value that P4 assigns to this artifact is probably less than the other participants since the memory is not that personal when compared to the others (see Table 6 Participants' audio recording preferences). This lack of personal connection might be the cause for the search for a functional value. "Curious artifacts," as he defines the resulting artifact, can have connections with P3's artifact that can be talked about when asked. Curiosity evokes questions and questions lead to conversations about the artifact and its meaning.

The usage of the functionless cylinder as the base form appears to be beneficial for the separation of participants' suggestions about the functional use cases. P4 does not see any functional value in the manufactured artifact and the transformation process other than creating "curious artifacts." When his selection of the audio is considered -a music piece (L'Offrande Musicales) that they use the piece's notes on the awards they give in the music foundation- it appears to be the least personal one among all the participants. Therefore, the symbolic value P4 assigns to his artifact might be less compared to other participants because other participants' selections of audio can be regarded as more personal recordings such as life motto (P1), daughter's first words (P2), wedding song (P3), and theme song of a computer game from childhood memories (P5). Then, it might be argued that *as the memory related to the sound becomes more personal and meaningful, the motivation for finding use cases or potential functionalities for the transformed artifact increases:*

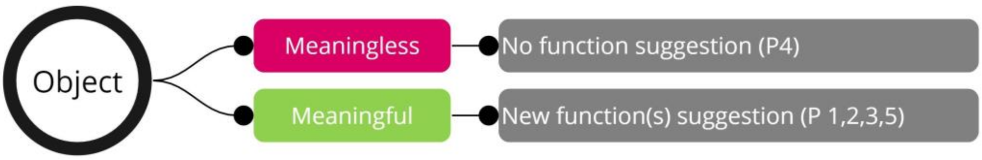


Figure 4.12 Artifact, meaning and function suggestion motivation.

In order to probe different use cases and receive feedback about their functional use cases, artifacts of different scales can be used as template artifacts. For example, during the personalization stage, *different template artifacts* can be presented side by side so that the participant can see the relative sizes of the artifacts to be personalized.

4.1.4.1.2 Sound distribution on surface

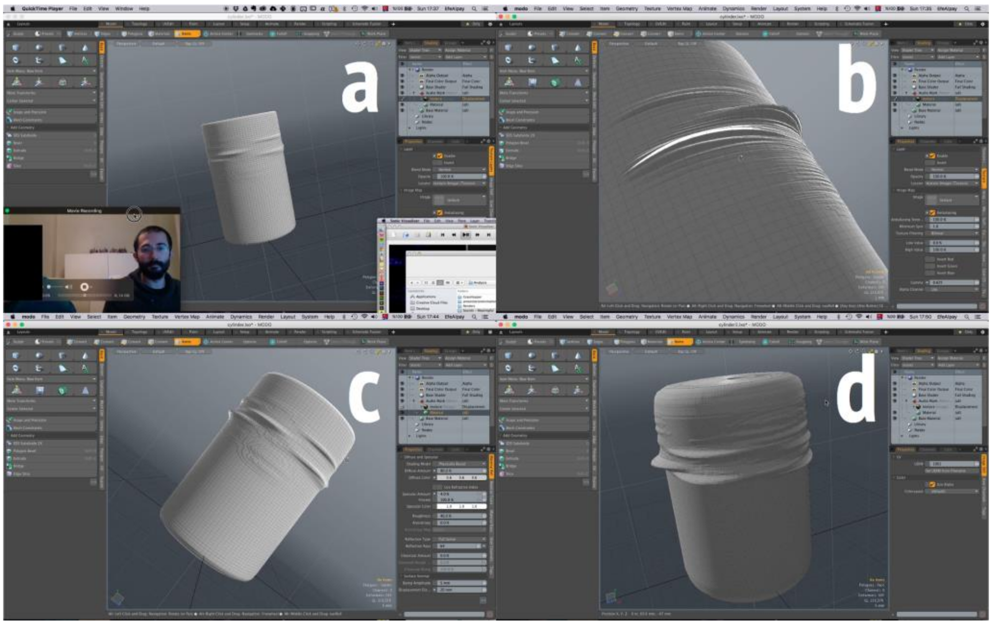


Figure 4.13 P1 - a) Initial representation of participant sound data on the surface of the artifact. b) artifact surface without smoothing c) more bumped version of “a”. d) P1’s final decision.

Participants' preferences and comments about the placement of the spectrogram image (and, in connection: sound data) on the artifact surface are presented here. During the transformation process, when P1 sees the first conversion of sound data to the artifact surface, she accepts that representation as “original” (Figure 4.13). She thinks the bottom part of the artifact is left empty. She becomes hesitant when the researcher suggests changing the composition and stretching the sound data on the artifact. Modifications like changing the composition (e.g., stretching or compressing) of the sound data on the artifact surface might cause “value loss” for P1. Her recording is a short voice recording of her saying, “Conscience and honesty should be together.” Thus, a rather simple one when compared to the songs other participants bring. P1 states that if the sound was a more “crowded” and longer one, the stretching might not affect the appearance too much and cause less or no “value loss.” Her audio’s lesser complexity causes a rather simple surface texture on the artifact.

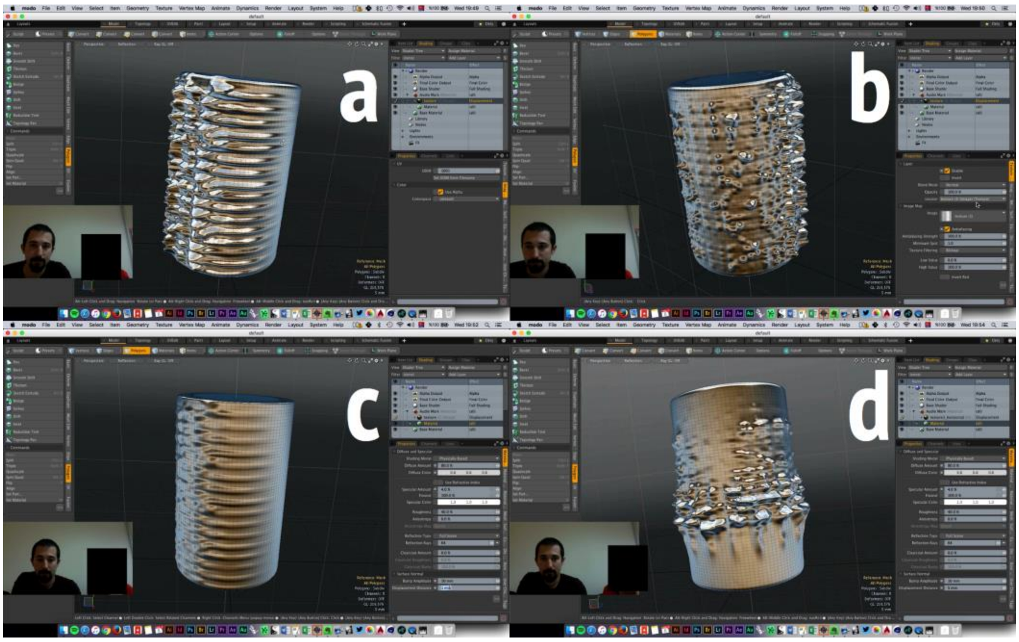


Figure 4.14 P3 - a) Initial representation of participant sound data on the artifact's surface. b) artifact surface without smoothing c) smoothed version of “b”. d) P1’s final decision with vertical time orientation

P3 likes the first appearance of the artifact after the sound data is applied to the surface (Figure 4.14, a and b). Upon examining the surface, like P1’s comments, she thinks the rear part of the artifact is left rather empty. She prefers higher bump amounts, as she states that she does not like the appearance in Figure 4.14, c. Then, the orientation of the sound is changed from vertical to horizontal, in which the perimeter of the cylinder represents time, and the height axis represents different frequencies (Figure 4.14, d). This way, P3 becomes more satisfied with the form after the parts that are left empty are also filled with sound data.

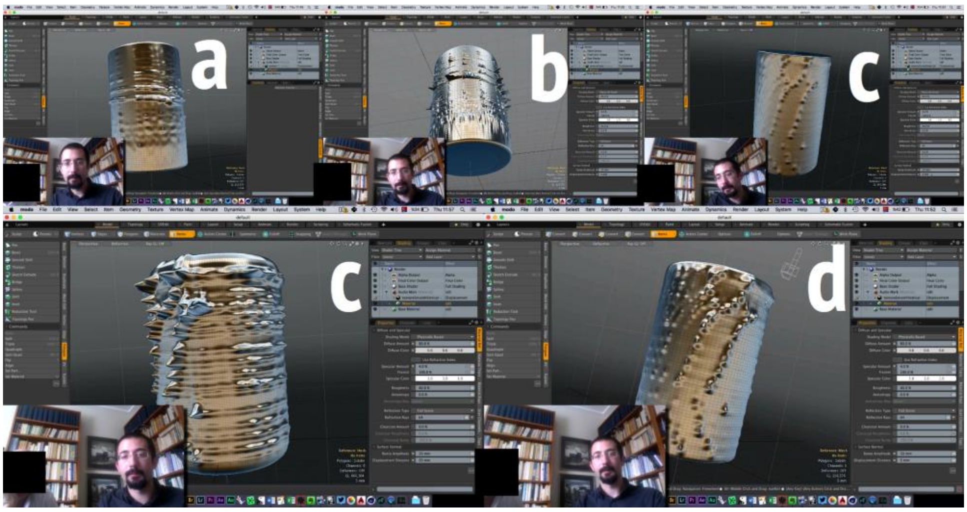


Figure 4.15 Modifications made on P4’s artifact surface

The transformation of sound data into bumps on the artifact surface is interesting for P4 (Figure 4.15, a). He states that it becomes a continuous thing and wonders about the beginning and end. When asked whether he prefers the sound to be mapped from bottom to top, he stated that he did not prefer that at the beginning of the interview. When the sound is mapped from bottom to top, he does not make any comments other than "hmm hmm". When he sees the spikes on the artifact, he mentions that it reminds him of recording sound onto CDs. When the orientation of the sound and progression of the notes is explained to him (Figure 4.15, a, b and c), he prefers to map the time axis to Z (Figure 4.15, c, and d) axis since the other option makes it hard to find the beginning and end of the recording. Because of this, instead of a cylindrical form, he offers to use a rectangular form to make it easier to find the beginning and end of the audio recording. In his words, wrapping time around the cylinder creates a looping sound. He names the looping sound as "infinity of time."

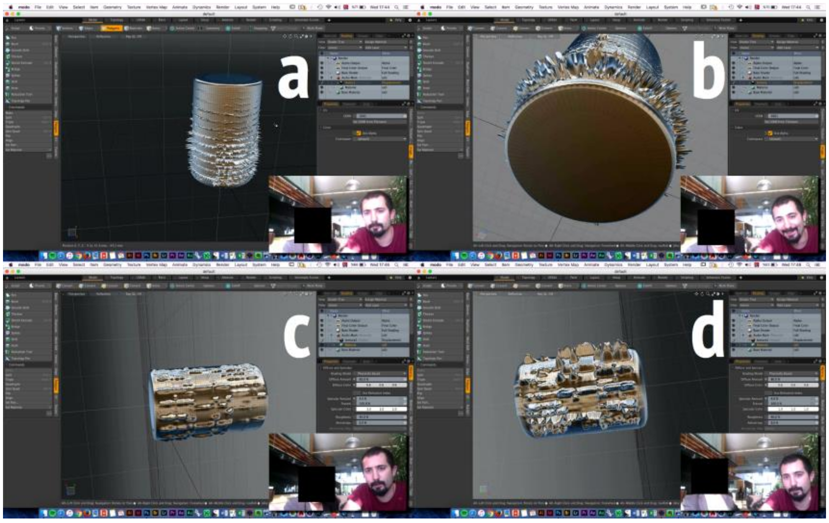


Figure 4.16 Modifications made on P5's artifact surface

P5, In the beginning, prefers the time axis to be around the cylinder since he states we are used to the horizontal axis of time and things that can be used for longer audio recordings. He thinks the box lacks continuity, so the best forms would be cylindrical or circular. However, after the other orientation option is presented to him, he decides to use the vertical axis as time and the cylinder perimeter as frequency distribution (Figure 4.16, c).

Suggestions for the improvement of the transformation process

The initial generation of the image file is critical since it affects how the sound is interpreted visually in the first place. This interpretation sticks to the participant and accepts it as an original of the sound data (P1). P1 and P3 find sound composition across the artifact surface "empty." Therefore, in order to be able to present a more balanced audio representation on the artifact surface, the sound file can be automatically adjusted to fit the entire surface before showing the result to the participant.

Regardless of the orientation of the sound data on the artifact surface, the deformations on the artifact surface caused by the audio data should be recognizable by the participants. Also, most participants prefer a homogeneous distribution of the sound data on the artifact surface. Thus, *either the audio length or the orientation of* *it on the surface should be optimized so that it creates a clearly visible deformation spread throughout the artifact surface. No matter the orientation and complexity of the data, the audio features should be recognizable. Identifying start and end points might increase the artifact's readability*.

P4's comments about the looping sound and his concerns about understanding the beginning and end of the sound recording might provide suggestions about a way to present different orientation types of sound on the artifact. The composition selection connects with the sound's context and depends on how the participant wants to interpret its physical form. For example, when time is mapped along the artifact's perimeter, it might connect with the infinity concept, whereas time mapped to the z-axis might mean a discrete beginning and an end.

4.1.4.1.3 Surface enhancement

This property covers participant comments about participants' preferences about the surface smoothness and bump amount of the resulting form. All the participants prefer a certain amount of bump that makes audio deformation on the artifact visible. Like the *Sound distribution on the surface* property, no matter how loud or silent the audio recording is, the participants need to easily see the bumps on the surface. However, *the bump and smoothness amount appear to be determined by participants' interpretation of the audio recording*. Thus, this property connects with *translating sound's perceived properties into form* in section 5.2.1.6.

P1 thinks that the artifact's surface should not be too sharp, which can cause harm to people who hold it or when they fall upon it. P1 wants to increase the bumps and make it sharper since P1 thinks Figure 4.13a is very close to a soap.

Like all other participants, P2 prefers different bump heights from the initial application of the sound data to the artifact. After translating sound data onto the surface, the initial form seems like a space shuttle for P2 (Figure 4.17a). When the bumps are too high, like in Figure 4.17 b and c, she mentions that it is like the sound of a man instead of her daughter’s. It becomes frightening for her when she thinks about the artifact and connects with her daughter. P2 prefers the surface to be smoother, like Figure 4.17d, and mentions that it is “pure,” like her daughter’s voice. When the surface is smoothed, and the bumps become barely visible, she states that she does not prefer that because then it becomes as if the sound is not there, and the artifact becomes “too simple.”

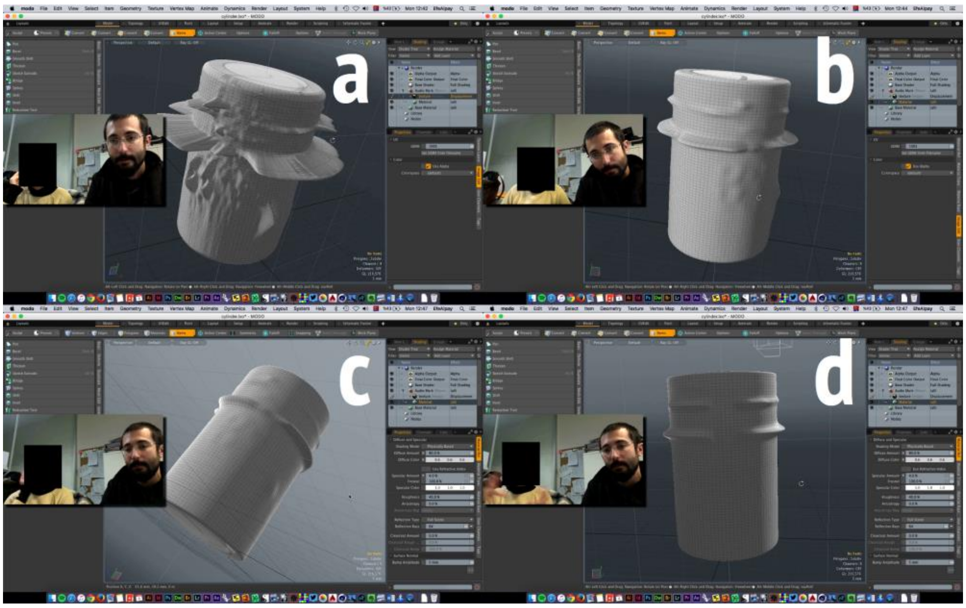


Figure 4.17 Smoothness and bump modifications made on P2’s artifact surface

For P3, when the initial spectrogram image is used, the form is not much noticeable. She thinks if we were to put the same waveform, the result would be very dull. P3 likes the spiked version that emerges in the beginning. She prefers more bumped surfaces that become more evident. She wonders how it would be if we were to listen to this artifact. Also, she wants to be able to create higher bumps on the surface of the artifact.

P4 shows an artifact he has, a deep, relieved French mint stamp made of metal, and mentions that the depth of the figures increases the beauty and asks for a higher relief amount in the 3D form. P4, among various bump amounts, prefers the notes to be visible on the artifact surface and is satisfied with the option in Figure 4.15, d.

P5 immediately likes the result after the audio data is applied to the surface (Figure 4.16, a, and b). However, after it is mentioned that such spikey forms are hard to be manufactured and might not come out as expected, he decides that a smoother surface can be used. Although it seems that he accepts the smoother form instead of the spikey one after the explanation, later in the interview, he states that a smoother form would be more suitable for this song. He mentions that the sound is never smooth and wants to increase the bump amount. P5 states that this song has emotions and explosions, so it should not be very smooth. After several adjustments to the bump amount, he is satisfied with the form in Figure 4.16, d.

Rougher and spikey forms are favored by participants 1, 3, and 5. However, they are warned against the manufacturing constraints and the chance of failure in the printing process when printing spiky forms. Then the participants prefer higher bumps instead of a spikey form.

Suggestions for improving the transformation process

There is an intricate balance between analogies and surface forms. For example, just a little increase in the surface bumps can make the artifact worrying for P2 since she starts associating the artifact with a man's voice. Also, when the artifact surface becomes too smooth, it might become too simple for the participant (P2). Thus, *a method of normalizing the amount of displacement on the artifact surface is needed to prevent such dissatisfactory initial results.*

The participants do not have any control over the sound's propagation along the artifact and the bump amount. They do not know the maximum amount of distortion that can be attained on the artifact. The lack of this knowledge prevents any experimentation and data gathering from those experiments that would be possible if the participants could modify the form by themselves. Thus, participants should be empowered and encouraged to play with the artifact by themselves. The height of bumps on the artifact surface relates to the presence of the memory/sound. Thus, lower bumps are not preferred. P3 prefers to make the deformations more apparent and visible. However, after the completion of her artifact, she sees another participant's artifact (P5), which had higher bumps on the surface, and likes that a lot. This might point to a miscommunicated preference between the researcher and P3. Throughout the process, the researcher probably could not communicate the possibility of further distorting the surface. Thus, *the participant should be able to experiment by herself to see if it is possible or not. Participants should be able to experiment with surface properties to see how they can be matched to their taste.* Participants cannot directly modify the artifact in primary studies, so some of their thoughts might remain unexplored.

4.1.4.1.4 Stylistic attributes

This property covers participant comments related to participants' preferences that relate to the visual and kinesthetic properties of the artifact, such as form, color, material, and style (when "style" is specifically used). When the style is considered, participants comment on the material and color of the resulting artifact. Generally, plastic is a poor choice according to some usage contexts and functional uses. P2 thinks this is too plain to use it a decorative artifact. For her, it could have been livelier and more attractive to people. She prefers glass for the material.

Similarly, P3 thinks that glass material would add a new dimension to the artifact. In terms of color, P3 prefers vivid colors like magenta, orange, and red. She thinks that metal material would be very stylish. For P3, glass can make an exceptional personal gift.

P4 prefers a heavier artifact. Plastic material looks cheap to him. For him, the artifact would be more stylish if made from metallic materials. Metal, as a material, is mentioned by participants 3, 4, and 5, defined as "stylish" (P3, P4) and a "stone fallen from the sky" (P5).

The artifact's shading is changed to a different method (Figure 4.18) from a reflective surface to a slightly colorfully shaded mode during the adjustments. Upon seeing that, P5 mentions that he wants to paint the resulting artifact.

Suggestions for the improvement of the transformation process

Transforming sound into a physical artifact can relate to permanence (P1, P2, P5). However, making the final artifact from plastic can contradict the value given to that concept since plastic is mainly viewed as a cheap material. Therefore, other material types can be presented to the participants, enhancing the meaning and increasing the value given to the artifact through its material selection.

Some materials might be considered impossible for some participants since they might be prejudiced about the manufacturability of some materials. For example, P3 is surprised to know that the artifacts can also be made from clay. Thus, *presenting different colored and materialled renders of the artifact and asking participants about them can enable more detailed feedback about different material and color options.*

The weight of the artifacts appears to connect with its stylishness for P4. When the metal preference of most participants is also considered, increasing the artifact's weight will increase the final artifact's perceived quality.

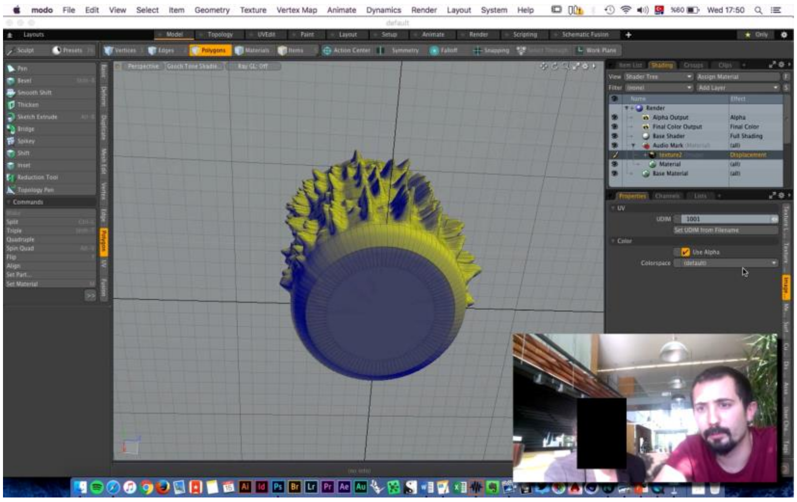


Figure 4.18 Change in visual appearance of P5’s 3D model when shading mode is changed from reflective to color tone shading.

A change in the shading method during the study immediately brought painting the artifact to P5’s mind (Figure 4.18). Thus, a change in the display method might enable new ways of interpreting the artifact, material, color, and other attributes. The option to change the artifact material in the viewport could be introduced to simulate what the artifact would look like if it were made from different materials.

4.1.4.1.5 Using diverse sound sources

This property covers participant comments related to participants who want to personalize the form by trying other sound sources quickly and seeing what comes out of it. During the study, P1 mentions many things she would do if this transformation process were widespread. She gives many examples of what she would create, from personalized gifts to artifacts created from family-related memories, making artifacts from the performances of actors throughout their plays to recording her voice saying “Bon Appetit” and transforming it into salt and pepper shakers. Her examples provide a variety of use cases, from actors' performances to personal family memories. P3 wants to try this process again for many other sounds, such as her grandmother’s audio and video recordings. She mentions that she would take the essential parts from that video and transform them into artifacts.

Suggestions for improving the transformation process

The current transformation process is mainly based on the researcher taking the necessary actions that user feedback requires. As mentioned 4.1.3.1 Flow of Process section, this type of workflow causes interruptions and prevents the participants from trying things that come into their minds. For this study, the participants must bring a single audio recording. Thus, although it is hard to predict their reactions if they were to try transforming many other recordings into artifacts, an interactive system would provide a faster and more engaging way of trying other recordings or data from other sound sources. *Such a system should allow easy swapping of different recordings, enabling the participants to see the results of their actions in real-time.*

4.1.5 Social Clarity of Transformation

This category covers participants' comments related to their ideas about how the resulting artifact would be interpreted in a social context. Responses are evaluated in "Suggestions for the improvement of the transformation process" titles at the end of each property. The sub-categories and related properties are outlined in the following table:

Table 4.8 Follow-up hierarchy table showing the mentioned category in the hierarchy.

s	Subcategory	Properties
Social clarity of transformation	Connecting people	Sharing a common memory
	Comprehending sound-artifact connection	Interpreting the connection by an audience

Connecting people subcategory focuses on the responses related to artifacts creating a connection between people that share a common memory. *Comprehending the sound-artifact connection* subcategory refers to constructing a connection between the sound and the resulting artifact by the participants.

The following sections present the sub-categories for the *Social clarity of transformation* category.

4.1.5.1 Connecting People

This subcategory covers participant comments concerning how the artifact connects people with the same memory. The participants' experience is then evaluated by their contribution to the *social clarity of transformation* category.

4.1.5.1.1 Sharing a Common Memory

This property covers participants' comments about the artifact becoming a symbolizer for something shared between many people. When P5 first hears the process from the researcher, he thinks about gifts given to the lover. He states it is the most external and intense connection between two people. This artifact, according to P5, is the state of sound gaining a form and like a reflection of it. He has never given a present to his lover, and he thinks of himself as unable to buy a present for her since he has never done such a thing. However, he thinks this kind of present would be precious if he were to buy one.

P5 thinks that he needs to make an explanation after giving the artifact to somebody. After that explanation, it can remain a secret between two people. If the person wants an exclusive feeling, according to him, it turns into that. P5 thinks that the real meaning of it arises when it is shared between two or more people. For him, it is still meaningful for personal use, but if that would represent something meaningful to a group, that would also symbolize belonging and connectedness. He likens it to a team logo or a religious book.

P2 states that she would also want her daughter to keep this artifact. When asked about how she would tell the story of the artifact to her daughter, she responded:

> "I am already planning to show the video to her and tell her that the sound is obtained from this video and it consists of these words... because it will mean more if I do this… Then I think she'll keep it more carefully, and it will be a memory for her too."

The plans of P2 on passing the artifact to her daughter point to a use case of creating common memories for different generations to share with each other. Also, this use case connects with the permanence of the transformation theme since it establishes a pathway for memory to reach the future as a tangible artifact.

Suggestions for improving the transformation process

The resulting form becomes understandable to the extent that it can be explained to someone who has not seen the process. It can be used to give an exclusive feeling to a group of people with the same memory. P5 feels the necessity to explain the artifact and process to a person who is not involved in the transformation phase. Thus, for the artifact to connect people through sharing a common memory, the transformation process should be clear to someone who has not seen the process. There is a need to explain the process to a person not involved in it. As previously suggested by P4, a time-lapse video of the making of the artifact can be integrated into the final artifact. However, the outsider to the process would probably need to know about not only the manufacturing phase but also about

1. What the audio recording is
2. How it translates onto the artifact surface
3. How the artifact becomes physical (optional)

Therefore, integrating these stages as a brief presentation of the final artifact would let *the artifact become self-explanatory and better convey the artifact's meaning to an outsider*. Currently, social clarity of the transformation appears to be established only with the participant's help explaining the process to an outsider. In this explanation attempt, the participant is limited to a final artifact but no visuals or videos from the transformation process. If they were to have some visuals from the various stages of the study, that would probably facilitate the communication of the process to an outsider. Therefore*, integrating a self-explanation method into the transformation phase would considerably enhance the communication of the process to an outsider, thus increasing the social clarity of transformation.*

4.1.5.2 Comprehending Sound-Artifact Connection

This subcategory covers participant comments providing insights into the understandability of a connection existence between the artifact and sound. The participants' experience is then evaluated by their contribution to the *social clarity of transformation* category.

4.1.5.2.1 Interpreting the Connection by Audience

This property covers participants' comments, concerns, and solutions about the artifact's understandability by strangers. All participants are concerned about the artifact's communication with someone who has not seen the process. P1 thinks that the readability of the final artifact is crucial for keeping the data permanently, allowing her to send a message to a person she has not seen for years. If an outsider can understand the artifact without participant explanation, it integrates permanence into the artifact and increases its value (P1). Similarly, P2 thinks that if she could show the step-by-step transformation process to her daughter, her daughter would value the artifact more. She defines the artifact as an emotional artifact. P5 thinks that showing the artifact to someone and talking about the process is not enough for that person to understand the connection and meaning of the artifact and the sound. The connection is in the participant’s mind, and the process makes this connection between sound and the artifact (P5). P5 thinks the participant detaches the artifact-sound connection by modifying the form according to his/her aesthetic preferences.

For this reason, P5 thinks a soft song does not need to be translated into a soft artifact surface. Then, it becomes entirely incomprehensible for an outsider. However, that connection happens and lives in the mind of the participant.

If the artifact becomes incomprehensible, it will be no different from geological fossils (P3). Still, it will have meaning for the participant (P4) but no social meaning. Then, after seeing the artifact, any outsider would ask, “so what?” according to P4. P2 suggests the artifact might make more people feel something when they hold it in their hands. Something in the form of a toy that can attract children’s attention.

For all the participants, understanding the artifact sound connection was important. Most of the time, it is so vital that it makes the artifact more valuable (P1, P2, P4) for the participant since it makes the artifact understandable without the participant's presence. Understandability of the artifact by the audience makes the artifact and connected memory more permanent, according to P1. The interpretation of permanence might be because even if the participant goes away, the artifact continues its existence and is still understandable to people who do not have previous knowledge about it. *Although value increases with social clarity and the artifact’s understandability by an audience, the artifact’s meaning for the person seems to remain constant since none of the participants mention any change in the artifact's* *meaning for themselves*. P2, P3, and P5 mention that the artifact is still meaningful for them, although it may not be understandable to strangers. Participants already know about the process and how the sound becomes the artifact so that it does not change the artifact's meaning. The step-by-step progression of the transformation process seems to help this meaning construction, as discussed in the *clarity of transformation* category.

Towards the end of the transformation process, P4 is asked whether he would want to participate in the manufacturing phase of the artifact. He mentions that he does not have much idle time to travel to Middle East Technical University for the manufacturing phase, and he offers to see a short video from the manufacturing phase.

Suggestions for improving the transformation process

P2's attempt to make the artifact attract attention might imply that the artifact's meaninglessness from other people's perspectives raises some concerns in the participant. P2 also suggests more aesthetically pleasing materials than plastic. When these are considered, the transformation process' social clarity has a determining role in the value given to the artifact by the participant.

When the comments on social clarity are considered, any method that would increase the transformation's social clarity will increase the value of the final artifact for the participants. In addition, it will also increase the memory's permanence so that the artifact's meaning and value can be transferred in time.

The artifact's story -being able to talk about it when asked- can be another source of meaning and value. However, talking about it may not be enough for strangers. Thus, some things might be shown. For this, P4's suggestion can show ways of enhancing the meaning and value of the process. He suggests seeing the manufacturing phase from a video. Thus, a video presentation might be extended to how the artifact form takes shape with sound and becomes a physical artifact.

In the current version of the transformation process, the users are handed the final artifact but not any other info, marker, or data to reach any additional meaning about the artifact. Nothing from the process is handed to them or the cropped and adjusted sound data. The transformation process only lives in their memory and cannot be shared with an outsider other than telling about it. Therefore, when comments about the social clarity of transformation are considered, *a transformation process narrative can be incorporated into the final artifact so that it can be reached through it.* For this, a short video that includes the following elements is proposed:

Audio section selection phase;
Playing selected sound;
Real-time translation of sound data onto the artifact surface;
Final artifact's 3D rendering with a scanline synchronized with audio playback that shows which part of the artifact corresponds to the selected audio;
3D printing of the artifact.

This video can then be embedded onto the artifact surface with a QR code that can enable the participants to reach the narrative of the transformation process via scanning the QR code with a smartphone. This way, the participants or somebody that finds the artifact will be able to reach the moment of the transformation process together with the original memory. Such a method can provide a narrative that enhances the social clarity of the transformation by providing access to the making of the artifact.

4.1.6 Permanence of Transformation

This category covers comments about how the transformation process makes the memory-connected sound more permanent.

Table 4.9 Follow-up hierarchy table showing the mentioned category in the hierarchy.

Category	Subcategory	Properties
Permanence of transformation	Becoming a permanent memory	Tangibility of memory through artifact
		Translation among senses – from hearing to seeing
		Multisensoriality

4.1.6.1 Becoming a Permanent Memory

This sub-category presents participant responses about the transformation of sound into a physical artifact and its implications from the perspective of the permanence concept.

4.1.6.1.1 The Tangibility of Memory Through Artifact

Participants' comments on sound transforming into a solid artifact and its conceptual connection with permanence are presented here. Most participants state that making the sound into a physical artifact makes it more permanent (P1, P3, P5), and the physical existence of the sound as an artifact makes it more valuable (P1, P5). P1 states that people say "I love you" to each other, but it goes away. By converting that moment into an artifact, their message can gain permanence. P1 states that although the sound is not heard, the artifact is her voice, her frequencies. It is like a thing that P1 wants to be buried with and states that that artifact is more than just a CD recording. She can follow the things she said on the artifact surface. P1 likens the form to the artifacts of ancient civilizations. Like relics and enduring columns of these civilizations.

Like P1's permanence argument, P5 argues that transforming sound into an artifact brings the happiness of making things concrete that generally we cannot. Mainly he does not think there is a difference from the meaning perspective. However, he thinks that it is always good for something to be a tangible thing rather than an abstract, invisible thing in the cloud. Because of this, it becomes more valuable. Even the digital file is more valuable than the physical one because it is a "mimesis" of a digital artifact. When transformed into a physical artifact, its value increases since it becomes tangible. P1 holds something that will be in the future. P1 thinks that this will be used in many types of data records in the future. People will send each other things that say "I love you," and everyone will be permanent. When only said, it passes away. However, with this method, they will hold it in their hands. P1 thinks this is especially important for a specific age range. The importance of the artifact will increase according to the period of their love.

P1 is worried about what would happen if the recording is lost. Then nobody would know what is written there. P1 wants the readability of this artifact to be established. P1 thinks that the data stored in hard disk drives can be gone in a disaster. However, the vanishing of such artifacts is less probable than data stored in those disks getting lost. P1 offers to make monuments like Orhun. Future generations will try to find what they are—a precious gift. P1 thinks of transforming the constitution into an artifact like this. She emphasizes the importance of an artifact and gives an example of burial artifacts that people get buried with. Simultaneously seeing and feeling the sound is important for P1. It creates something so personal for her that it becomes like an extension. Artifact is perceived as a lasting artifact by P1, and she likens it to artifacts of ancient civilizations. She defines them as "relics." Thus, probably connoting their permanence in reaching the following generations. She thinks the sound becoming an artifact is a warranty of the data's permanence. P1 might think that since her voice is a solid artifact now, it is much more durable to time and other factors that can cause her voice recording to disappear. Therefore, the sound becoming an artifact symbolizes becoming permanent, durable, and solid. The same also appears to be the case for participants 3 and 5 since they connect the artifact's permanence with its value.

P3 mentions it is said that the sound is not lost in space but, in a way, trapped somewhere. With this method, we are making it much more defined. Beyond hearing, we are making it perceivable with our eyes. She states that this transformation adds a different dimension to sound. For P3, transforming the sound into a form and the reverse is very interesting and can enable different things in the future. She defines sound transformation into a 3D artifact as transforming something likely to disappear into something permanent. The printed image does not mean anything for P3, and she likens it to a chromatogram. However, she states that when it is transformed into an artifact, it becomes a memory and a symbolic thing that will remind of that memory.

P4 thinks "preserving the sound in this way" does not add something to him. He gives examples from the speeches of Atatürk that are cleaned, fixed, and published. That provides a return to the past, which is not the case for music recordings since musical notes allow them to be repeated continuously. However, he states that Atatürk's speech is for once and is over. Looking at the artifact does not make him hear the sound itself.

P5 wants to store the artifact and likens it to a collectible item. He thinks that this transformation is very suitable for gifts. It is proof of the existence of something’s recording. If two lovers want proof of themselves saying “I love you,” then such a pendant can be made. He mentions things that people collect, such as games, magazines, etc., and he has hundreds of them too. He keeps some of them behind closed closets, but he likes knowing they are there. He keeps the scratched CD of a game he played 20 years ago. He will never be able to use that cd and play that again, but he likes knowing that 20-year-old box is there.

P1’s example of Orhun Monuments signifies that P1 connects these artifacts with permanence. Also, at the same time, it is somehow hard to understand what the artifact is about for her.

For P2, understanding the process is still essential when explaining the artifact to another person. When the person is the one that will keep the artifact, the process becomes the meaning and value-strengthening aspect of the artifact. P2 wants to be able to reach the video through the artifact.

Manufacturing the artifact in a physical form relates to the permanence of the sound. P3 thinks that we are recording the sound into the artifact. Also, in the following parts of the interviews, P3 mentions that she is already assuming that we will be able to return to the sound somehow. Thus, the artifact should contain the sound somehow or provide a way of reaching sound to become permanent.

P4 sees this method as a way of storing sound, which might lead him to compare this method with traditional methods continuously. The process should be doing something other than allowing a repeated playing of a recording that is already reachable by other methods and devices such as CDs. The type of recording is also important. A speech that has happened once and gone (temporality) can make you return to that moment, but music pieces are not like that. The meaning and value of the transformed sound can only exist if the recording intent captures a one-time event rather than a musical piece that is recorded to be repeatedly played. It can be argued that *there is a subconscious correlation between temporality with human speech and permanence with music in P4's mind*. Therefore, the concept of permanence can be explored more by using historic recordings (such as Azzaro's 3D printed sculptıure of Obama's speech on the next industrial revolution) in further studies.

Suggestions for the improvement of the transformation process

The main suggestion for improvement concerning this category is to integrate a way of reaching the sound recording through the physical artifact.

4.1.6.1.2 Translation Between Senses

The participants' comments on how something that can only be heard is transformed into something visible and tangible, adding to its value and permanence, are presented in this section. When P1 is asked if anything changed after the sound's transformation into an artifact, she states that the sound transforms into a *tangible* artifact. P3 mentions it is said that the sound is not lost in space but, in a way, "trapped somewhere." With this method, we are making it much more defined.

Beyond hearing, making it perceivable with our eyes. Perception, as P3 states, is a different dimension. When a person perceives the artifact, it makes him/her remember the sound since s/he knows they are related, as P3 states.

Suggestions for the improvement of the transformation process

P3 compares the existence of sound with the existence of the artifact and states that when it becomes an artifact, even though we do not look at the artifact or see it, we know it is there. However, it is not the case for the existence of sound if not repeatedly played. It is there only when it is played. However, things related to seeing are not like that. We can know an artifact is there. So, in a way, it becomes trapped in time and space. Then it becomes permanent for the participant. Therefore, the transformation process makes the sound permanent only by creating a physical dimension for that sound to live. Then, knowing the presence of the artifact becomes the reminder of the sound and then the connected memory.

4.1.6.1.3 Multisensoriality

Participants' comments about how the experience becomes multisensory and makes the experience more memorable are presented here.

For P3, the artifact becomes a visual connector between sound and form. This connection unifies three senses: *a scene you remember, an artifact you can touch, and a sound you can hear*. This multisensorial experience makes the memory more memorable. When the benefits of data physicalizations explored in section 2.7 are considered, transforming sound into a physical representation of it enables it to be sensed with multiple senses, thus creating new possibilities for self-reflection.

Suggestions for the improvement of the transformation process

The transformation process addresses multiple senses, touching, seeing, and hearing. Artifact becomes an emotional trigger recalling the memories and emotions that the sound reminds. The multisensorial experience of the final artifact increases the persistence of the memory (van Gorp & Adams, 2012, p. 11). Combining three senses in an artifact makes it a more robust experience. This combination of senses can also enhance the permanence of the memory itself by enriching the experience of hearing with seeing and touching. Artifact becomes a trigger for the emotions the sound-related memory evokes.

4.2 Primary Study Overview

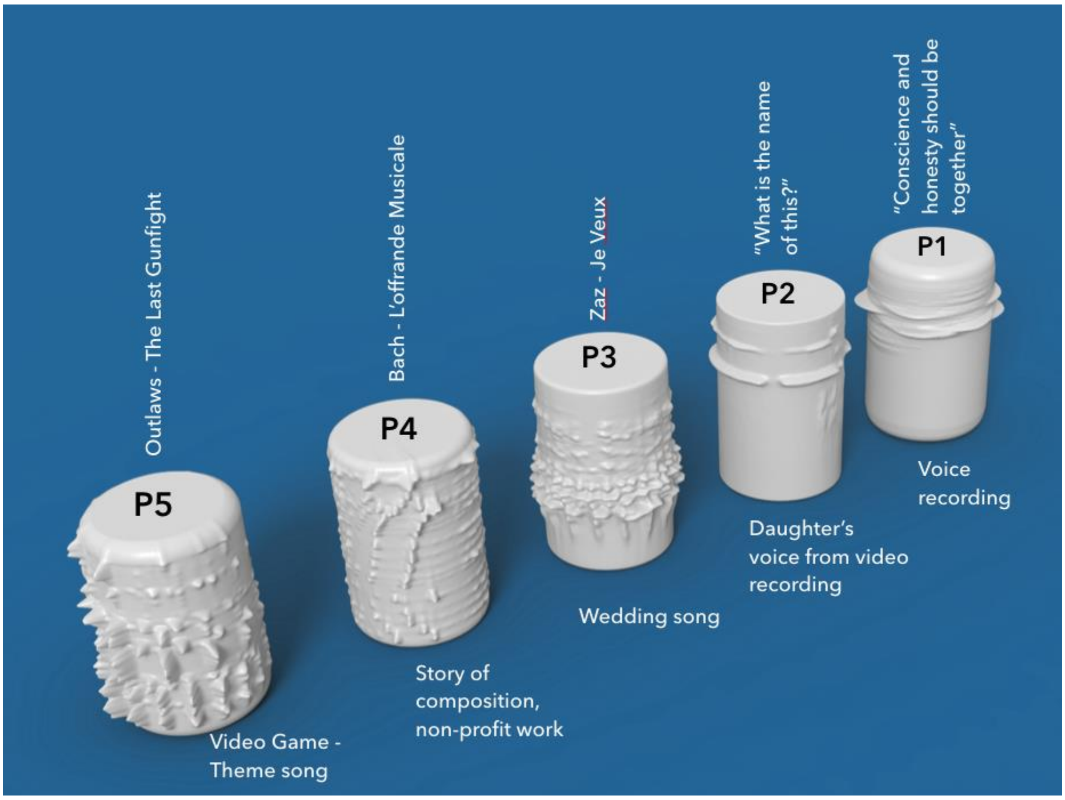


Figure 4.19 Participants' audio files and the resulting artifacts.

The process I tested resulted in the creation of valuable and meaningful artifacts that participants want to keep and even want to pass on to their loved ones. However, some developments are needed to increase the personal meaning generation potential of the transformation process. Although the five participant studies are very limited in terms of the diversity of the type of audio recordings brought, they provided in-depth insights into the perception of the process and the resulting experience.

Therefore, the insights obtained from this primary study and its analysis are used to further develop the transformation method and test in a workshop environment in the following stages of the study.

Although the first two participants were very excited about the process and the results, both wished for ways of knowing what is on the artifact's surface. In other words, being able to reach the audio recording from the artifact so what it represents becomes understandable. This might be needed for two reasons: one, for the permanence of the audio recording so that others can know it, and second for transferring the meaning and value to other people.

In phase five, although I was focusing on the meaning and value from the participant's perspective, P2 mentioned that she plans to give the artifact to her daughter when she grows up and ask her to keep the artifact. This was something unexpected; in a way, the artifact immediately gains an heirloom-like status.

Audio recording selection process

In the first primary study with P1, I requested a ten-second long audio recording from the user. However, P1 found it long. Thus, I decided to change the protocol to request *a maximum of* 10 seconds of recording. P1 might have found the duration of 10 seconds too long because she wanted to record her own voice so she might have felt forced to elongate the duration to 10 seconds. *Thus, the duration should be more flexible but not too long since the file's length will decrease the visualized form's legibility.*

I had some difficulties explaining audio spectrogram images and their relationships in both studies. In P1, I used the term “overlap” while asking about the relationship between the images with sound, and it was not understood well. Then I changed the term “overlap” into “relationship” by modifying the interview protocol.

Also, since I did not present the audio spectrogram analysis of different sounds and their corresponding images previously, I also needed to spend some time explaining which type of sounds correspond to what. My explanations were received well. However, that caused a little disorder in the flow of phase two.

In the first study, I asked whether the user wanted to modify the form without making the surface deformation observable enough. Initially, the artifact was not so relieved; thus, the bumps on the surface were not that recognizable. In the study, I tried to talk about that form too much without realizing that the artifact should have more relief on the surface to be more observable. So, I also changed the order of the questions and modified the form first and then asked whether the user wants to change the surface smoothness and bumps. When the user is satisfied with the final form, I pass on to the other questions. Following the first two studies, I made minor modifications to the interview protocol and added new questions. After those changes, I conducted three more studies that resulted in five different artifacts being manufactured.

4.2.1 Transformation Stages Throughout the Study

The next three sections provide an understanding of the user responses to three different stages of the transformation process: sound to spectrogram image, spectrogram image to 3D virtual form, and 3D virtual form to the physical artifact.

Sound to image

After I opened the audio recording in Sonic Visualizer and played the audio in sync with the spectrogram image (Figure 4.20), P1 immediately recognized the pattern between her words and the images. However, she mentioned at first that she had not made these additional lines.

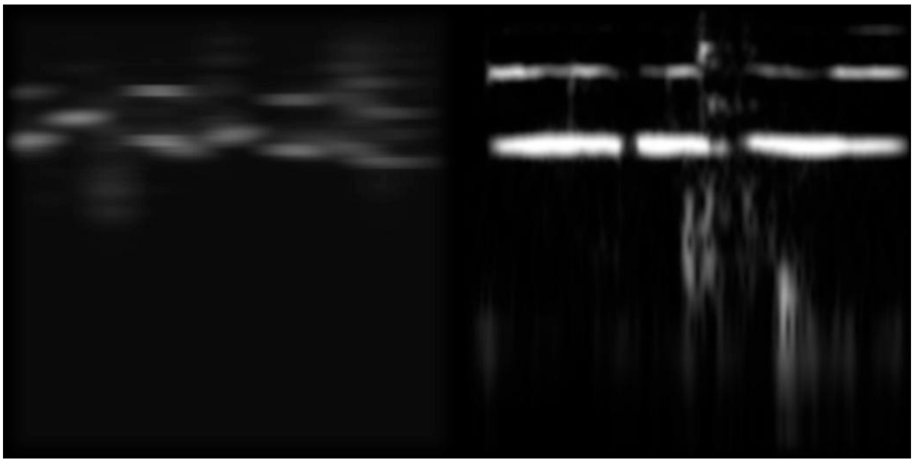


Figure 4.20 Audio spectrogram images of P1 (left) and P2 (right).

After explanations of the spectrogram analysis, she reads the image word by word and thinks that they relate to each other well. P1 also adds that this image would be a very nice poster. When I used the image to modify the cylinder and show P1 the resulting artifact, the first thing that came to her mind was that "This artifact resembles traces in columns of prehistoric artifacts... looks like the artifacts of destroyed communities that are mentioned in holy books." Later, however, she compares it with a music box playing a rotating cylinder and wishes these artifacts could be read back. P1 later asked whether we can transform sound into other artifacts or forms since she wants to keep it as a thin and long artifact. P1 also suggested that these can transform into accessories.

Most of the participants describe the transformation from sound to image as “different” while trying to understand how that transformation occurs. They find it hard to explain “different” exactly. However, P1’s comments discussed in the following sections point to an explanation of this perception of the transformation method as different might be related to not being widespread and known. Participants continuously try to understand what is happening and try to connect what they see and hear.

Image to Virtual 3D Form

When passing from a 2D image to a 3D cylinder form, the same curiosity continues. Still, the participants remain silent and observe the things that are shown on screen, listening to the explanations that the researcher makes. When the 3D form has taken its shape with the data coming from sound, all the participants can trace the parts coming from the 2D spectrogram image. In this way, they are also able to connect the surface of the artifact to the sound they provided. However, all of them state that if there was no 2D spectrogram image, then connecting the form to the sound would not be possible. However, for participants to understand that connection, some verbal and technical explanations are necessary. For instance, the transformation of the bright spots in the image into bumps on the virtual form, and dark parts in the image into dents on the virtual form. Also, the volume of the sound affects the relative height of these bumps on the surface of the virtual form.

After the transformation of the audio data to a 3D form, the participants start to provide comments and insights. Some analogies about the virtual 3D form are outlined in the table below

Table 4.10 Analogies made by the participants about generated virtual 3D forms.

P1	"ancient monuments", "scrolls", "from the future", "musical instrument"
P2	"space shuttle"
P3	"musical instrument"
P4	"musical instrument", "Rorschach test", "seismograph plates", "CD recording", "polyphone"
P5	"torture tool"

When the types of analogies and comments the participants make are examined, some connections with their backgrounds come forward. P1, an interior architect, connects the virtual form to ancient monuments and scrolls. P4 is a professor of public administration, but he also is a board member of a non-profit music organization and an explorer/writer. Thus, the analogies he makes revolve around music, recordings, seismograph plates, and the Rorschach test (a psychological test in which a subject's perceptions of an inkblot are recorded and analyzed using psychological interpretation).

P2, an accountant, connects the form to a space shuttle in the virtual form phase. P2 mainly focuses on her child, so the things that she relates to continuously correspond with the sound of her child. For example, when the surface displacement is increased too much, she immediately relates the form to a man's voice rather than a small girl's.

P1 also states that the resulting form is like it has come from the future. She mentions that she has seen and lived through all different technologies related to sound and music starting from magnetic roll tapes to mp3, and thinks this is the next step. She also states:

> You are giving this to me now and this kind of thing exists nowhere else. Since this is not a thing that I am used to seeing around, the effect is not like that but rather the effect of a strange thing. If that is what you are asking, it is like a gift from the future.

When the surface texture of the artifact is examined, several factors can be the reason for this comment. First, the organic texture of the surface gives the impression of a handmade artifact. Yet, some carefully shaped curves and some repeating patterns may refer to something that needs high precision and, thus high tech. Those precise surface textures also give the impression of code, like the information written on the artifact. Concerning these, it can easily be related to an artifact coming from the future.

P1 gives other examples like roll tapes and mp3s to tell those are widespread technologies and we are used to them. However, since she is seeing this for the first time, she interprets this as coming from the near future. In order to understand her reaction, we need the progression of the interview:

> R- Why from the future?
> P1- Because it is not widespread now
> R- What would happen if it were widespread?
> P1- I would say: "Where is this machine? I want to record my sounds or do something else. I want to print that. I want to make a testament to my children and print that"

Thus, being from the future is more connected with the widespread usage of the methods. Since she also values the resulting artifacts as gifts, the value coming from authenticity (or not being widespread) can also be further investigated. For that, she is asked what would happen if the technology for transforming sound into artifacts was widespread and she starts to tell the practical things that she would do with those machines.

P3 states that the "sound does not disappear but remain in space", pointing to the permanence of sound as a physical artifact. This comment may refer to a value coming from the manifestation of a valuable memory with a solid and physical artifact. When digital media and memories saved in that medium are considered, the memories saved as digital files can be regarded as ephemeral beings that can be destroyed/deleted in the blink of an eye. Thus, forging those ephemeral beings into tangible matter can also bring new values and meanings and increase the perceived value of those digital data. In addition to that, the durability of the material used in the manufacturing of the resulting form can be further investigated, though this is not in the scope of this research.

"Reading" the resulting form

After the connections are constructed in the initial phase of sound-to-image transformation, all of the participants easily recognize the features on the surface of the virtual 3D form. However, since some participants have a stronger visual memory, they don't want to get back to the 2D spectrogram image, whereas for others returning back to the 2D spectrogram image facilitates their understanding of the 3D form. After the connections are made, the users are easily able to understand the parts of a song (P5), instruments (P4), or even words (P1, P2) in some cases. However, when asked about the importance of being able to “read” things so precisely on the surface of the artifact, the participants mentioned that after a certain point, that is not very important. Only reminding features become sufficient.

When asked about the necessity of one-to-one representation of sound data on the final form, the participants mentioned that it is necessary to some extent. In order for the resulting form to have a meaning, there should be a connection with the sound given. P4 interprets the artifact as a standalone artifact that is completely detached from the sound, whereas P3 assumes the artifact, with the help of a special device or link, may contain the sound or be a way to reach the sound recording. P1, on the other hand, has no pre-assumptions but wants a way to understand what is recorded on the surface of that artifact. Regardless of their preferences and assumptions, all of the participants, except P4, want to be able to get back to the origin of sound using the artifact. P4 states that if he were to get back to the recording, then he would prefer to listen to it from the original CD instead of the 3D printed form. He states that he does not see a real practical value in such kind of transformation. P4 adds that he can show the artifact to his friends, but even in that case, it would be hard to explain the artifact to them.

On the relationship between the artifact and sound, both participants mentioned that without the image, they could not even imagine a way of connecting these two. However, after explaining how the image was formed and understanding the relationship emerging between sound and image, they accepted the relation very easily and thought accordingly. Even when I asked P2 about other ways of realizing this representation and transformation, she -without noticing- explained a process that has an image generation part in it again. I emphasized that she again used the image generation, and she replied *she could not let that stage go away because without it she would not be able to connect them*.

The general feedback from the participants about the final virtual form and connection with the initial sound points to the main necessity of the participants’ understanding of the transformation process. *After the link between the audio file, image, and final form is constructed, the participants focus more on the visual appearance of the artifact itself, and just reminding features are sufficient for them to keep the connection*.

Orientation Preference & Implications for Meaning Generation

Although not possible in the first two user studies, the orientation preference of the participants is asked to P3, P4, and P5. P3 wants the Z direction to represent the frequency range and the perimeter of the cylinder to represent time. She reaches this conclusion after seeing the back of the artifact become "empty" (this aesthetic statement of empty areas is also mentioned by P1 and explained in the following paragraph). Also, she states that since the songs are played again and again, time wrapping around the cylinder and forming a loop is suitable. But she also states that If the recording was someone's voice, she would prefer the other way since she would want the beginning and end of the recording to be recognizable. P4, on the other hand, wants an orientation that allows the recognition of beginning and end, thus prefers to wrap the frequency spectrum around the cylinder perimeter and time to the Z axis. P5 chose the Z direction for time and the perimeter for the frequency range.

In the initial protocol that is used in the first two studies, there are no questions regarding the orientation of the sound data on the artifact. However, P1 mentions by herself that the bottom part is left too empty. Upon that comment, she is asked if she would prefer to change orientation so that the bottom parts also get displaced. However, she does not want it because she thinks that would stretch the artifact's appearance too much. She does not prefer that because *she also thinks stretching this little area to all of the artifact surface might cause losses*. She also mentions that if the surface texture had been more crowded, that could have been done.

Virtual 3D Form to Physical Artifact

The common reaction when I handed the printed artifacts to the participants was amazement mixed with other feelings. This shows a similarity to the facial gestures of participants in Andres et al.'s study (2016, p. 888). In primary studies, when the participants are handed the 3D-printed artifact of their audio recordings, their emotional responses (from facial expressions) are surprise, happiness, and familiarity. The virtual 3D model the participants see in the previous stage acts as an introduction to the 3D model. However, there are happy expressions on all of the participants after they examine the artifact for a few seconds. Although they make additional comments that are presented in the following paragraphs, they act as if they have something they expected in some way.

Figure 4.21 Participants' facial gestures upon receiving the artifact.

All of the participants directly recognize the patterns on the artifact's surface and connect -as they do with the virtual 3D model- the form to the audio file they bring. However, this time, they also use their fingers to track the sounds. All the participants mentioned that if they had not been shown the spectrogram image, they would not be able to relate that to the sound they initially gave, as mentioned in the previous stages. P3 makes an interesting statement when defining the connection between the sound and the resulting form: “The interesting part is because I was shown the audio waves and their *direct* transformation.” *Although she cannot relate the form to the audio file she brings without an intermediary spectrogram image, she mentions that the audio file is “directly” transformed into the form.* Based on this definition of the participant and general feedback from the other participants, it can be argued that *the spectrogram image used in the process creates a conceptual bridge connecting the sound and the form.*

On the other hand, P1 mentions her surprise as “being able to see the image on the surface of this is a very strange feeling.” From those two comments of different participants, it can be deduced that the image generation phase plays an important role. Because of this, although it does not belong to the audio file the participants bring, the image generation phase and the spectrogram image forcefully become embedded into the process. Yet, it also captures the interest of the participants and helps them create connections between the audio file and the resulting form.

Some analogies coming forward are outlined in the following table.

Table 4.11 Analogies made by participants about the resulting physical artifacts

P1	“a memory”, “a very valuable gift”
P2	“an heirloom”
P3	“a toy from your childhood you cannot throw away and reminds you of childhood memories”
P4	“geography”, “relief map”, “mountain range”, “porte”

Table 4.11 (Continued)

P5	“between two people”, “real meaning shows itself when this is something that is shared”, “aestheticized reflection of the original sound”, “secret”

4.2.2 Flow of the Study

During user studies, it is observed that the flow of the process differs from one participant to another. Some participants ask more questions than others, and some grasp the concept and process faster than others. Since the questions asked by some participants need longer explanations and some shorter ones, the flow of the process varies, which can increase the variations in the experience obtained from the process by the participants. Although the complete standardization of the experience would not be possible concerning the participants' different past experiences and backgrounds, the outer interventions (such as the researcher’s descriptions and modifications of the form) through the experience can be minimized. For instance, in order for the participant to change the surface smoothness of the artifact, s/he has to tell the researcher to change the surface smoothness. Then wait for the necessary changes, assess the resulting form, and tell the researcher again if that is suitable. After some number of attempts, even if the participant is not content with the result, s/he can accept the form for the sake of not taking more time of the researcher. This type of form modification can create a barrier for the participant and accept the result after a few attempts. *Therefore, a completely interactive setup, from which the researcher is removed, would enhance the experience and the transformation of the sound to a form more believably and seamlessly*. Thus, it might introduce new insights that were previously impossible to gather because of the lack of fluidity in the process.

4.2.2.1 Researcher Intervention Through the Transformation Process

According to all the participants, the process had no problems and had gone in the direction they wanted. When asked, nearly all of them stated that the artifact reminds them of the sound's origin and related things, except P4. P4 mentions that when reminiscing about this artifact, he will remember a young researcher doing this work. Thus, the researcher being part of the process and his interventions can create a kind of noise in the transformation process. On the other hand, this comment refers to the experience itself becoming memorable and valuable. In other words, in addition to the sound recording's meaning, the process that the participants go through also leads to new memories which can be valued in the future. Thus this might create uniqueness value that comes from the common history of the participant with the artifact, as Raz argues (Raz, 2001). However, the only participant that mentions the involvement of a person (the researcher) is P4, who also cannot find a practical reason for transforming sound into an artifact. When his sound selection is considered, it can be seen that there is not much of a personal memory of him related to the sound. Since he cannot find a personal connection with the artifact, he might have created that connection during the process with the involvement of the researcher, myself, which creates value through shared history.

During the explanations in phase two, some technical explanations about a subject the participants might be unfamiliar with are made. This situation also includes verbal definitions like "bright areas in the spectrogram images becoming bumps and other places remaining unchanged." Such verbal definitions, the way they are used by the researcher, and even things worn by the researcher, can all become a part of the memory that participants construct during the process.

I first explain how the audio file the participants bring is translated into a 2D image and the meanings in that 2D image. Then I transform the image into a virtual 3D form by operating some computer software. This time I explain the modified surface of the virtual 3D form and its connection with the previous 2D image. After the connections are made, I continuously modify the form according to feedback coming from the participant. As discussed in the previous sections, in the studies until now, I am positioned in such a way in the study that in all of the stages, I remain an explainer/translator, intervener, and operator.

During the studies, the participants are asked to reflect upon what they see on the computer screen (and the physical artifact which is given to them in Phase 4) and answer questions related to the transformation process of their audio file into a physical artifact. Throughout the interview schedule, the only phase they are actively involved in the process is the second phase, in which the audio provided by the participants is analyzed and transformed into a virtual 3D form. They direct me by stating their preferences about the resulting form while reflecting upon their decisions and answering the related questions.

Participant comments about an unattended transformation process imply that being able to realize the transformation process by themselves would:

- Increase the sense of identity
- A better reflection of personal preferences
- Experiment with different surfaces and form alternatives

Therefore, for the development of the transformation process, letting participants realize the process by themselves through an interactive interface gains importance.

Initial participant selection had the criteria of participants having no experience with 3D modeling and related software. Although this decision was made to prevent any biased opinions that may result from participants' prior experience, it seems to be hindering some valuable suggestions that could have been made if they were familiar with the processes used.

4.2.2.2 Breaking Points in the Flow of the Process

During the process, different programs and menu items are needed to be cycled between in order to make the requested differences on the 3D artifact:

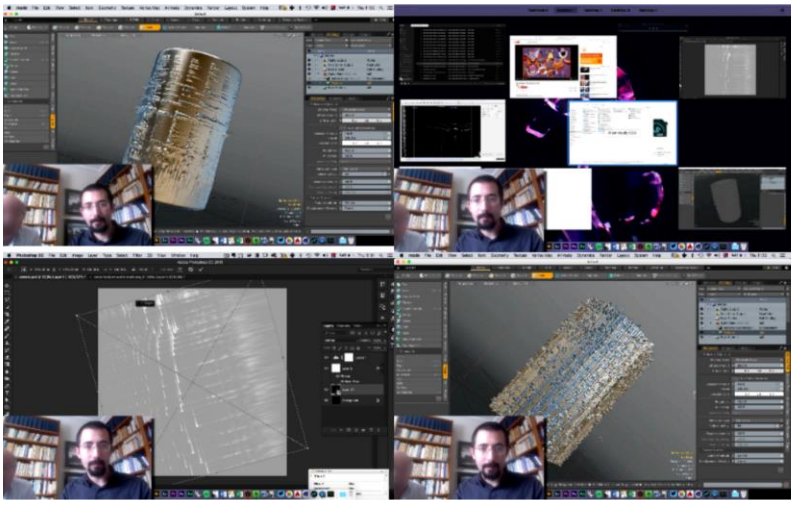


Figure 4.22 Going back and forth between different applications and windows.

When the participant wants a smoother surface, I switch to Photoshop and increase the blur amount of the displacement texture. Then return to Modo and refresh the file, and then ask the participant if it is the desired amount or not. For the bumpiness of the artifact surface, I need to change a numerical value and then press *Enter* to see the change. These parameters are in different dialogue boxes or windows, making switching back and forth between these apps and menus a necessity. During these operations, the participant tries to follow what is being done, although s/he may not understand anything. Thus, a simple process of projecting sound onto an artifact's surface can seem a very complicated and "high-tech" phenomenon. This, in return, might introduce a distancing from the artifact itself since, during the creation process, many interventions take place.

Another breaking point is remembering the connection between sound and image and then recalling that in the transformation to the 3D form phase. For the 3D form to be understood by the participant, s/he must have grasped the connection between 2D image and sound. Furthermore, s/he must remember the relationship between them and transform that knowledge into the formed 3D model. Although not mentioned directly by the participants, any lack of this type of cognitive transformation can result in an artifact losing meaning, value, and connections to the initial sound. This can be deduced from the comments about the artifact's meaninglessness without the explanation or origin of the sound source or what is written/encoded on the surface of the artifact. Also, the users mention that this is a very different experience and like “learning a new language”. When combined with the difficulties a person passes through when learning a new language, this analogy points to the difficulties in learning this new way of sound representation.

4.2.2.3 Participant Definition of Sound Before and After the Transformation

Most of the time, after a participant understands the “new language” used in the process, the connections s/he makes to the sound are carried through phases 2 to the end. However, during the transformation from the spectrogram image to a virtual 3D form, P2 makes a statement that connects the aesthetic properties of the artifact with the things the sound represents. After the bumpiness of the artifact is increased upon request from the participant, she immediately mentions that the form has become like a male voice, which disturbs her because of the connections that she makes with her daughter’s “purity.” Although she prefers the artifact surface to be more bumped, the “purity” association and “river” analogy stops her from making this a bumpy artifact since it loses the connection to her child as soon as she likens it to a male voice. *This points to a blurred area during the transformation from meaning to 3D form where aesthetic properties of the resulting form can conflict with the meaning-led associations that are made by the participants.*

Similarly, P5 refers to the final appearance of the artifact as an “aestheticized reflection of the original sound.” After he understood the connection between sound and the virtual form, he wanted to aestheticize the resulting form according to his taste. According to his comments, if he prefers a *one-to-one correspondence between the form and the sound,* he could leave the form smoother. However, *he thinks that he will not be able to tell this artifact to anyone other than himself; therefore, he doesn't need to preserve the initial appearance of the artifact.* He also states that the meaning now is between the artifact and himself.

4.2.3 Sound-Memory-Artifact Connection

P4’s preference of using the original CD to listen to that song leads to additional ways to be explored. His audio file selection, Bach’s L’Offrande Musicale, is reachable in many other ways, like listening from a computer or a CD. However, the existence of the audio on a physical artifact in his home, as a CD, starts to blur the artifact's function from P4’s perspective. He tries to assign some practical function to the artifact and sees it as a way to reach the audio. Since he already has another way to listen to Bach’s piece, he prefers using a CD. When he views the artifact from this perspective, the artifact does not seem to have that much value and meaning.

A similar audio file selection (a piece of music) is present in P3 and P5. However, their responses to the artifact and its function are entirely different than P4’s. P3 and P5 state that the artifact becomes a reminder of the emotions and thoughts related to the songs they selected, whereas P4 generally tries to see the artifact as an intermediary that should lead to the original music. The 3D-printed artifact fails to be a substitute for that; thus, he finds it hard to give any symbolic meaning to the artifact itself. Although the substitutability of the physical artifact (CD instead of the 3D printed artifact) can be one factor affecting the meaning and value of the resulting form for P4, the selection of audio and related meanings provides further insights into the underlying reasons for these perceptual differences between mentioned participants. The piece P4 chose has historical and personal meaning for him, though it may not be that much personal value. During the interview, he states three sources of value and meaning for his audio file. First, he likes the melody and the theme personally. Second, its historical story (related to King Frederick 2nd and Bach) is interesting to him. Third, the nine measures of this composition are used in the award medals they give to the music foundation.

On the other hand, the other participants, 3 and 5, also choose a music piece. Yet, theirs are much more personal. One is a wedding song, and the other one is a game theme song that represents a very important personal achievement. Therefore, there can be a degree of personal connection depth that these artifacts can start to make meaning for their possessors, which can be further investigated in further studies.

The participants' demographics may also have a determining role in the value given to the resulting artifacts since P4 was the oldest among the participants. Since the number of participants is very low to make any generalizations, it may point to areas that can be further investigated.

4.3 Summary

This chapter presented the emergent themes obtained from the analysis of participant responses. The next chapter discusses and describes suggestions for developing the transformation process. Building upon insights and suggestions from this primary study, the design of an interactive data transformation interface is presented.

CHAPTER 5

CONSIDERATIONS FOR INTERACTIVE DATA TRANSFORMATION INTERFACE

The previous chapter discusses improvements related to the properties that have emerged from the participant responses and improvements for the conducted transformation process. Appendix B summarizes those suggestions in a table. The considerations for developing the transformation interface are explained in detail in this chapter.

It should be noted that the following sections *5.1 Suggested Developments for the Transformation Process* and *5.2 Software Trials*, present figures and interface images from the development phases of the interface. Therefore, they are presented as documentation of an ongoing development period during this stud. Section *5.3 Developed Interactive Data Transformation Interface* for Design Workshop presents the final version of the interface.

Then, this process is used in a remote workshop conducted by the researcher as a part of the National Design Research Conference (UTAK) 2020 organized at Middle East Technical University.

5.1 Suggested Developments for the Transformation Process

5.1.1 Decrease researcher intervention

Category: Accessibility of transformation

Subcategory: Flow of the process

Property: Duration and progression of the process

Reduce, if not eliminate, the researcher's intervention in the transformation process by designing a parametric interface that lets the participants choose options from predetermined parameters and experiment with different combinations of options.

These parameters were initially determined in the initial user study protocol (Appendix A) under Phase 2: Audio Analysis and Artifact Personalization are the surface bumpiness and surface smoothness. After completing the user studies, it is seen that the sound orientation on the surface and the part of the audio selected should also be presented as options to the participants. Thus, the determined parameters are:

- Surface bumpiness (displacement caused by the sound data on the artifact surface)
- Surface smoothness
- The orientation of data on the artifact surface
- Audio section

As explained in the previous chapter's *Accessibility of Transformation* section, the initial transformation process involves many steps that require the intervention of the researcher to the process to reflect the participant's preferences on the artifact. These steps and researcher intervention make the transformation process less accessible. Thus, to increase the *accessibility of transformation,* a parametric interface that lets participants conduct the transformation process by himself/herself is decided to be developed.

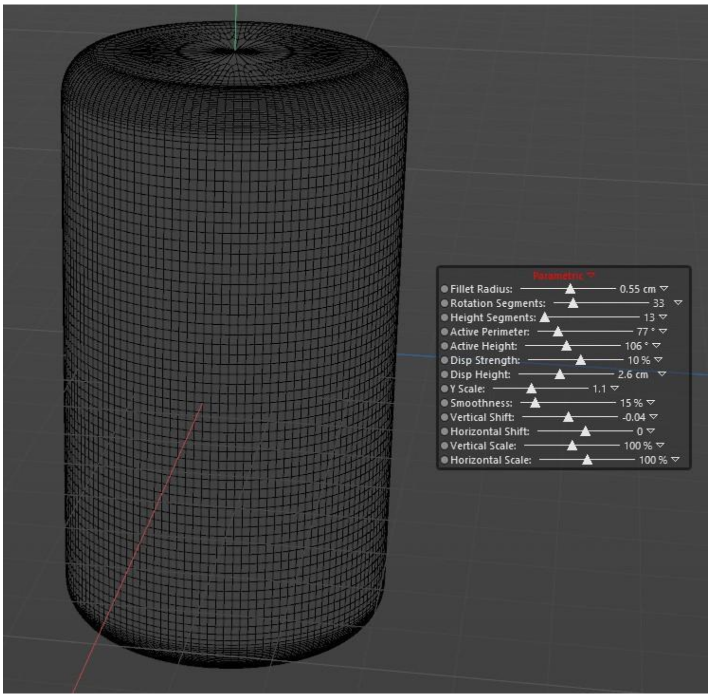


Figure 5.1 An example parametric interface in Maxon Cinema 4D.

By dragging the sliders in the interface (Figure 5.1), the participants can change the effect of sound on the artifact surface, eliminating the need for researcher intervention.

As discussed in section 4.2.2.2 Breaking Points in the Flow of the Process, the modification of the surface of the artifact requires many steps that can interrupt the thinking process of the participants and create barriers or frustrations. Although not mentioned by the participants, the flow of the process makes it hard for a person to explore as many options as s/he likes since every request takes time and requires additional conversation. Because of the parametric surface generation abilities in Maxon Cinema 4D, an interface that incorporates all the variables in the initial study is developed. By using this interface, after the spectrogram image file is assigned to the artifact, the participant can *play* with the virtual 3D form by changing parameters such as smoothness, surface displacement amount, corner fillet radius of top and bottom parts of cylinder, and height of the cylinder (Figure 5.2).

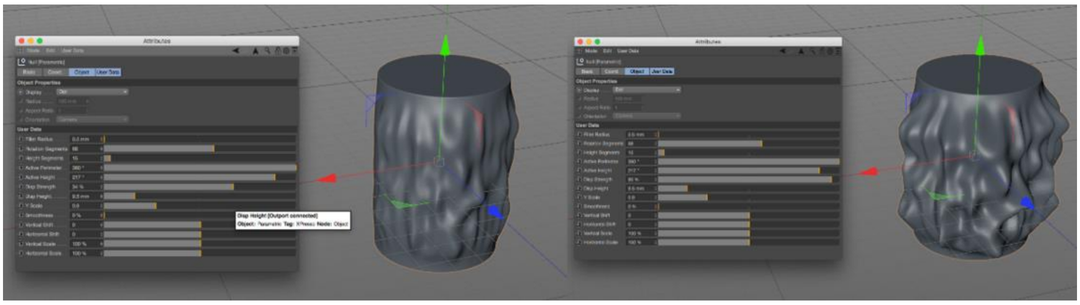


Figure 5.2 Parametric interface trials developed in Maxon Cinema 4D.

Figure 5.2 shows the attempts to parameterize the surface preferences for the artifact. It provides solutions to some flow problems in the user studies, such as the need for a researcher’s intervention to change the visual appearance of the surface. However, this system still needs to explain how this transformation from sound to form occurs. Therefore, a method that does not need such explanations is developed before continuing the user studies. The need for explanation is eliminated by a real-time surface modification method.

After experimentations with the Sound Effector in Maxon Cinema 4D, a better method for real-time visualization of sound on the artifact surface is discovered. Initially, the sound was deforming the surface, but later, those deformations returned to normal. Making those deformations permanent required another type of operator named Decay. The Decay operator enabled sound to cause permanent deformations on the artifact's surface while the sound was being played.

5.1.2 Increase participant involvement and let experimentation

Category: Accessibility of transformation

Subcategory: Unattended realization of transformation

Property: Stronger connection with the artifact

As discussed above, decreasing the researcher intervention through a parametric and interactive interface may enable participant personalization of form by themselves and provide the following benefits:

- Enable a better reflection of personal preferences,
- Eliminate the concern of being judged
- Increase the sense of identity and self-expression
- Facilitate experimentation with different surfaces, and form alternatives

The parametric interface mentioned above is also expected to increase participant involvement in the process and enable them to experiment and explore with different settings. This increase in participation will help increase the *accessibility of the transformation* process.

5.1.3 Easy selection of different sound sources

Category: Accessibility of transformation

Subcategory: Unattended realization of transformation

Property: Stronger connection with the artifact

Letting easy selection of different sound sources increases engagement and enables participants easily and quickly see how other sound sources come out in the process. Initially, the audio file needed to be processed in the transformation process to create a spectrogram image. After that, the sound data could be used for the transformation process. The aforementioned "Sound Effector" is used for the next version of the process. That operator accepts .wav and .mp3 file extensions and can analyze the spectrogram data in real-time. Thus, for the next version, the participant can try different audio recordings directly by selecting a different audio file. Also, there will be no need to pre-edit and crop the audio file since the participants can select which section of the sound they want to use through a slider.

5.1.4 Function-specific material selection

Category: Aesthetics of transformation

Subcategory: Personalization of artifact

Property: Functionalization of artifact

Different material visualizations such as steel, bronze, brass, glass, and polished plastic can be implemented into the interface. Also, material visualization is attained by the viewport rendering capabilities of Maxon Cinema 4D. The participant can choose from the materials named according to their functions, such as an accessory or decoration.

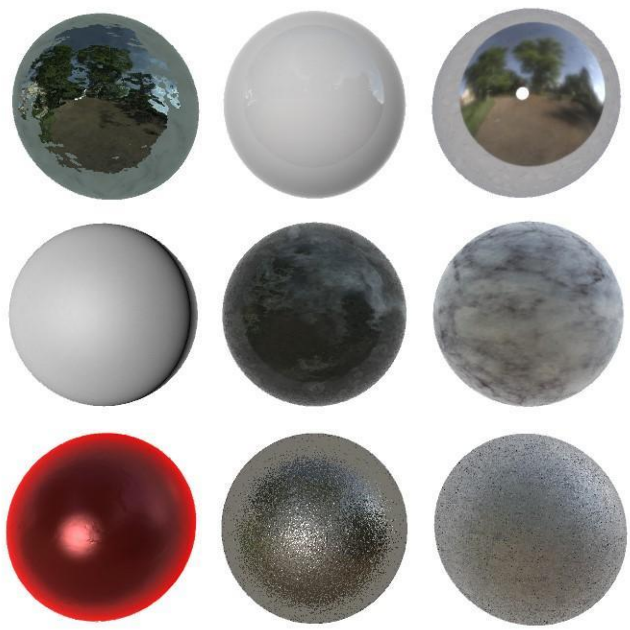


Figure 5.3 Material visualizations in C4D viewport

However, this study cannot fully explore material experience and its implications due to the material limitations of 3D printers within reach of the researcher. The 3D printer that is used in the study can print in plastics. Although material selection may have the potential for further research, the interface will only visualize these different material options for the current study.

5.1.5 Homogeneous sound data distribution across the surface

Category: Aesthetics of transformation

Subcategory: Personalization of artifact

Property: Sound distribution across the artifact surface

The interface is developed so that it automatically adjusts itself according to the audio recording length. xPresso, a node-based programming environment in Cinema 4D is used to resize the deformations automatically. The logic behind the automatic resizing is presented in Figure 5.4. This interface runs in the background and will be invisible to the participant. This node based interface and the logic behind is eplained in more detail in section 5.3 Developed Interactive Data Transformation Interface for Design Workshop.

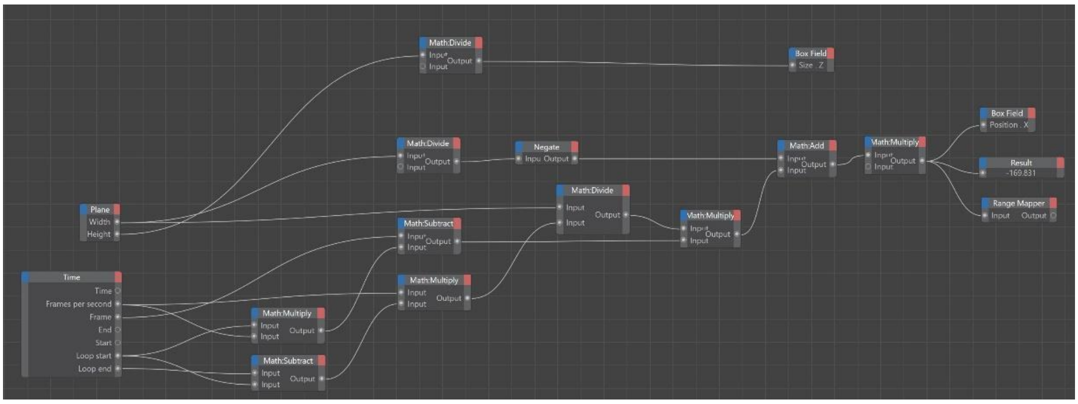


Figure 5.4 Node-based xPresso setup for the automatic adjustment of audio distribution

The developed method fits the selected audio section's length to the artifact's surface. In this way, if the participant changes the duration of the recording section (see section 6.1.9) -for example, decides to use a shorter part of the recording- the system automatically adjusts the length of deformations to the length of the surface.

5.1.6 Audio data orientation selection

Category: Aesthetics of transformation

Subcategory: Personalization of artifact

Property: Sound distribution across the artifact surface

In the user studies section (6.4.1.2), some participants wanted to change the orientation of sound data on the artifact surface. The orientation of sound data on the artifact surface is seen to be a determining factor of the beginning and end of the time of audio data. Thus, changing the orientation would allow the interpretation of time progression on the artifact surface. This orientation change can make understanding the sound’s beginning and end easier by looking at the form of the artifact. A slider interface will be presented to the participants to control the angle of the sweeping sound modifier that deforms the artifact's surface with sound data.

5.1.7 Parametric surface properties

Category: Aesthetics of transformation

Subcategory: Personalization of artifact

Property: Surface enhancement

Participants should be enabled and encouraged to play with the artifact by themselves since they do not know how far they can go with the deformations on the artifact's surface.

Figure 5.1 shows the parameter sliders that can be used to control the artifact. Such an interface will allow the participants to change bumpiness, smoothness, and orientation parameters through a slider interface. Changing the surface parameters phase is where most of the dialogues between the researcher and the participants took place in the initial study. Thus, the new interface will decrease the researcher's intervention and increase participant involvement by parametrizing this phase which is believed to result in a better realization of participant preferences about the *aesthetics of transformation*.

5.1.8 Easy switching between audio files

Category: Aesthetics of transformation

Subcategory: Personalization of artifact

Property: Use of different sound sources

One of the biggest challenges in the user studies about easy experimentation with different sound files was the necessity of audio processing and spectrogram image generation in the transformation process's initial version (see section 4.4.2).

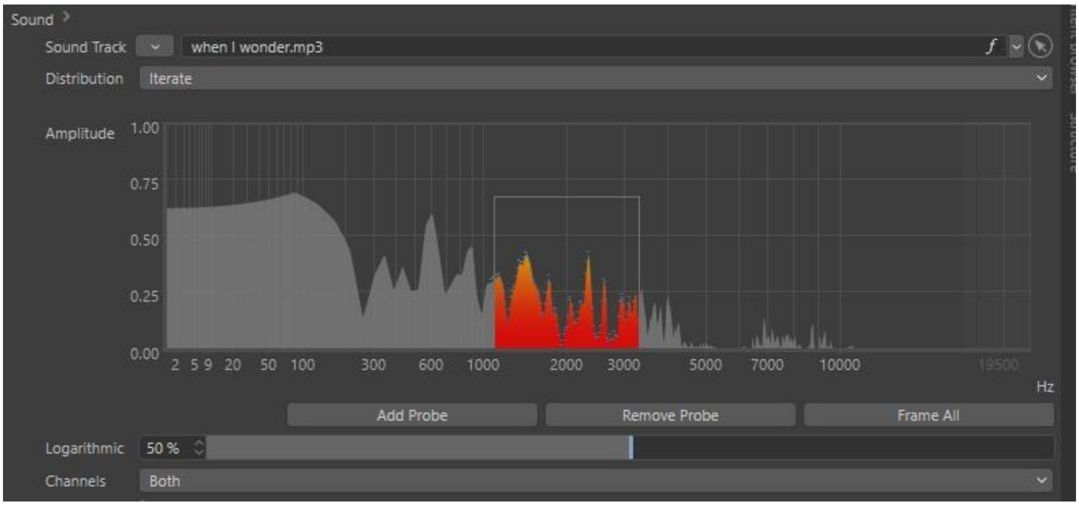


Figure 5.5 Sound Effector Interface

Utilizing the Sound Effector in Cinema 4D solved this problem by letting the user load any audio file in MP3 or Wave file format. After selecting the audio file, the frequency analysis is executed in real-time, thus eliminating the need for spectrogram image generation (Figure 5.5). Another benefit of using this method is that it allows specific audio frequency ranges to be selectively applied on the artifact surface. The area colored in red shows the active frequency range in Figure 5.5.

5.1.9 Audio section selection

Category: Clarity of transformation

Subcategory: Audio-visual connection

Property: Beginning and ending of sound/looping non-looping

The next version of the process should let the participant decide on the audio section; a way of emphasizing the recording's beginning and end should be developed.

This is achieved using Cinema 4D’s animation *Preview Range* feature embedded into the *Timeline* interface. This way, the participant will use the gray bar shown in Figure 5.6 to define the duration and range of the audio recording.

Figure 5.6 Audio section selection interface in Cinema 4D

With Audio data orientation selection improvement, the participants can interactively determine how their audio file is visualized on the artifact's surface. This improvement is aimed to improve the *audio-visual connection* between the form and sound in the mind of the participants by letting them play with different possibilities and experience their effects in real-time. In contrast to the researcher’s narration and guidance about the process, this improved process provides a hands-on approach to the transformation process. It lets the participants understand the process better, thus, increasing the *clarity of transformation*.

5.1.10 Realtime transformation of sound to an artifact

Category: Clarity of transformation

Subcategory: Audio-visual connection

Property: Degree of need for specific marks

Through the real-time audio analysis features of Cinema 4D, it became possible to eliminate the spectrogram phase and directly transform audio into artifact form. The aim of executing this transformation in real-time is: to decrease cognitive processing, increase the transformation process's clarity, and construct a stronger audio-visual connection.

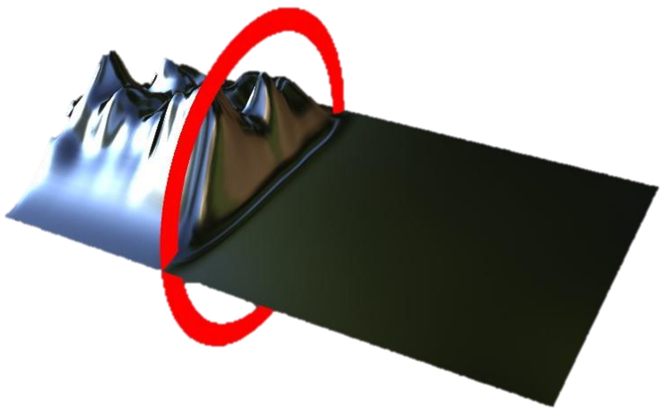


Figure 5.7 Real-time transformation of sound to an artifact.

The red circular form in Figure 5.7 above moves towards the right as time passes on the surface. Beneath that, the circle marker is displaced according to the sound data.

5.1.11 Realtime playback of sound

Category: Clarity of transformation

Subcategory: Audio-visual connection

Property: Realtime experience of transformation moment

As explained under the previous title, the method allows the real-time generation of the artifact surface according to sound. Thus, it automatically provides a method for playing the sound recording in real-time. Repeatedly playing of sound can let the participant see which moment in the audio recording causes bumps on the artifact surface, strengthening the audio-visual connection and increasing the *clarity of transformation.*

5.1.12 Making the transformation process a part of the memory

Category: Clarity of transformation

Subcategory: Audio-visual connection

Property: Realtime experience of transformation moment

Initial studies with the transformation process in Chapter 4 show that the participant's experience through the process starts to become a part of the memory. Apart from memories related to the audio file, researcher interventions, participant decisions, and the evolution of the form with sound start to play a role when a participant reminisces about the experience. Thus, the transformation process will be recorded as a part of the memory in the form of a video. Later, the video can be reached through a QR code located under the artifact.

5.1.13 Reaching the sound through the artifact

Category: Clarity of transformation / Permanence of transformation

Subcategory: Audio-visual connection / Becoming a permanent memory

Property: Returning back to sound / Tangibility of artifact

One of the frequent requests from the users' studies was the chance to return to the sound through the artifact. The original sound recording will be reachable through a QR code under the artifact. Through this code, the participant can reach both the video of the transformation moment and the original audio recording. This way, the *audio-visual connection* is not lost even after completing the process. Sound, which is usually connected to ephemerality by the participants, becomes permanent. An ephemeral entity is transformed into a tangible and permanent artifact that increases the *permanence of transformation.*

5.1.14 Allow more dramatic changes on the artifact surface

Category: Clarity of transformation

Subcategory: Audio-visual connection

Property: Role of rhythm for recognizing patterns

This suggestion for improvement is resolved after the suggestions in "6.1.1 Decrease researcher intervention" and "6.1.2 Increase participant involvement and let experimentation" are implemented. When the transformation process becomes parametric and more reachable, the participant will be empowered by the freedom to experiment with different settings. Combined with real-time audio processing, the effects of participant choices and rhythms in the sound will become visible immediately on the surface.

5.1.15 Allow more control over the form of the artifact

Category: Clarity of transformation

Subcategory: Audio-visual connection

Property: Translating sound's perceived properties into form

This suggestion for improvement is also resolved after the suggestions in "6.1.1 Decrease researcher intervention" and "6.1.2 Increase participant involvement and let experimentation" are implemented. The reason for this suggestion was the participants' efforts to translate how they perceived the sound in their recordings into how they perceived the artifact. Because of the continuous researcher's intervention is deduced that it is highly probable that the participants might have given up after some back-and-forth conversations about how the form should be according to them.

Thus, decreasing the researcher's intervention and giving more control to the participant through a parametric interface is believed to facilitate and support *translating perceived properties of sound to artifact form*.

5.1.16 Adjustable audio duration and section

Category: Meaning of transformation

Subcategory: Connection to memory

Property: Audio sample part representing the whole memory

This suggestion for improvement is also resolved after the suggestions in 6.1.9 Audio section selection are implemented. For some participants, using only a fragment of the audio recording can represent the whole's meaning. Thus, empowering the participant to select the part and experiment with it is believed to increase the meaning of transformation through being able to use the most meaningful part for the participant.

5.1.17 Requesting audio recording with intense personal meaning

Category: Meaning of transformation

Subcategory: Connection to memory

Property: Connection to positive feelings

This suggestion is more related to the interview methods rather than the interface. Initial studies showed that a participant with a rather impersonal connection with the memory the sound represents had a hard time finding meaning in such kind of a transformation process. However, all the other participants who selected more personal sounds, such as daughter’s first words, life motto, and wedding song, found the process meaningful. Inspired by this difference, it is decided to make a more detailed request about the audio selection and require a recording with an intensely personal meaning.

5.2 Software Trials

Several trials with different 3d modeling software and plugins (McNeel Rhinoceros 3D with Grasshopper plugin, Maxon Cinema 4D) were made to implement the extracted suggestions into the transformation process. The main reason for experimenting with these two software packages was the parametric design possibilities brought by their *node-based interfaces* and *design workflows*. This way, it is aimed to design a parametric system that would let the participants modify the form according to their preferences by simply changing parameters instead of telling a researcher what to do. For example, by moving a slider, the participant can change the artifact's surface properties.

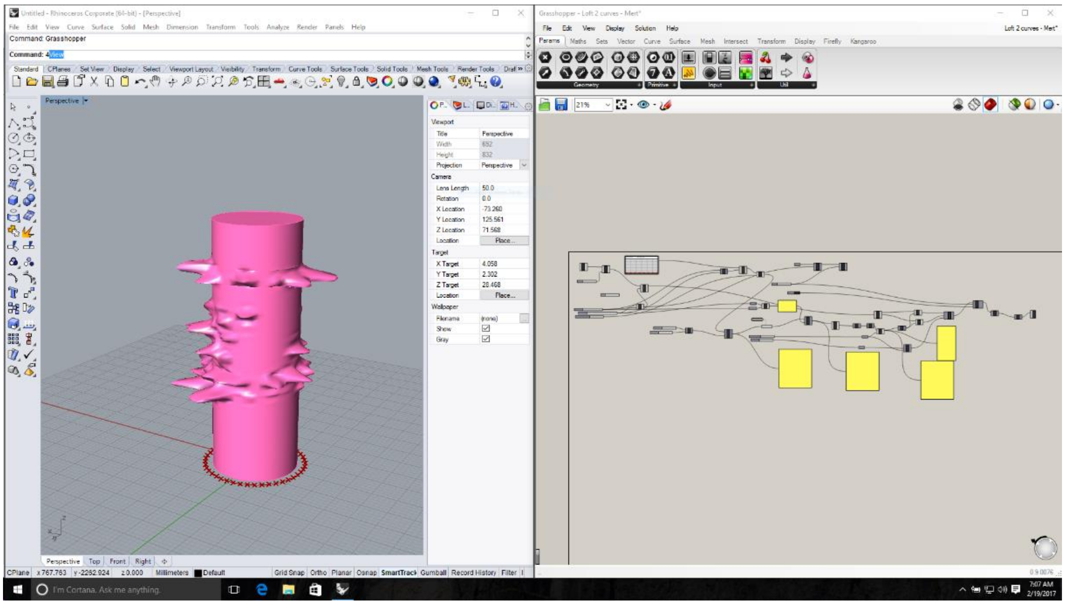


Figure 5.8 Real-time generation of the artifact surface in Grasshopper for Rhinoceros 3D using real-time audio input.

The first trial was made with Grasshopper for McNeel's Rhinoceros 3D software to convert sound data to the 3D form. A plug-in for Grasshopper named Firefly is used for real-time audio input and frequency analysis. Using this setup (Figure 5.1), the interface allows the user to press a record button and modify the artifact's surface in real-time. Then the user can stop the recording and change the parameters like surface smoothness, detail, cylinder height, and displacement amount.

The main problem with this setup was the resulting form's update interval. The displacements caused by audio resource moves around 1.5 frames per second. This slow number of frames makes it very hard to understand which sound causes which parts of the form to be displaced. Since the 3D form requires complex surface generation methods, it becomes processor-intensive, requiring a powerful processor. For this method to provide the illusion of shaping the artifact with sound, the framerates should be around 25 frames per second and above.

Finally, it is decided to use Maxon's Cinema 4D because of its faster viewport performance. A fast viewport performance was the determining factor since the playback of the sound and its effects on the artifact surface become harder to observe as the software's viewport fails to update the model in short intervals. Moreover, Cinema 4D offers more advanced visualization techniques, including material selection features.

5.3 Developed Interactive Data Transformation Interface for Design Workshop

Considering the discussions in the previous sections and using the features of the Maxon Cinema 4D application, an interactive interface that allows the modification of a cylinder form with sound data is developed. Figure 5.9 shows the interactive personalization interface prepared for the remote design workshop.

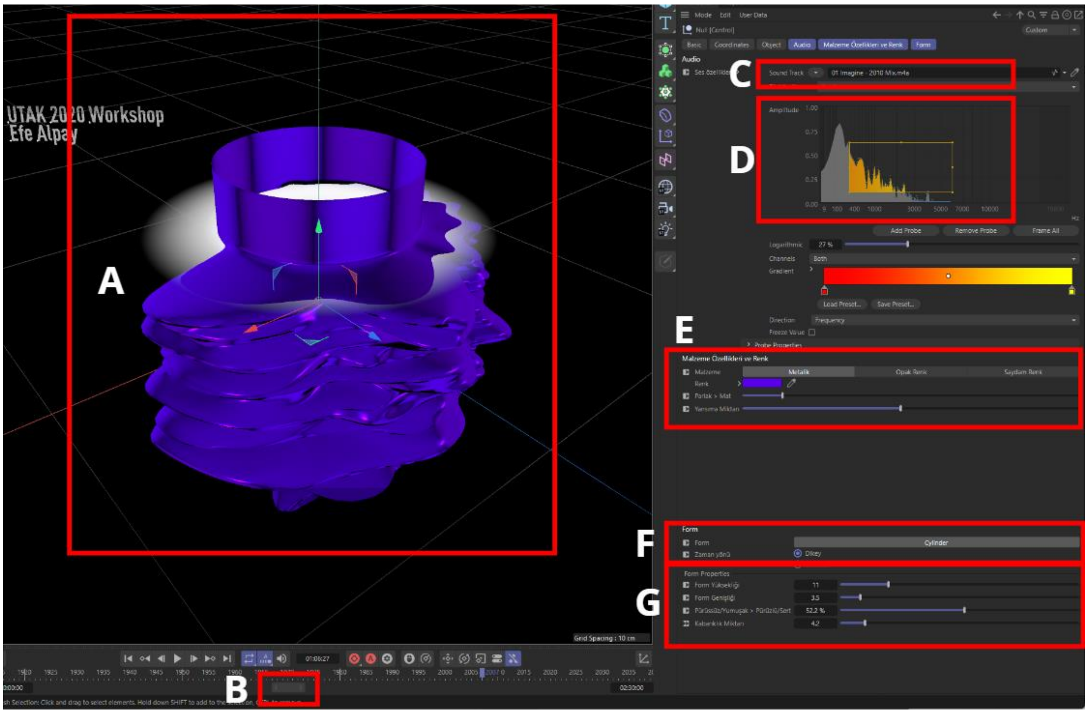


Figure 5.9 Interface of the Interactive Data Transformation Interface (IDTI) prepared in Cinema 4D.

Figure 5.9 shows the general interface of the developed personalization software as the participants see it. Since the software is a 3D modeling program, the regular interface might be complicated for ordinary users. Therefore many of the interface elements have been omitted. The artifact is constrained to always remain at the center of the viewport. The user can zoom in and out and rotate around the artifact to see it from different angles but cannot pan in the viewport.

Through the usage of xPresso (node-based programming environment of Cinema 4D, Figure 5.10), special modules that let the personalization of the form according to the considerations developed in previous sections are created. Different modules in the interface allow the personalization of the form according to the features discussed previously (Figure 5.9). Part A in the figure is the main viewport that visualizes the generated form in sync with the audio being played in the background. The white area towards the top of this cylinder moves in-sync with the audio being played. This way, it shows which part of the cylinder is affected by the audio data. The user can rotate the form, thus being able to see the from different angles.

Part B allows the participant to select the section of the audio file s/he brings. By scaling the length of the bar, the participant can increase or decrease the duration of the audio recording. With the help of visual programming (Figure 5.10, Temporal computations part), the designed interface adjusts the cylinder form and the speed of the scanning line according to the user’s time duration preference.

Part C allows the participant to easily select different audio files if s/he wants to experiment with different data sources. Part D allows the participant to select different audio frequencies affecting the form. The orange section shows an active audio frequency range selected from the full spectrum of the audio frequencies present in the audio being played. This way, the participant can make the form responsive to low-frequency or high-frequency sounds, beats, speeches, high-pitched voices, etc.

Part E provides an interface to adjust material-related properties of the form, such as reflection amount, color, metalness, and transparency. Part F allows the participant to choose the direction of time on the object's surface. For example, either circular or linear progression can be selected. Part G allows changing parameters such as the cylinder's height and width, the surface bumps' smoothness, and the displacement amount of the surface bumps.

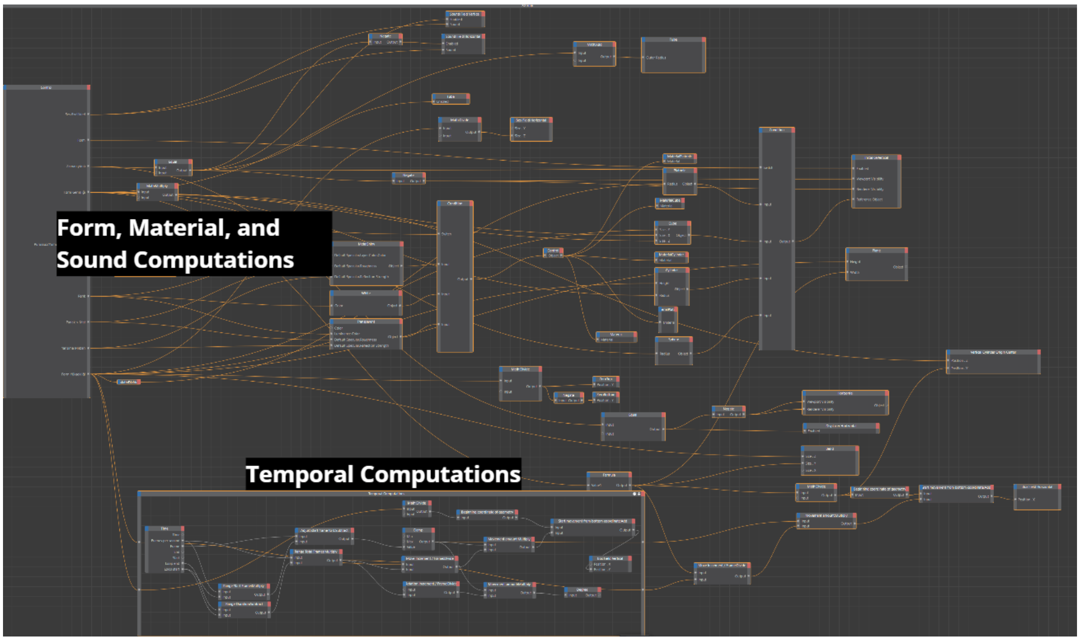


Figure 5.10 Visual programming of the defined features through xPresso (node-based programming interface of Cinema 4D).

Using the node-based programming environment (Figure 5.10), I created a parametric interface that lets the user change the properties of the generated form. Attributes such as sound attributes, the direction of time, form width and height, material, surface smoothness, bump amount, color, shininess, and reflection amount (Figure 5.11) can be changed simply by dragging sliders in the interface modules (Figure 5.10 C, D, E, F, and G). The node-based environment and designed algorithms work in the background. Thus, it s not seen by the user and does not interfere with the user experience. All the necessary calculations are done in the background

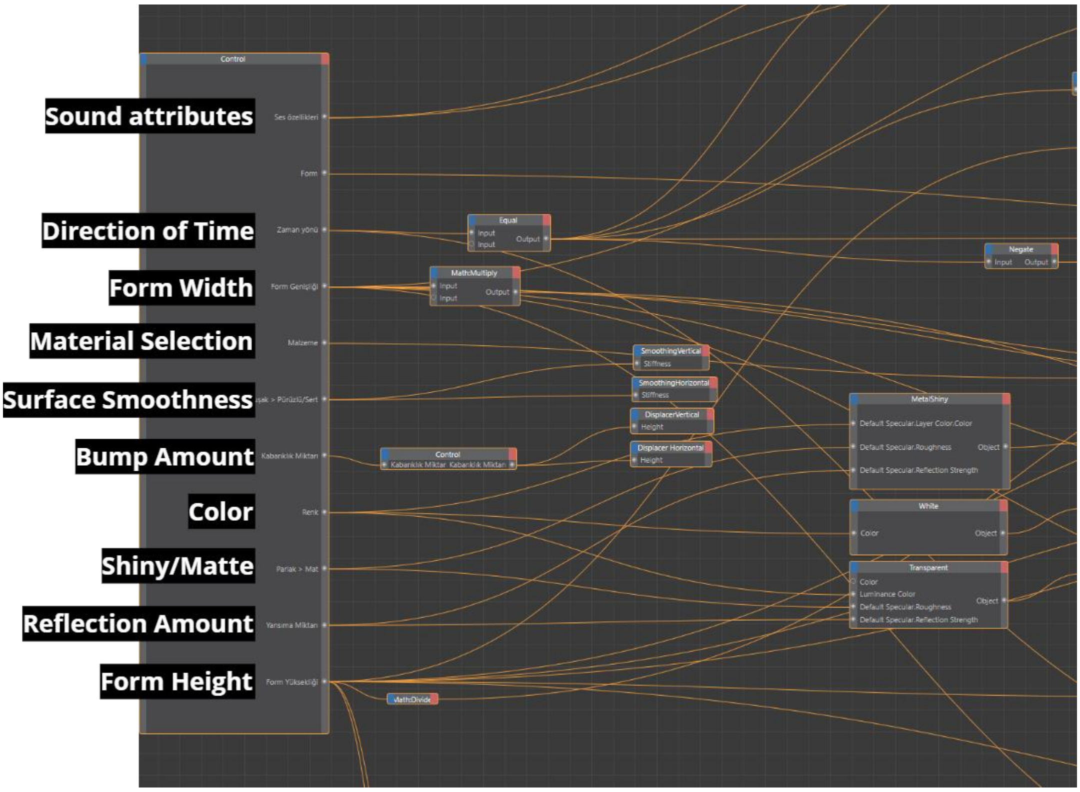


Figure 5.11 Features of the form that are controlled with the xPresso nodes.

The nodes in the last figures function as little programming boxes that provide different operations to be done, such as math operations, logic, and boolean operations, merging different data sets and converting one type of data to another. By combining different operators through the connection between their nodes, I created a *fully functional interface that lets the user personalize a form without researcher intervention*.

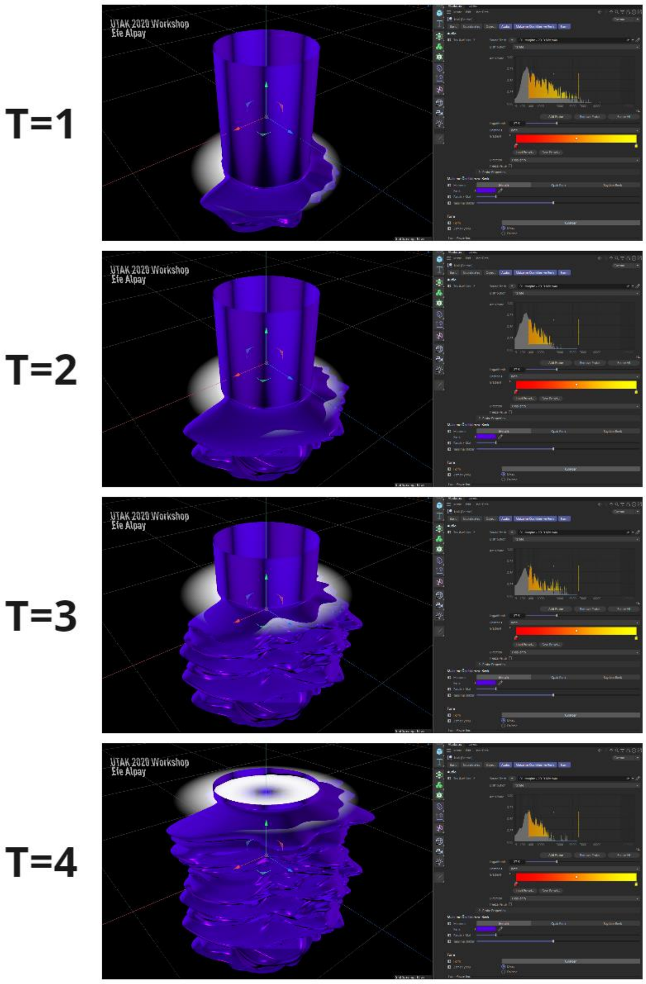


Figure 5.12 Real-time playback of sound while modifying the artifact's surface—white disc as an indicator showing the current time.

When the Cinema 4D’s play button is pressed, the selected audio recording starts to play, and the white disc starts to move upwards with progressing time. During this movement, audio frequencies are mapped around the perimeter of the cylinder and displaced the surface according to the intensity of different frequencies being heard. Thus, a regular cylinder at T=1 starts to be personalized according to the sound data until T=4 (Figure 5.12).

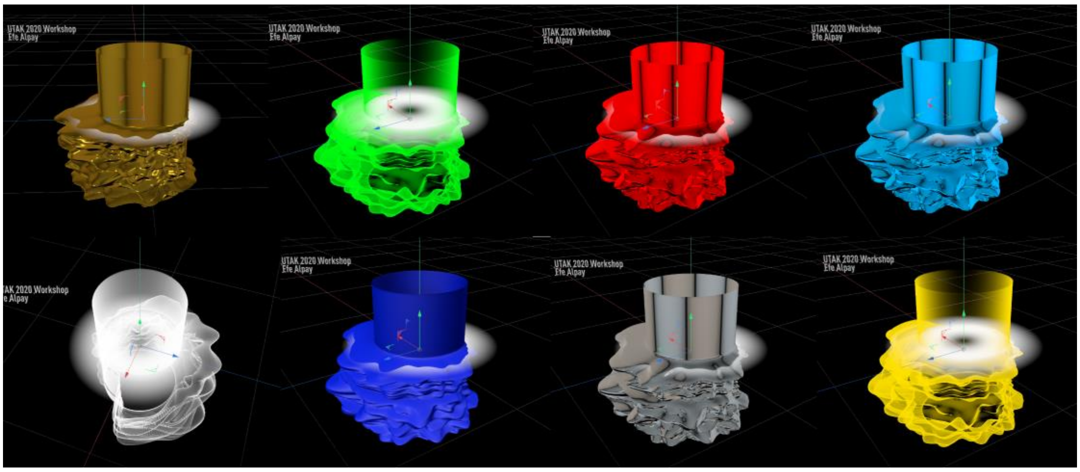


Figure 5.13 Different colors and material properties.

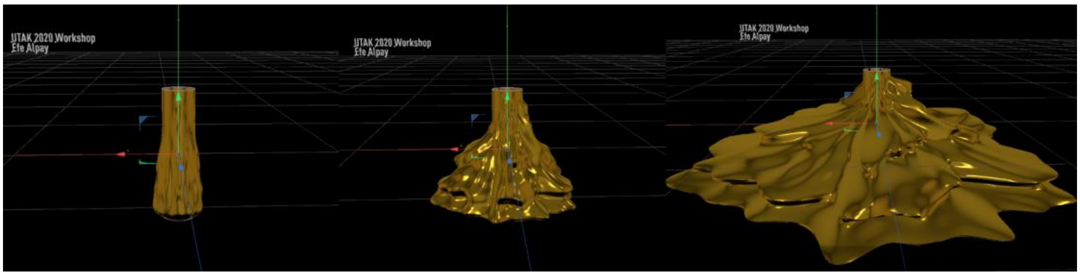


Figure 5.14 Dramatic changes on the artifact's surface by changing the bump amount slider.

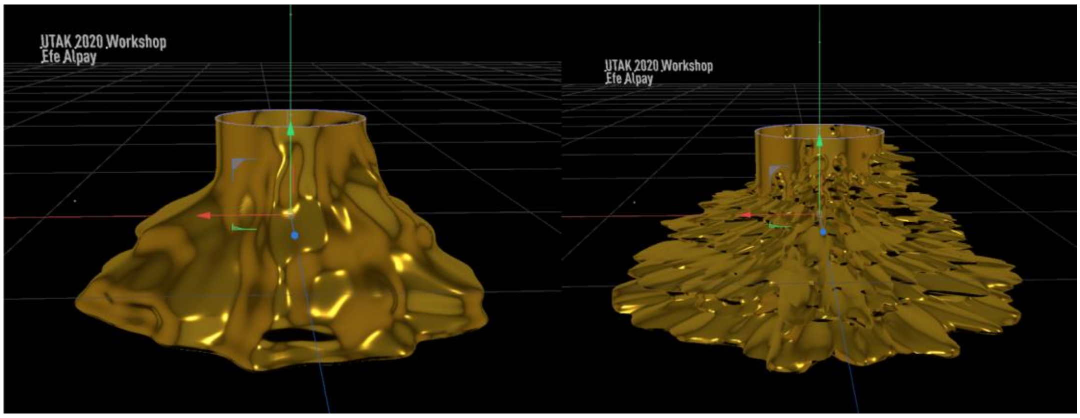


Figure 5.15 Controlling the smoothness of the surface with a slider

Figure 5.13 to 5.15 illustrate the form and material diversity that can be obtained by changing parameters in the presented interface.

5.4 Summary of the Integrated Interface Developments for the Design Workshop

Considering Ph.D. time constraints and the duration of the conference that this interface will be presented in a workshop setting, I had to eliminate some of the considerations for suggested developments in the interface. Some are eliminated due to the online nature of the conference and COVID-19 pandemic measures, and some to the length of the conference program.

- Decrease researcher intervention
- Increase participant involvement and lead experimentation
- Easy selection of different sound sources
- Function-specific material selection
- Homogeneous sound data distribution across the surface
- Audio data orientation selection
- Parametric surface properties
- Easy switching between audio files
- Real-time transformation of sound to an artifact
- Real-time playback of sound
- Allow more dramatic changes on the artifact surface
- Allow more control over the form of the artifact
- Adjustable audio duration and section selection
- Requesting audio with intense meaning

The following chapter presents the design workshop study that utilizes the developed IDTI in real life, participant responses and related insights obtained from them.

CHAPTER 6

DESIGN WORKSHOP

The interactive interface developed in the previous chapter is tested in a remote workshop environment due to the COVID-19 pandemic. The workshop took place as a part of the National Design Research Conference (UTAK) in 2020. It was organized by Middle East Technical University's Department of Industrial Design between the 8^{th} and 10^{th} of September.

This chapter presents how the study was conducted, used methods and tools, the flow and procedure of the workshops, findings, and insights. The conference language was Turkish, and some texts related to the study protocol were translated into English and included next to the Turkish definitions of the study phases, which can be found in Appendix D.

6.1 Methodology and Research Design

This study uses the same methodology and research design presented in Chapter 3, Primary Research. However, the main difference in this study is the interventions and involvement of the researcher in the personalization process for the transformation method incorporated into the design workshop.

In the primary studies, The process starts with the communication of the audio analysis process through the generation of a spectrogram image. However, the new interactive interface makes this step obsolete regarding research findings and insights obtained from the primary research. The audio file is visualized in real-time as bumps on the surface of a cylinder form.

Another significant difference from the primary studies is how the participant interacts with the 3D virtual form. Previously, the virtual form could only be seen from different angles by the participant through communication with the researcher, me. In the workshop, the participants use their personal computers to explore and use the interactive interface directly. This way, they can rotate the 3D form, zoom in and out, play the sound continuously, or stop or loop it as they wish. This direct involvement of the participants in the process dramatically reduces verbal communication during decision-making. Because previously, the participants were only able to realize their preferences through the agency of the researcher. I change the artifact form, ask a question to the participant, receive feedback, and then reapply the desired changes to the artifact form. Thus, in the design workshop, with the interactive real-time interface, the participants can focus more on reflecting their personal preferences on the form.

The development of the COVID-19 pandemic required this study to be conducted remotely. Thus, I needed methods and tools to design a study that allowed all the participants directly interact with the interface I developed. The main problem with this kind of remote study would be the lag between the user input and the response that s/he gets from the remote computer. Usually, if I were to conduct the study In a computer lab, the participant would be sitting in front of the computer, interacting with the interface, and I would be only asking questions and recording the session simultaneously. However, for the specified reasons, I needed a way for the participant to reach my computer and control the interface remotely. Software and services like TeamViewer allow users to reach and control a computer remotely. However, the latency of the response the user gets from the system interface has a crucial role in this study.

For the same reason, I could not use McNeel Rhinoceros 3D software and its Grasshopper plugin since the interface I developed was not fast enough to provide low-latency feedback about the form being generated according to the sound that is played. My research about low-latency and high-speed remote-connection software resulted in a service called Parsec (www.parsecgaming.com). Parsec started as a service to stream gaming content and to play games remotely. Thus low-latency remote connection and control were a crucial priority for developing this service. I used Parsec to grant the participants access to my computer remotely and control the *Interactive Data Transformation Interface (IDTI)* with their mice and keyboards.

In addition to the interactive interface access, I needed an interface for face-to-face communication with the participants. I used Zoom for video and audio communication with the participants and recording the design workshop session. The reason for choosing Zoom over other services was that during the pandemic, the lock-down situations forced everyone to learn video conferencing. Zoom was the most commonly used one, based on my observations. Because of that, I thought the participants' familiarity would be greater with this software.

In order to prevent any recording issues of the different software windows that were used during the workshops, I used OBS (open broadcast software) to record the screen of the researcher, the interface, and the participant at the same time. This also allowed a higher quality video capture since the compression algorithms of Zoom sometimes make intricate details on the video is unreadable

During the workshops, there were two communication streams between the researcher and the participants (Figure 6.1). One is through Zoom (Figure 6.1 blue box), which handles human-to-human communication, and the other is through Parsec (Figure 6.1 red box), which handles human-to-software interactions. In contrast to the primary studies, my role as a researcher was to observe user behavior during the personalization process and ask questions related to the insights generated in the previous study. Also, if the participant needed help or had questions, I guided them through the interface.

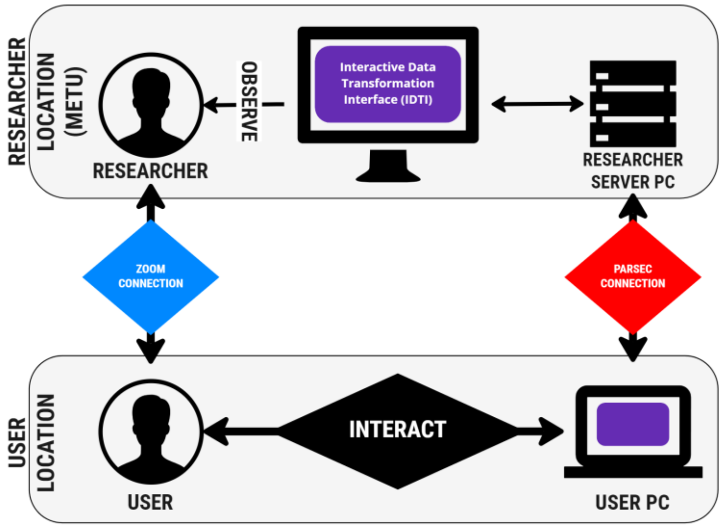


Figure 6.1 User-IDTI-Researcher connection scheme.

Another difference from the primary study was the location of the user and researcher. During the workshops, I was located in Middle East Technical University's Department of Industrial Design, and the participants were located in various places in Ankara, Izmir, and Istanbul. Because of the different distances between the participants and me, I had also to consider the users' internet connection speeds. Several days before the study, I arranged a test meeting to ask the participants to install the necessary software on their computers to prevent any possible problems due to connection speeds. After a successful connection, I also showed them the interface and wanted them to try it and see if there were any latency or audio-related problems. Because while interacting with the interface, they should also be hearing the audio recordings they have brought. Therefore, I advised the participants to bring headphones with microphones so that they could hear the sounds well and I would have a clearer recording of their voices while answering my questions.

During the workshop sessions, remote connection to the interactive interface worked seamlessly. However, due to the different audio setups of the participants, I had some problems with the communication and audio playback with two participants, participant four and participant nine. With participant four, the problem was she could not hear me well in some parts of the interview, so I had to change the audio levels of myself and the audio being played in the interface. The problem with participant nine was due to audio and video communication through Zoom. Somehow we could not talk through the Zoom interface, so finally, I had to call her with a phone and record her voice through the hands-free mode of my mobile phone. The part where I introduced the interface to P4 is missing in the recordings due to communication problems that happened at the beginning of the session. The duration of the recorded material of P9 is shorter than the other participants because of this. Recording P9 responses through the phone speaker caused some problems in the transcription, making it harder to understand what she said in some parts. Other than these, the sessions had no problems regarding communication and connection.

6.2 Recruitment of Participants

Since the workshop has been a part of the national design research conference, it was announced in the workshops program of the conference. Therefore that made the target group mainly the conference participants. In addition to that, I published a post on my Instagram account. As a result, fourteen people registered, but nine participants could attend the workshop, of which three were people who knew my research previously, and six were conference participants. Also, the audience is primarily design-oriented; six are from industrial design, one from graphic design, one from architecture, and one from sculpture. The demographics of the participants are presented in Table 6.1.

Table 6.1 Participant demographics of the workshop.

P#	Age	Gender	Occupation	Background	City	Duration (min:sec)
1	18-24	Female	Design professional	Graphic Design	Ankara	92:22
2	18-24	Female	Student	Industrial Design	İzmir	92:48
3	25-34	Female	Master’s Student	Architecture	Izmir	76:15
4	35-44	Female	Design Professional	Industrial Design	Istanbul	82:20
5	25-34	Female	Master’s Student	Industrial Design	Istanbul	47:26

Table 6.1 (Continued)

6	25-34	Female	Design Professional	Industrial Design	Ankara	95:30
7	25-34	Female	Artist	Sculptor	Ankara	70:00
8	18-24	Female	Student	Industrial Design	Ankara	72:27
9	18-24	Female	Student	Industrial Design	Ankara	69:38

As seen from the information above, the participants are all female, with an average age of 27.

6.3 Pre-Workshop Preparations

After completing the interface design and doing the initial tests with the people around me, I also conducted tests on remotely accessing the IDTI. During that tests, I discovered that some Internet service providers were somehow blocked from that remote connection. Thus, I had to ensure that all the participants could access my computer. Several days before the workshop day, I took the computer (Figure 6.1 Researcher Server PC) to the room I will be using on the workshop day at Middle East Technical University and tried to access that computer from various locations outside METU remotely. After ensuring everything was working, I prepared a video for the announcement of the workshop (Figure 6.2).

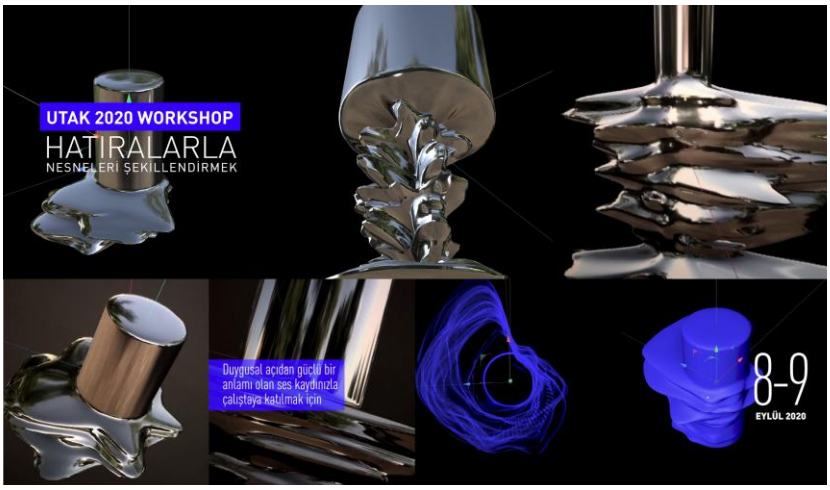


Figure 6.2 Frames from the Instagram post for the announcement of the workshop.

This post brought three participants to the workshop, while the remaining six participants found the workshop through the conference program and announcements.

Receiving applications through an online form

I have prepared a web page to gather participant information and sound files in a table that gives general information about the workshop and the underlying ideas (Figure 6.3). By clicking a link called *Data Entry*, the dialog box opens (Figure 6.4). The participants entered the related information such as name, age range, gender, audio file upload, the significance of the audio file for the participant, and reasons for choosing the audio recording (Figure 6.4).

Figure 6.3 Participant recruitment page on the researcher's personal website.

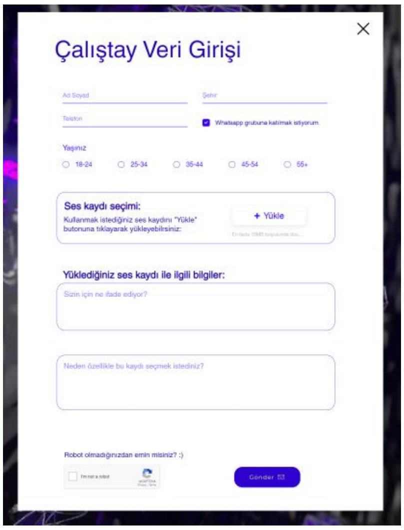


Figure 6.4 Participation form prepared for the participants to receive data.

Setting suitable time frames with participants

After receiving the initial participant contact information, I emailed all of the participants mentioning the required steps they had to take before the workshop began (Appendix D). In that e-mail, the participants are informed about installing Zoom and Parsec software on their computers. Also, I included the link to the form address (Figure 6.4) and requested an audio recording that connects to a memory of them which is also emotionally significant.

The workshop ran in parallel with the conference program. Thus, I had to arrange the timing to fit two days. While allocating time slots to the participants, I decided to give each participant one hour and fifteen minutes and arrange the schedule accordingly while giving 15-minute tolerances between the participants. I determined this duration according to my experience in primary studies. In primary studies, the personalization phase took around an hour. Because of the new interactive interface, I anticipated that the participants would be able to realize their preferences faster when compared to the conversational progression of primary studies. Therefore, an hour per participant sounded reasonable.

Connection tests before the workshop

As mentioned in the methodology part, before the workshops began, I had to make connection tests with the participants to ensure that everything was working and that they could install the required software for the workshop.

6.4 Phases of Design Workshop

The workshop had three main parts. The first part consists of a general introductory meeting to which all the participants were invited. Individual participant sessions make up the second part of the workshop, in which all the participants were interviewed with one-to-one remote connections in separate time slots. After completing all sessions, a group discussion meeting was held. All participants talked about their artifacts and the creation process. The following sections present more detailed information on these phases.

6.4.1 General Introduction Meeting

In this session, a general meeting was conducted with all the participants, although three of them could not connect to the meeting during the introductions. The session started with an introduction of every member of the meeting. Following my introduction of the transformation method and the interface, I showed the interface's features, how we could navigate through the interface, material changes, surface deformations, time, and other related settings. This introductory meeting took around twenty minutes, and the program schedule was explained.

6.4.2 Individual sessions

In these sessions, each participant was interviewed through the setup explained in Figure 6.1. Each session started with a five to fifteen minutes introduction to the interface and ensuring that everything was working fine in the connection and the user could control the interface without any problems. All the steps and explanations followed in the user sessions are presented in Appendix G, Design Research protocol. All participants registered for the workshop attended the sessions, which resulted in nine studies.

6.4.3 Presentation of Results and Group Discussions

On the second day of the workshop, after completing all the individual sessions, I created video animations that show the real-time generation of forms with sound for all resulting artifacts. I informed the participants that they would discuss their artifacts and their process. Seven participants attended this general discussion and presented their artifacts. The participants started by talking about the recording they brought and the meaning of these sound recordings. Later they explained the changes that they had made and their related train of thought. This session took about two hours.

6.5 Resulting Artifacts

The final results of nine different sections of the design workshop with different participants are presented in Figure 6.5.

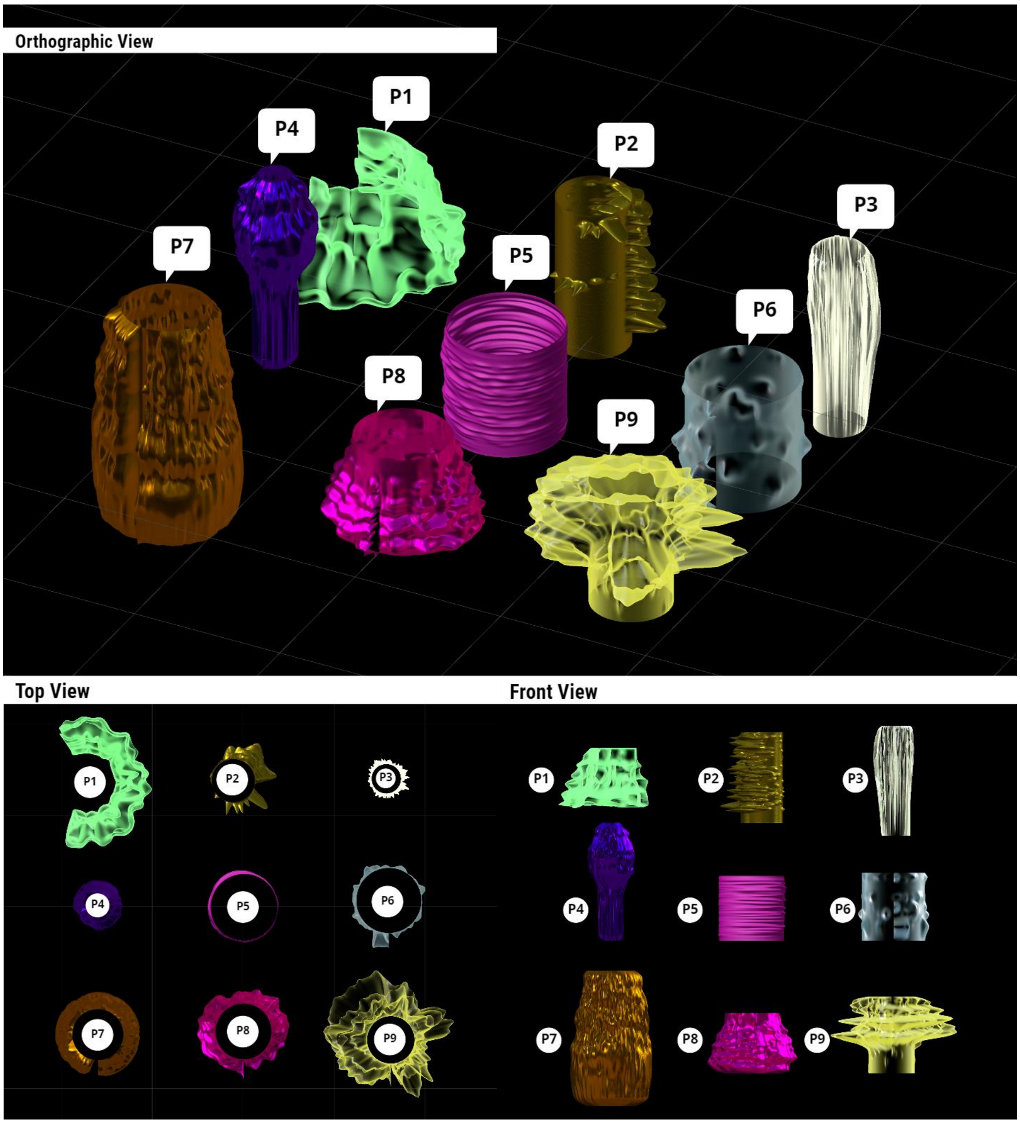


Figure 6.5 All resulting artifacts of nine participants through participant sessions.

All of these artifacts were personalized by different participants, and these resulting artifacts are saved after they mention that they are happy with the resulting form. Then all the separate artifacts are compiled into the same scene in Cinema 4D without changing dimensions or colors. Although they are in different scales when compared to each other, the ability to zoom in and out while personalizing these forms and the absence of any reference object around these forms for scale makes it hard to assess the accurate life scale of these objects. Therefore, the presented artifacts do not provide insights into the effects of scale on the perception of the artifact.

In the following nine figures, the progression of participant personalization is presented as contact sheet images. These images are generated from the video recordings of the workshop sessions with the participants. The videos start with an explanation of the interface and participants explaining the meaning of the sound recording for them. After some time, usually around 10 minutes, the participant is handed the interface control. So until the participant starts personalizing the form, I modify the form to illustrate the features of the interface. Each contact sheet image begins when the participants take control of the interface to eliminate frames coming from those moments. They begin personalizing the form by rotating the artifact and changing surface, material, and color parameters. During these changes, they are requested to think out loud while making changes and thinking of something. Also, they are expected to explain the reasoning behind their modifications. If they wander through the interface without doing anything, questions such as “What is on your mind” to probe possible insights are asked. On several occasions, this probing also allowed the researcher to help realize the participant what she wanted to do. After they stop making changes to the artifact, the timecode of that moment is recorded to determine the ending frame of the contact sheet image. In other words, these contact sheet images are like time-lapse shots of the form personalized by the participants. For each recording, the duration of interaction with the interface is divided into 30 frames. However, since the duration of interaction is different for each participant, the time interval between these frames for different figures varies. Also, it is essential to note that many frames exist between the images presented in each participant contact sheet. The presented images aim to illustrate the progression of the virtual artifact through the workshop interval. Therefore it does not show each change the participant makes using the interface. Between each frame in those images, there is around a minute of content that is not shown. However, as mentioned, these images are for illustrative purposes, which can function as visual summaries of the workshop sessions.

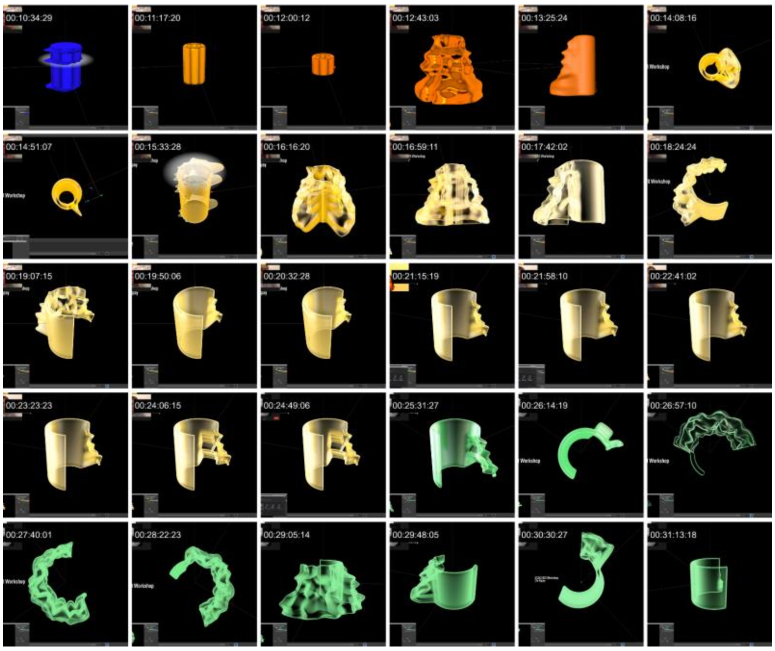


Figure 6.6 Form modifications done by P1 using the Interactive Data Transformation Interface (IDTI).

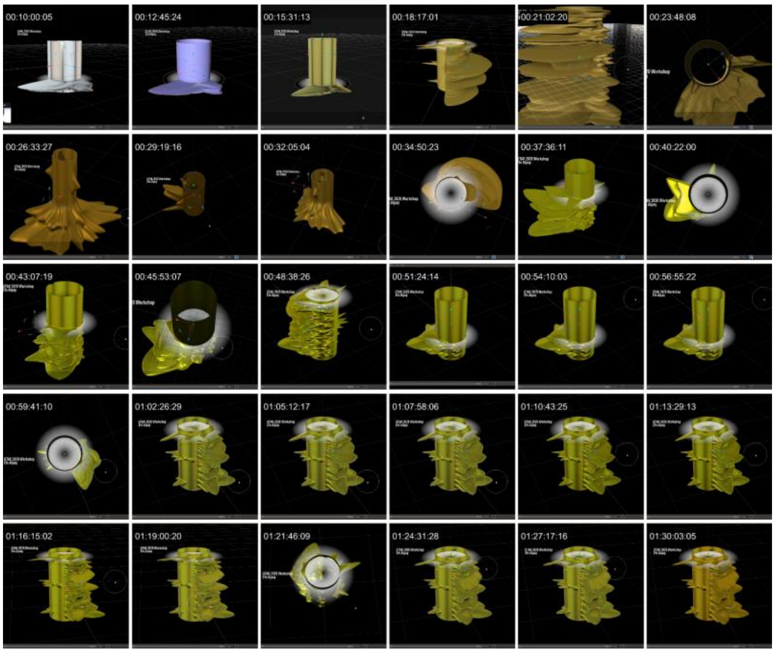


Figure 6.7 Form modifications done by P2 using the Interactive Data Transformation Interface (IDTI).

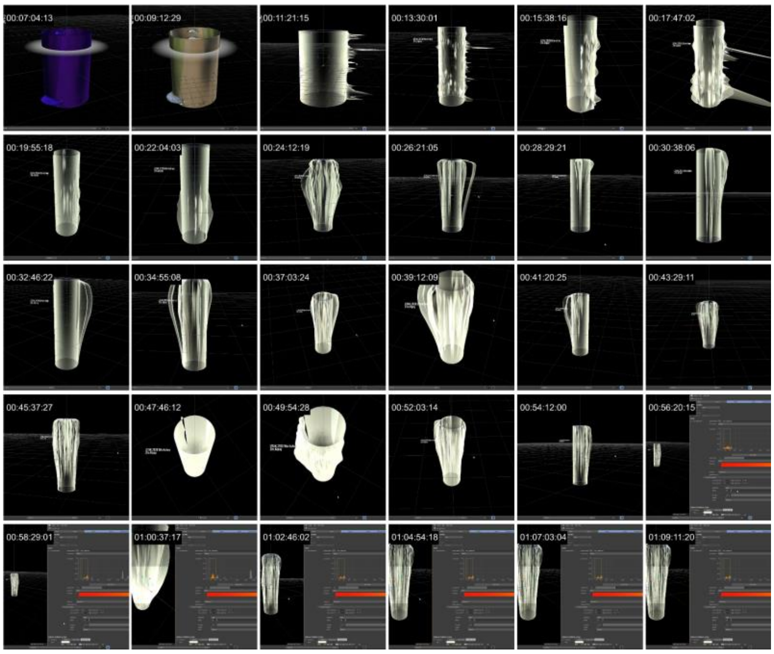


Figure 6.8 Form modifications done by P3 using the Interactive Data Transformation Interface (IDTI).

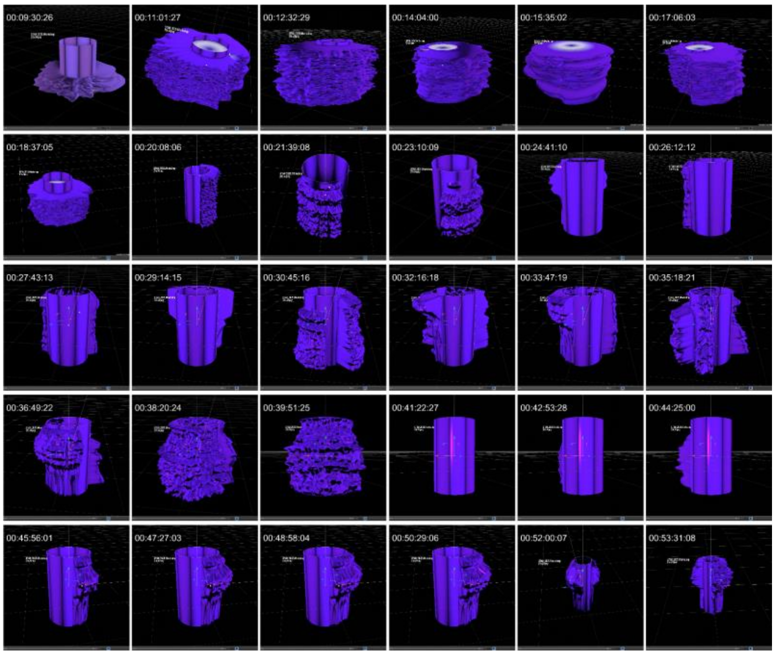


Figure 6.9 Form modifications done by P4 using the Interactive Data Transformation Interface (IDTI).

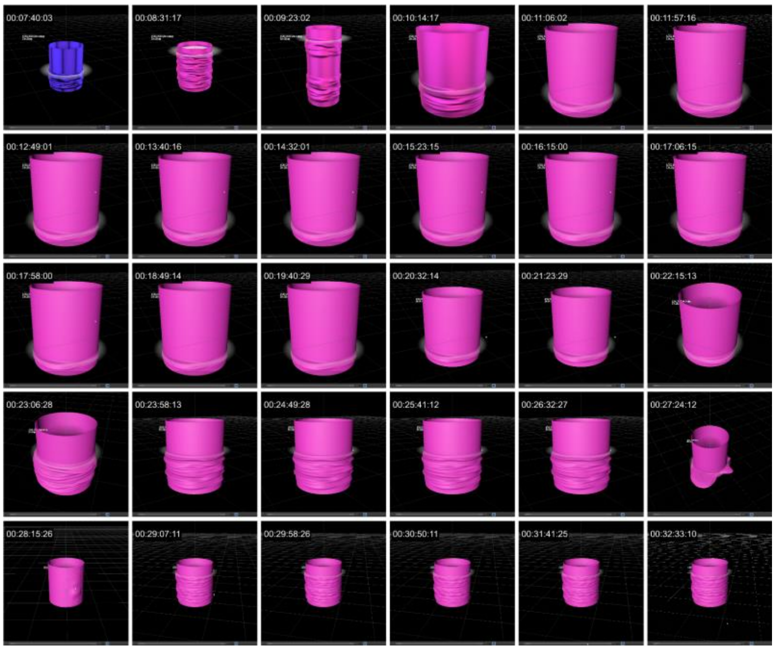


Figure 6.10 Form modifications done by P5 using the Interactive Data Transformation Interface (IDTI).

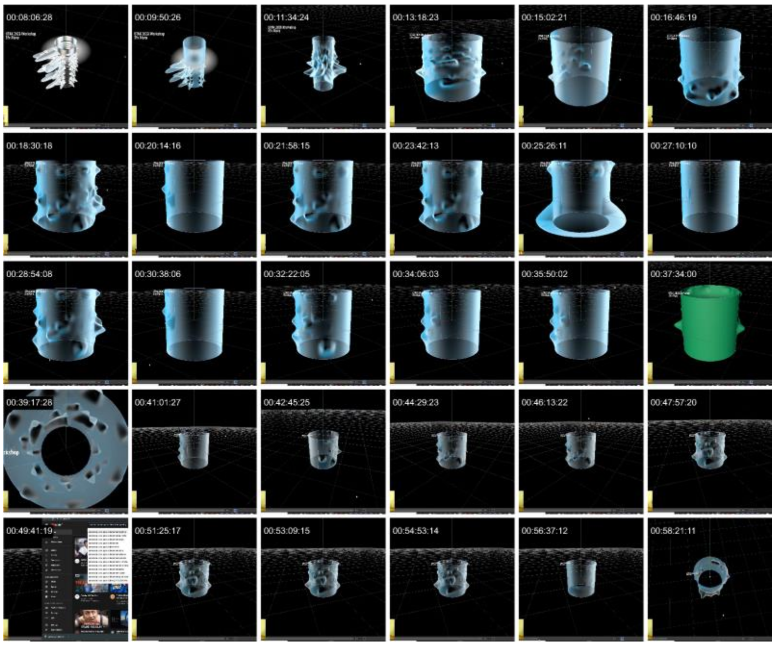


Figure 6.11 Form modifications done by P6 using the Interactive Data Transformation Interface (IDTI).

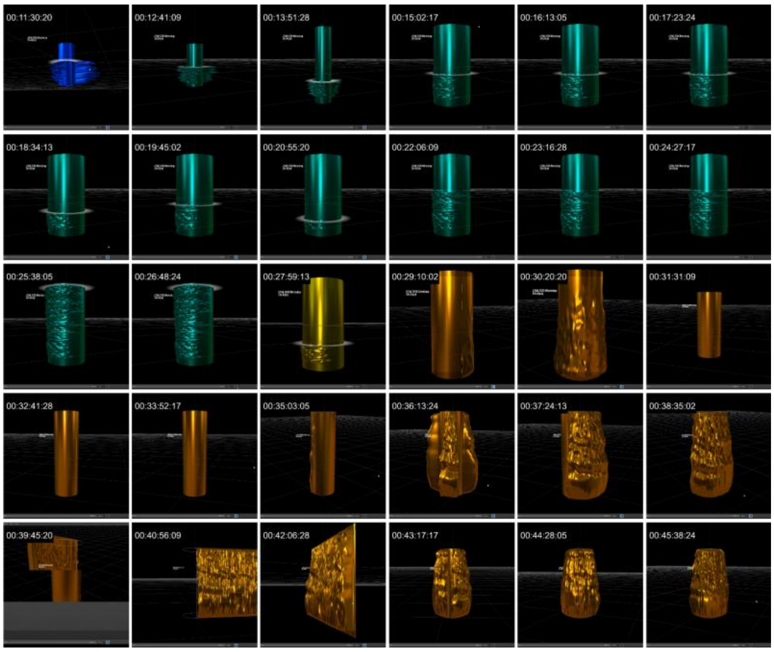


Figure 6.12 Form modifications done by P7 using the Interactive Data Transformation Interface (IDTI).

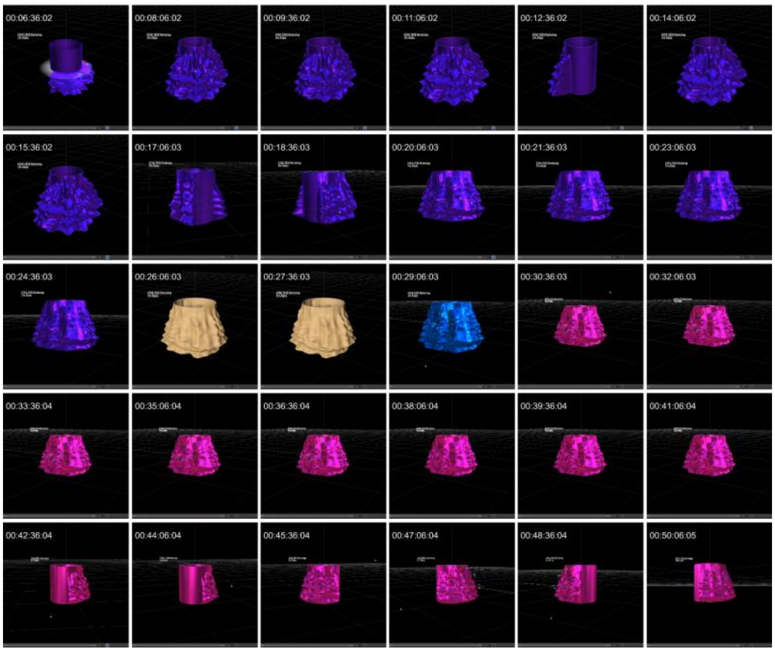


Figure 6.13 Form modifications done by P8 using the Interactive Data Transformation Interface (IDTI).

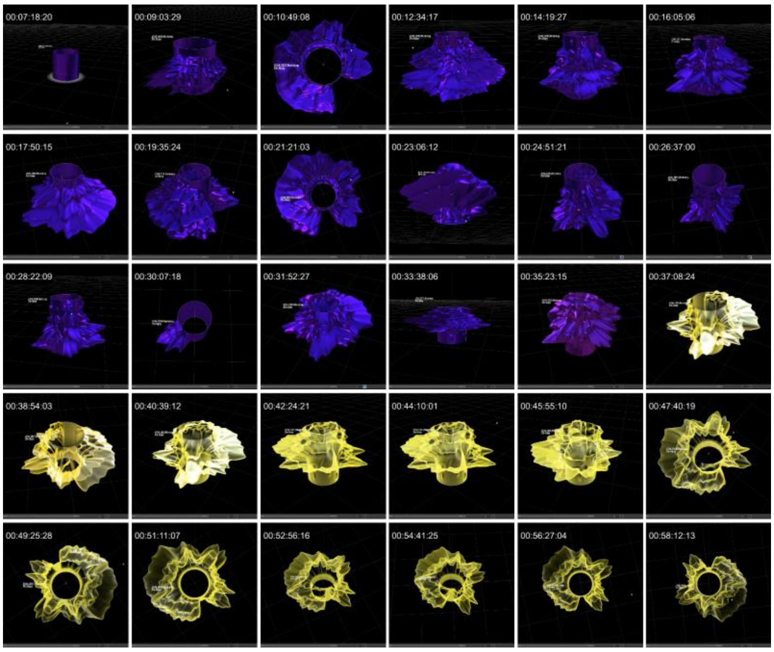


Figure 6.14 Form modifications done by P9 using the Interactive Data Transformation Interface (IDTI).

In addition to these summary images, another analysis method is used to compare the participant behavior with each other. Each workshop session video is placed in a three-by-three grid in Adobe After Effects (Figure 6.15). Their periods of user interaction are normalized against each other so that all the videos begin and end simultaneously. This allowed me to view and compare the number of changes the participants do over the form, such as when and until when they changed material properties, surface properties, and color. A screenshot from that video is presented in Figure 6.15.

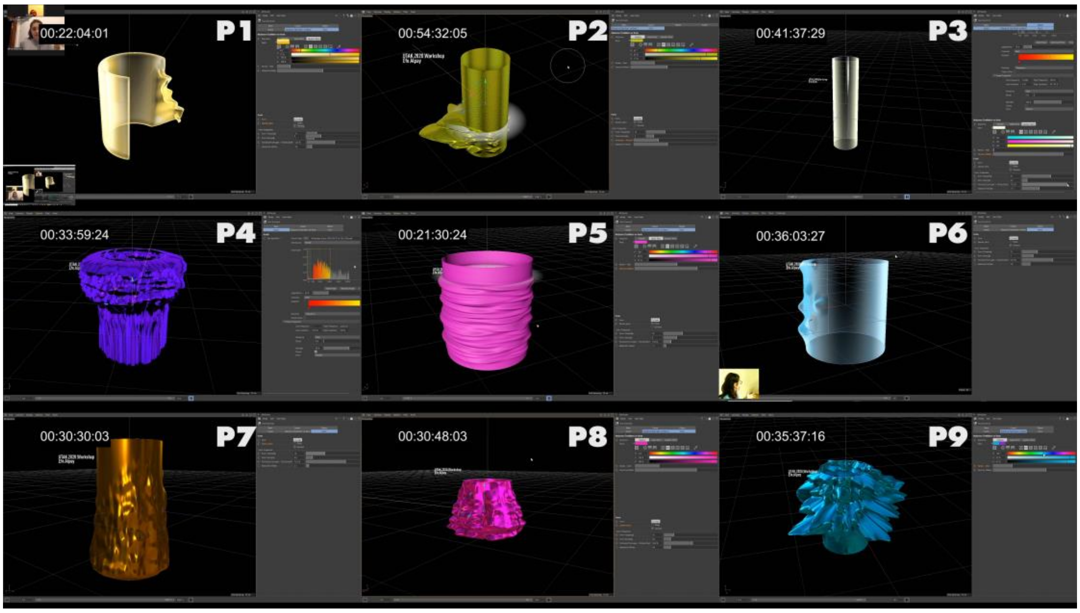


Figure 6.15 All participant sessions' video recordings are playing in sync.

Note that all the images have time codes and participant names on them. Also, in this video, the interface and participants' mouse movements are included to see which parts of the interface they use to make changes to the form.

It is important to note that there are other sections of the workshop sessions than the images presented here. The participants answer my questions in the remaining parts of the video recordings. While answering the questions, they look at the form from different angles, rotate, zoom in, and zoom out to *think with the form and audio*. Also, they are requested to think out loud during the modifications they make.

The following section presents workshop findings evaluated under the themes generated in primary studies. Also, participant responses and insights obtained from them are included.

6.6 Participant Responses

The sessions with the participants are recorded as video and audio files as mentioned in the 6.1 Methodology and Research Design section. Those recordings are then transcribed into a Google Sheets document. Most prominent participant responses related to the previously emerged themes are highlighted and summarized. This study section presents them under the related themes, which are then used to draw insights in the following pages.

In terms of a summary of the differences among the participant responses, some notable areas of discussion emerge. One difference among the participants is their personal experiences and memories associated with their chosen sounds. Some participants selected sounds that had personal significance and evoked specific memories, while others chose sounds that they found aesthetically pleasing or that represented a particular emotion.

Another difference among the participants is their preferences for the form of the object representing the sound. Some participants preferred circular forms, while others preferred vertical or more abstract shapes. Some participants also preferred specific textures or materials for the object, such as metal or clay.

There were also differences among the participants regarding the personalization options they preferred. Some participants wanted more options for personalization and adaptation, while others were satisfied with the available options. Some participants also preferred to add additional elements, such as color or texture, to the object, while others preferred the simplicity of the original object.

To understand the user responses better, a table that presents the meaning of the sound for the participant, kind of the chosen form, and participant comments related to the transformation process are summarized in the following table.

Table 6.2 Summary of participant responses

P#	Audio type	Significance for the participant	Sound recording content	Properties of Sound & Related Feelings	Sound-form (1-7)	Memory-Form (1-7)	Workshop-Form (1-7)
1	Speech of a friend in a bar	Memories with a newly met friend in a bar	her friend speaks, teasing her	friendship, warm, funny, personal	5	4	3 (states 7 as sum)
2	Sound of a video she liked	Reflect her, feels nature whenever she closes her eyes, reminded of her experiences in nature camps she has gone	generic bird sounds and bare feet running sound	warm, tickling	7	5	5
3	Ambient sound from a vacation in Datça	Reminds her of a place she has been on her vacation, freedom, being on holiday	sounds of a bottle installation with ambient sound defining the place she has been	Freedom	5 (technical limitations)	6	5
4	Ambient sound from her home (recorded for this workshop)	represents her noisy home in the city	Traffic sounds, prayer sounds, city noise	Familiarity, safety, exhausting	7	-	-
5	Personal voice recording (recorded for this workshop)	A story about her lost cat's giving birth, something related to her, making tangible something that she remembers inside	A narration of the things that happened with the participant's voice	Funny, happy, sad	7	No rating but mentions that reminds her of both the memory and the workshop day	
6	Animation film soundtrack	Childhood memories from the best summer vacation	Movie soundtrack music piece	Happiness mixed with Melancholy, calm, serene	6-7	5	7
7	Personal ambient recording (recorded for this workshop)	Ambient soundscape representing the university she lived for ten years with an unexpected sound, something from her	Nature sounds dominated by a helicopter passing by	Militarist, usual, disturbing, mechanical, irritating	7	No rating but mentions that reminds her of both the sound (slightly more) and the workshop day	
8	Song	A song she loves, and makes her emotional every time she listens, with no relation to her memories	Music piece with lyrics	Excitement, disappointment	2-3	7	7
9	Curling team cheering together	An exciting memory from a tournament she and her team attended and had new friendships	Team members counting 1,2,3	Encouraging, longing, happiness,	6	7	7

6.7 Workshop Findings and Insights from the Perspective of Prominent Themes

Compared to the primary studies in which all the participants were selected from people without CAD software knowledge, almost all design workshop participants (Table 6.1) were designers with related software knowledge.

6.7.1 Meaning

Many participants (P1, P2, P4, P5, P6, P7, P8) described their choices of sound and form as being influenced by personal memories or emotional associations. For example, P1 chose a sound recording of a friend because it reminds her of the sincerity of her newly met friend and the good times they had together, and P6 chose a sound form that brought back memories of a memorable summer vacation during her childhood.

Most participants found the transformation process and resulting artifact meaningful in the interviews. P1 mentioned that the process was meaningful because it allowed her to connect with their memories personally and creatively. P2 also found the process meaningful because it allowed her to connect with their past experiences and express themselves through the personalization options. P3 found the process meaningful because it helped her to reflect on their personal experiences and emotions and allowed them to explore new ways of expressing themselves. P5 found the process meaningful because it allowed her to revisit and reflect on old memories and also explore new ways of expressing themselves through the personalization options. P6 found the process meaningful because it allowed her to connect with their childhood memories and emotions and to explore the theme of loss and connection through the personalization options. P7 found the process meaningful because it allowed her to express her personal experiences and emotions through the personalization options. P9 found the process meaningful because it allowed her to express their creativity and personal experiences through the personalization options.

On the other hand, some participants did not find the transformation process or resulting artifact particularly meaningful. P4 mentioned that she does not have any context for the function or use case. P8 also mentioned that she did not find the process or artifact particularly meaningful because she did not have strong personal memories associated with the sound they chose.

As the participants spent time in the transformation process, they understood the process better. All the participants derived their own meanings related to the artifacts they had personalized with their sound data. It is seen that some are more strongly related to the memory connected to the sound, and some are related more to the process itself and the aesthetic choices they make during the transformation process, which were discussed in the previous *Aesthetics* title.

Connection to memory

The participants brought four types of audio recordings to the workshop. The first is a file they recorded for the workshop (P2, P4, P5, P7). The second is a recording from a past moment (P1, P3, P9). The third is music connected to past memories (P6), and the fourth is a piece of music that they liked and evokes emotions (P8).

P6 mentions that the object does not re-create the memory or help her remember the memory but remembers the emotions she had. When asked what it would mean if the artifact was manufactured, she states that she could create and own her childhood memory, which is a memory that she does not have anything else to keep.

P6 mentions that the flight ticket becomes more meaningful for her than a photo taken before or during a trip abroad. When she compares the artifact with a photograph, she mentions that photographs remind her of the exact moment the photo was taken. However, artifacts do more, according to her.

6.7.2 Clarity

Audio-visual connection

All participants mentioned finding the resulting form or artifact connected or related to the sound they brought, with varying meaning levels. For example, P1 reflected the warmth and sincerity of her friend’s speech with transparency and orange color. P2 described the sound as "warm and tickling" and chose a form that reflected those qualities, with sudden bumps and warm colors. P3 described the relationship between the form and sound as closely related, with the form representing the "rhythm and melody" of the sound. P5 also mentioned finding a strong connection between the form and sound, with the form representing the "notes" and "melody" of the sound. P8, on the other hand, mentioned finding the relationship between form and sound somewhat abstract and subjective.

P4 mentioned that a strong connection between the form and sound is lacking, stating that the form did not accurately represent the "complexity" and "dynamic" nature of the sound. However, that is later understood to be caused by some other variables in the process, such as frequency variations that create understandable differences on the form’s surface that can be attained by selecting different frequencies in the interface.

The participants' responses suggest that the connection between form and sound can vary and may depend on individual interpretation and subjective experiences. Some participants found a strong connection between form and sound, while others found the connection more abstract.

Degree of need for specific marks

One factor that affects the strength of the *audio-visual connection* is the amount or intensity of surface marks/bumps connected to the sound by the participant's perception. This need is evident in many of the participants.

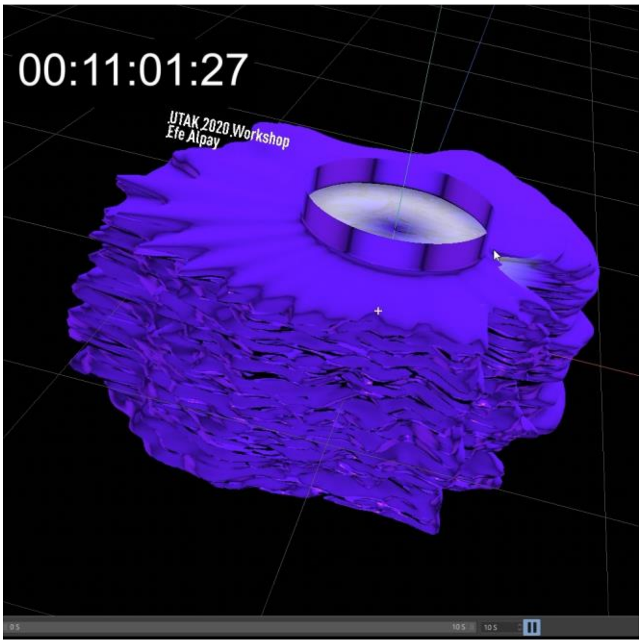


Figure 6.16 P4's form at the beginning of the workshop.

For example, P4 does not recognize the connection between the form and sound since the sound recording produces very homogeneous surfaces (Figure 6.16). This is very similar to the interview in which a helicopter sound was used (P7, Figure 6.17). A less obvious but very similar example related to the perception of surface marks and their connection with the sound recording can be given from the responses of P7. Although the participant did not mention that directly during the interview, she found connecting the surface bumps to the audio recording hard. This can only be understood after using the interface that lets the participant change the audio duration. The original sound recording she brought called relatively homogeneous surface bumps on the artifact's surface (Figure 6.17 Audio length 9.97 sec).

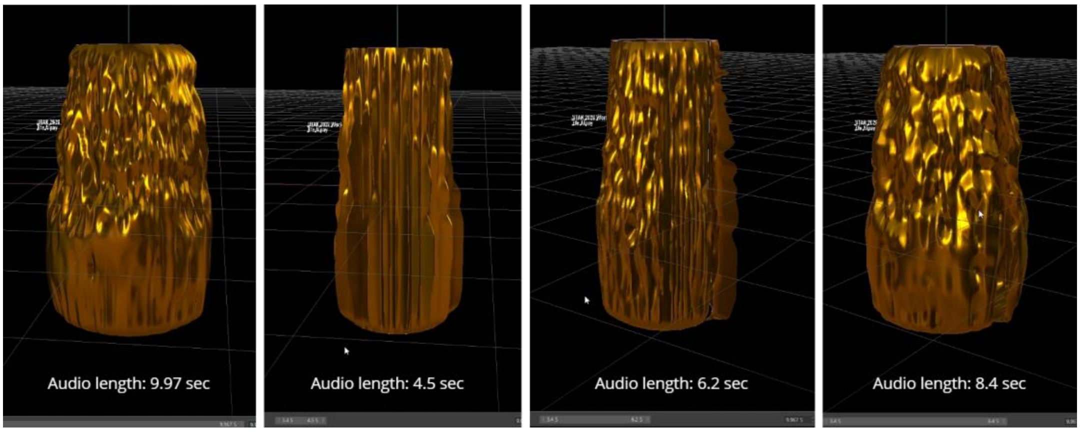


Figure 6.17 P7 changing the duration of audio recording

Then she was asked whether she would want to try shortening the recording through the interface since she has not played with that part before. She accepted this but mentioned that it would not change much. However, immediately after seeing the change (Figure 6.17 audio length 4.5 sec to 8.4 sec), she changed her mind, for she stated that there is an incredible speed and it stretches the intervals of waves. She stated that “the passage wave can be understood more.” About the relation of sound with form, she stated that since each wave is sensed more, the sound is reflected more on the form. In the end, she decided on the 8.4-sec version in Figure 6.17.

A completely different example can be given from P6's response. The song she brought had distinctive notes that also caused distinctive surface marks. In order to understand the importance of this, an unedited response from P6 is presented below:

> Basically, you can follow each individual note or the rhythm or the rise and fall of the sound, and you can also see this visually. Normally, you can also follow the sound wave by looking at it, but this is not a line or a two-dimensional thing. It's not just about something being high or low, but also about its position, for example, if something is lower or higher here, or maybe something else is happening here when it rises. So everything has a different meaning. To summarize, when we look at the normal sound frequency, we see a two-dimensional thing rising and falling. When it rises, the sound becomes very high or very high-pitched and suddenly becomes sharp, or when it falls. But I think it's hard to distinguish all the sounds like this. Even if I raise the sound from here, it still seems to rise. But there is something about this, it seems that each peak represents a different note. The way these peaks are arranged side by side instead of following each other represents something else. Some peaks are not in the form of a note, but rather follow each other, representing

> something else. All of this gives us information about music. But I can understand it because I can listen to and watch music.

In her responses, it seems evident that she has grasped that each bump on the surface is caused by a different frequency in the sound recording.

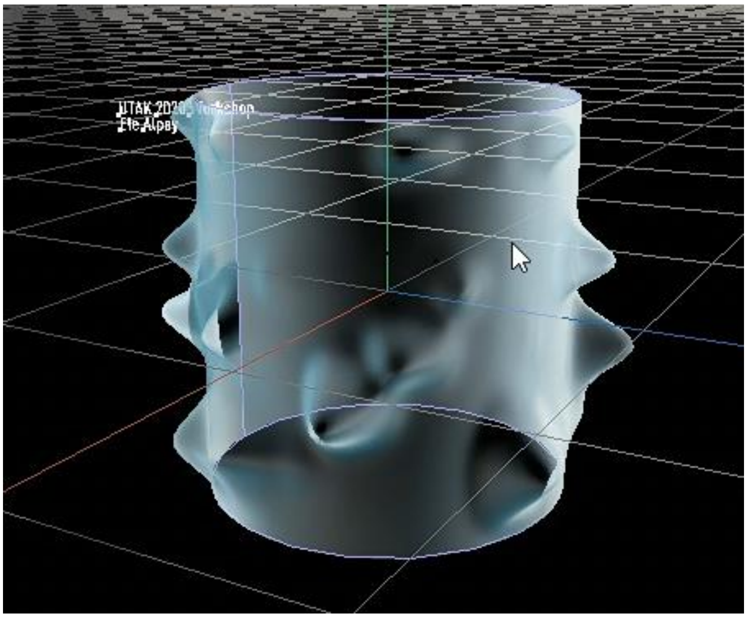


Figure 6.18 P6 response on the connection of surface bumps with sound.

This way of understanding the connection between sound and form enabled her to literally follow the song over the artifact's surface. This behavior is very similar to the primary studies in which P1 was able to follow the words that she recorded. In that way, each bump on the surface starts to represent a word of hers.

Role of rhythm in recognition of surface properties.

P2 tries to see the rhythmic sound of footsteps on the artifact's surface and establishes that after being able to select different frequencies. P5 connects her rhythmic talking to the rhythmic bumps on the artifact's surface. She states that she cannot exactly show which part of speech is which part of that artifact. However, she perceives a connection between them. Similarly, P6 talks about the rhythmic progression of the song and her being able to follow that progression on the form’s surface. After modifying the artifact form, P8 states that the rhythm establishes *eye-ear synchronization*.

Frequency Selection

In the initial design of the workshop, the participants were not allowed to change the frequencies of the found file to prevent any complex interface interactions. However, several participants (2, 3, 4, 5, 6, 7, and 9) asked for a way to select certain sounds from the recording. For some recordings, they mentioned that it is difficult to obtain any distinguishable surface textures. Upon similar requests, it is decided to show them the frequency selection part of the interface.

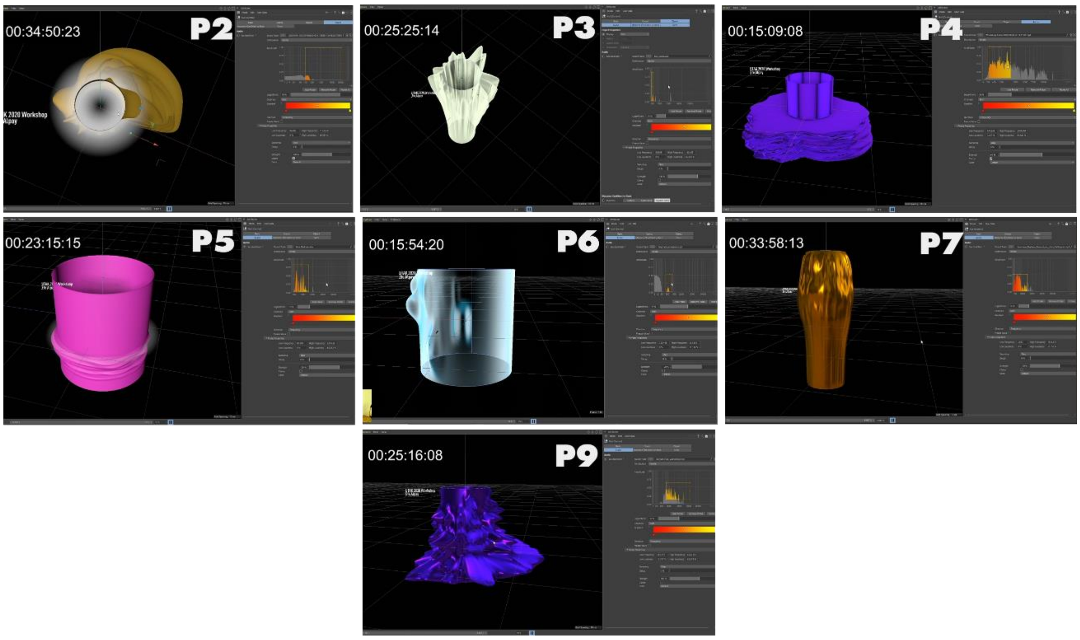


Figure 6.19 Frequency selection interactions of different participants.

Upon being able to select different frequencies, the participants realized that the surface form could be dramatically changed. Then, they started experimenting with different frequencies and tried transforming and emphasizing what they heard into what they saw. This process, in general, causes excitement in the participants.

Transferring perceived feelings from the sound to the surface of the form

The participants try to replicate the emotions and feelings they get from the sound recording and the memory to the artifact's appearance. It seems that color and material play an important role. However, they might already be taking the sound data for granted, so they do not specifically mention that. Still, more than one participant specifically mentioned that the sound is already generating the form. Hence, the sound data provides the starting point which is further personalized by the participant.

P4 notes that color is an important factor in personalizing/individualizing the object through sound and suggests that they would use darker colors for negative memories and metallic colors for exciting memories. P4 also mentions that the object's width is important and that she would use a narrow width for a suffocating memory and a wide width for a memory that she wants to allow something beautiful to enter. P4 also notes that proximity to the memory is important in this process.

Color and material properties are used by other participants also as strong signifiers of emotions and symbols for the meanings related to the memories the sound recordings represent. P1 relates sincerity and warmth with her color selections and transparency of the form, while P9 associates reflection amount and metalness with artifact and memory being "flashy" and shouting as "I am here." Since the memory P9 brought was not a milestone moment for her, she did not want to make it very flashy. During the process, it might be argued that P9 also thinks of how this artifact would get along with other artifacts if she were to create more.

P5 mentioned that the length of the sound recording does not significantly affect the form or meaning of the object but that the *sound's frequency and intensity impact the object's appearance and how it resonates with the participant*. P4 also stated that the form and sound are highly interconnected, with the sound influencing the object's smoothness, softness, and overall shape.

Some participants expressed confusion or uncertainty about certain aspects of the transformation process. P2 and P3 both mentioned feeling unsure about connecting the object's form to the sound's form. P4 and P5 also mentioned feeling unsure about the relationship between the object's form and the sound's form, with P4 noting that it was a difficult concept to understand. P8 mentioned feeling uncertain about the relationship between the object's form and the sound's form, stating that it is subjective. However, it is seen that as the interviews progressed, each participant managed to connect certain features of sound with the form in their artifacts.

6.7.3 Accessibility

There seems to be a consensus among the participants that the transformation process is clear regarding the steps and options available. P1, P2, and P3 all mentioned the clear instructions and layout of the interface, with P1 noting that it was easy to follow and understand. P4 also mentioned the clear layout and options for personalization, and P5 noted the clear representation of the sound through the visualization. P6 and P7 also commented on the clear instructions and layout of the interface, with P6 noting that it was easy to understand and use. P8 and P9 also mentioned the clear instructions and options for personalization, with P9 noting that the interface was intuitive and easy to navigate. P9 also mentioned that she could do things in her mind without asking the researcher. This was a critical involvement barrier in the primary studies since the participants needed the researcher’s agency to realize their preferences.

Participants 3, 4, and 5 wished for more expressive controls like sketching, painting, and hands-on intervention methods, while P8 suggested introducing some unpredictability to the form generation process. She points to the importance of using hands in the creative process and the potential for a deeper connection with the created object. P8 also discusses the possibility of adding features to the interface, such as drawing on the object or adding texture.

In contrast to these suggestions, P5 argues that when the participants are given too many options and control over the form for personalization of the artifact, it can be overwhelming since it would be harder for the participant to decide. Also, having many options can divert the user from memory, making the process more like an industrial design process.

6.7.4 Aesthetics

Many participants (P1, P3, P4, P6, P7, P8, P9) described the appearance and form of the object representing the sound as being important to their overall experience and interpretation. P1 described the object representing their chosen sound as being "funny" and "personal," and P8 described the object as having a "matte, dough-like surface" that gave off a sense of excitement and unexpectedness.

The progression of time over the cylindrical object property in the interface received severe attention from nearly every participant when concerned about the visual appearance of sound and its connection with the meaning of the sound for them. Some participants associated the cyclical mapping of sound to form with repetition, the cyclical nature of life, and loops. In contrast, some participants associated the vertical progression of sound and time on the surface with recordings that need to have a certain beginning and an end. However, in cases like P7's, although the meaning of the sound tells her otherwise, she prefers to map time in a cyclical manner since that seems more aesthetically pleasing to her.

While comparing the sound and surface deformations, P7 wanted to see the form generated without hearing the sound. At that moment, she realized that without sound, the perception of the surface becomes very smooth (although nothing is changed in the parameters).

Functionality

All of the participants searched for the function for the generated artifact. Some participants directly asked whether they could choose something else than the cylinder, while others tried to find some functions for the cylinder. Being from an industrial design background can be one source of this desire to find a function for the form. However, one graphic designer from this study and several participants from the primary studies also searched for functions for the generated artifact.

Getting away from the Original

Although this is connected with the meaning of transformation, it is thought to be more related to the aesthetic section. When the participants modified the form's visual properties, some were concerned about getting away from the original. The initial form shown at the beginning of the transformation process seems to create an "original" interpretation of the sound data. The primary study finding also pointed to this concern. However, one participant's comment in the primary study (P3, page 181) for modifying these resulting forms according to their esthetic preferences is like making covers to the songs, so she thinks it does not affect the original but reflects their own preferences. Still, connected with the following property in the paragraphs below, modifying the form triggers concern about getting away from the original. Thus, the initial representation of the sound data to the participant gains importance.

Getting Away from the Memory

When asked about seeing the artifact made of different materials, P5 responded that it would make her think from the perspective of product design and shift her focus away from memory. This gives insights into the workshop design, which normally does not have selection steps. However, introducing steps into the process, such as form generation with sound, material, and color, might help the user to keep his/her focus more on the memory by limiting him/her to make comparisons towards one variable at all times instead of multiple variables.

Form Selection

Several participants mentioned that the cylindrical form of the artifact was a limitation in the personalization process. P1 stated that the cylindrical form felt too rigid and did not allow for enough flexibility in the design. P2 also mentioned that the cylindrical form was too static and did not allow for enough variety in the design. P3 expressed a desire to have more options for the form of the artifact, including the ability to change the shape or add more complexity. P5 mentioned that the cylindrical form was too limiting and preferred a more organic shape.

The cylinder form is criticized by more than half of the participants. Still, it provoked the participants to find functions for an artifact they see as functionless, thus realizing its function in this research. Also, it provided some insights into the selection of the time dimension’s progression direction on the surface. Radial progression is mainly related to cyclical events and recordings related to atmospheric or ambient sound memories. In comparison, the vertical progression of the time dimension is connected to things the participants relate to with a specific beginning and end. Another decision criterion was the aesthetic qualities of the surface. In this case, the main selection criteria can be surface textures' richness, diversity, and significance. All participants wanted some significant features on the surface since it helped them to connect the sound with artifact form. However, some preferred them more significantly while some less.

The primary aim of choosing a cylinder during the workshop design was to eliminate any meaning and value that might be obtained due to the artifact's functionality. That decision seems to work well since most of the participants questioned the selection of the cylinder as a form and had difficulty giving meaning to the initial form. However, as the form was personalized with sound data and participant preferences, all the participants started to give meaning and value to the artifacts.

P8 finds the process, the connection between the sound and the form, too abstract. At the same time, she thinks that she enjoyed the process. She responded yes when asked if she wanted it manufactured as a physical object. Upon imagining some functions, such as a memento or a vase, and changing the function later, she mentions that she would like it. Also, she mentioned that she would not keep it hidden somewhere but rather keep it while showcasing it. The comments of P8 might point to a negative effect of the form selection in the study. Although the aim was to prevent function-related valuation of the resulting artifact, it might have hindered some feedback from the participants regarding different use cases and functionality since they might have had difficulty finding a function for such a process.

6.7.5 Social Clarity

Nearly all participants stated that this transformation process is highly personal, and an outsider can not understand the meaning. P2 also mentioned that the form could be interesting for an outsider because she has not seen anything like this. The responses are in line with the previous study responses.

6.7.6 Permanence

All participants argue that transforming sound into a tangible form increases the permanence of the related memory. This happens in several ways. One is making it durable and lasting (P5) through its transformation into a tangible physical artifact. The other is placing the memory in sight so that through continuous seeing and remembering the memory, it is reinforced in memory (P1, P5). Sound, as perceived by the participants, usually has an ephemeral nature. Thus, converting memories related to hearing into seeing brings permanence.

Upon being asked about the manufactured artifact's difference from a photograph in terms of memories, P6 compares the two and states that photographs are two-dimensional and trapped in frames. This, for her, gives the feeling of a finished and old event. In contrast, this *three-dimensional artifact lives in our environment and has multiple faces*, so there are more ways of interpreting them.

Multisensoriality

Almost all participants mentioned that being able to see and hear the form and sound is much more effective, which also relates to the permanence of the memory.

6.8 Insights

Primary research in Chapter 3 provided many insights into developing this interactive data transformation interface (IDTI) used in the workshops. Although many expected results arose from the participant responses, new insights that have been made possible by the greater involvement of the users in the process are presented below under related themes.

6.8.1 Meaning

Many participants (such as P1, P2, P3, P5, P7, and P9) mentioned that the meaning of the sound was important to them, and they chose sounds that had personal significance or evoked strong emotions. P4, P6, and P8, on the other hand, focused more on the sound's technical aspects, such as the melody or rhythm, and did not mention the sound's meaning as a primary factor in their selection.

The meaning of the sound participants selected and their relation to that sound appears to be an important factor that determines the meaning and value of the resulting artifact. When the recording they chose is not that personal or connected to a meaningful/emotional/personal memory, then the resulting artifact and its meaning seem to be less than the other participants' artifacts. The primary studies also had a participant who selected a music piece that was the least personally significant recording among the participants.

As observed from multiple participants, parallel to the primary research findings and parallel to the related literature, *the meaning and value of the artifacts increase as the participants invest their time and effort into the process*. P5 especially mentions the efforts she put into the process, although the recording she brought does not have a strong connection to a memory. When the participant responses are examined with the type of sound recording they have brought, there is a significant difference between the type of memory they are related to. Some participants have brought sound recordings that are newly recorded by the participants to be used in this workshop (P4, P5, P7). Other participants, however, brought recordings of past events that time has passed, so those sounds become reminders of memories, while these newly recorded ones are more related to the memory of this workshop. Those participants who brought new recordings were the ones who struggled with the meaning and value of this process. However, after time passed and towards the end of the workshop, they started to see value and meaning in the resulting artifact. That value and meaning come from investing time and effort into the artifact, which the meaning and memory of their sound recordings reinforce.

The type of sound recording the participants brought affected the valuation of the artifact and its meaning. The participants who brought recordings without strong connections to past memories had difficulty giving meaning to the artifact and the process in the beginning since the source data did not have a value coming from any memory. However, as the workshop progressed, and they invested their time and effort while reflecting on their personal preferences through the interactive interface, the result started to gain meaning because of the common history with the artifact, self-reflection, and expression of their identities through the preferences they realized.

As mentioned in previous sections, *the participants modify the artifact forms to reflect how they perceive the sound and the memory*. The emotions that sound recording evokes are also translated during this interpretation and reflection process. Thus, as P6 mentions, the resulting artifact becomes a representation and a reminder of the participant's emotions for the sound recording.

Another insight from P6’s responses about her becoming able to create and own her childhood memory as an artifact to keep is that this process allows the creation of tangible representations for the memories she does not have mementos. Thus, it enables a method to create representations of personal histories selectively.

For P6, a photograph might be a quantitative representation of the moment. However, an artifact related to a memory contains personal expressions and interpretations of that memory since it leaves room for imagination. Therefore, in terms of meaning generation, artifacts that are reminders of personal memories can contain a different layer for meaning-making process.

6.8.2 Clarity

From the participants' responses, it can be understood that the connection between form and sound is highly subjective. This high subjectivity makes sense since the meaning is generated in the minds of the perceivers. While modifying these forms, the participants continuously try to obtain the things they perceive from the memories and reflect those perceptions onto the form generated by sound. This is called *Translating Sound’s Perceived Properties into Form* in primary studies' themes. It can be argued that with the completely interactive interface, the participants became much more experimental about the form and material options since they could do many changes without asking the researcher (P9).

From P5’s comments, it can be understood that the feeling of rhythm in sound and form surface is one factor that connects in the participant's mind. This becomes more important in the cases in which the participant has a hard time seeing distinct connections between performance sound, but rather a general interpretation is made as both being rhythmic, which is what connects them. This might become significant for sound recordings without any perceivable frequency changes throughout their progression.

6.8.3 Accessibility

It is observed that the new design of the transformation method that allows participants to realize their decisions without researcher intervention greatly enhanced the accessibility of the transformation process. It decreased the amount of communication and increased the amount of self-reflection, allowing more data on the transformation process to be collected.

6.8.4 Aesthetics

The progression of the interviews among the participants had some instances where the participants had a hard time deciding how to proceed. Especially when a participant was to decide between sound's meaning coming from memory, most of the time, they had to think from two perspectives. The first is from artifact aesthetics and related meanings perspective. Second, the meanings are coming from the memory and their visual representations perspective. Then, they had to think about how these two perspectives could work together. When the meaning and aesthetics-led aspects of the transformation were in harmony with each other, there were no problems. However, when these two perspectives start to differ, some participants especially mention that they have difficulty deciding which one to choose. An in-depth analysis of how this conflict between aesthetics and meaning affects the resulting artifact's overall value is not possible from the data in this study. However, it can be hypothesized that when conflict arises, it might affect the value and meaning of the final form in a negative way compared to when meaning and aesthetics are in harmony.

Many participants (such as P1, P2, P3, P4, P5, P6, and P8) mentioned aesthetics as an important factor in their selection of sounds. P7 and P9 did not mention aesthetics as a primary factor in their selection and focused more on the sound's personal significance or emotional impact. P7 and P4 realize that the sound choice is unsuitable for the visualization since it creates repetitive surfaces that are hard to distinguish.

The Conflict between Aesthetics and Meaning

This happens to several participants, such as P7, the one with the soda bottles, and P2. Their aesthetic preferences sometimes contradict meaning-wise preferences, like reflecting the meaning coming from this sound to the visual properties of the form. P7 decides to focus on the meaning-wise aspects of the form and because of that, she prefers to map this sound in a radial form which enables her to perceive the sound recording without beginning and end.

The function of sound in the transformation process

There was a range of views on the function of sound in the transformation process. Some participants saw sound as a central component of the transformation process, with P2 and P4 explicitly mentioning the importance of sound for conveying emotion and evoking memories. Others, such as P1 and P3, saw sound as a secondary element, with the focus being more on the form of the object. P7 and P9 both mentioned the role of rhythm in the transformation process, with P7 focusing on the relationship between the rhythm and form of the music and P9 considering how the rhythm could be conveyed through changes in volume and intensity.

In P7's case, the sound and the form complement each other. The sound consists of a helicopter blade chopping the air. So it acts as an emphasizer for the bumps on the surface of the artifact. And when that is removed from the sensory perception of the participant, the sharpness of the surface remains insufficient. Therefore there are two ways of perceiving the artifact, one multisensorial, and the other mono-sensorial. P7's comments point out a difference between the two perception modes. Thus, the aesthetics of transformation is strongly connected with the meaning of transformation that comes from the meaning of the sound memory for the participant.

Emotional Resonance

The participants in this study continuously try to match their interpretations of the sound and memory to the aesthetic preferences of the form that is generated. However, since each decision related to the memory and sound interpretation changes the perception of the artifact's aesthetics, this performance works like a dynamic equilibrium. In other words, each change in the form related to its appearance is evaluated by the participant against the sound and memory's meaning. Each change done according to the sound and memory's meaning is evaluated against the participant's aesthetic preferences. When both preferences *feel in* *harmony for the participant*, the equilibrium is reached, and the user is satisfied with the result. This thesis defines the state where this equilibrium is reached as *emotional resonance*. In other words, *emotional resonance* means the *synchronization of meaning-wise and aesthetic preferences of an artifact so that it resonates with the participant and evokes* an *emotional response*.

6.8.5 Social Clarity

As in the primary studies, nobody thought an outsider could understand this. However, it is interesting that nobody has stated any concerns about this issue. The reason might be that the source sound recordings have highly personal meanings related to them. If there were sound data related to a public event, like Gilles Azzaro's Third Industrial Revolution sculpture in the examples (section 2.9.1), some arguments could have arisen.

6.8.6 Permanence

There is a consensus among the participants that transforming a sound connected to memories makes the memory more permanent. Moreover, it reinforces the memory since it increases the chances of remembering that memory more. Also, making it a three-dimensional artifact allows it to be approached from different angles, allowing it to be interpreted in different ways while making it live in the current environment of the participant instead of being "trapped" inside frames. These insights seem consistent with literature about *data physicalization* literature (Dragicevic et al., 2019; Dragicevic, Yansen, Moere, 2019; Wang et al., 2019), explored in chapter two. However, the insights from the participant responses add a new dimension to that by introducing personal sound memories into the data space.

6.9 Summary

This chapter has examined the use of an *interactive data transformation interface* (IDTI) in workshops, with the aim of exploring the connections between sound, form, memories, and meaning. The results of the workshops showed that the connection between form and sound is highly subjective, with the meaning being generated in the minds of the perceivers. The IDTI allowed the participants to be more experimental with the form and material options, and some participants focused on aesthetics while others focused on the personal significance or emotional impact of the sound. There was a range of views on the function of sound in the transformation process, with some participants seeing it as a central component and others as a secondary element. The study also highlighted the importance of sound in conveying emotion and evoking memories.

This chapter also discussed the conflict that can arise between aesthetics and meaning and the impact this can have on the value and meaning of the final form. Some participants had difficulty deciding between the meaning and aesthetics of the transformation, and it is hypothesized that when these two aspects conflict, it may negatively affect the overall value of the resulting artifact. The study found that the IDTI successfully allowed the participants to express their perceptions of sound through form by creating meaningful and valuable artifacts connected to the memories related to the sound and want to be kept by their creators.

In the next conclusion chapter, I will further examine and discuss the results of the primary research and design workshop and explore the connections between sound, form, and meaning in more detail. I will also discuss the implications of these findings and insights for the use of IDTIs in future workshops and research.

CHAPTER 7

CONCLUSIONS & DISCUSSIONS

This thesis develops a transformation method (and its dimensions) to create personally meaningful and valuable artifacts to establish emotional bonding to the artifact through the usage of personally meaningful memories (connected to sound data in particular). To develop the transformation method, the literature for creating meaning and value is first explored. In creating meaning and value, personal memories (autobiographical memory) are seen to have great potential. The implications of using data as material for creating meaningful artifacts remain unexplored due to lacking knowledge about what happens to the meaning coming from memories during their transformation into tangible artifacts. The transformation method this thesis develops aims to understand how this transformation of memories, related meanings, and value to the artifact happens and to what extent it creates personalized and meaningful artifacts. After the transformation process (and its dimensions) is understood, this knowledge can be adapted to the design process and different product categories since the foundations of the meaning and value transfer are understood.

This thesis borrows *embodiment* and *data mapping* concepts from the *data physicalization* field. It discusses the benefits of transformation from an intangible domain (hearing) into a tangible domain (touching and seeing) through the lens of *data physicalization*. This thesis sees audio recordings (connected to personal memories) as data to transform memories into tangible artifacts. Using computational tools, it transforms sound into three-dimensional artifact forms. For the development of this process, it uses two different user studies. The first one is to design a prototype transformation protocol that involves users in the process. Through semi-structured interviews, it obtains insights, and through thematic coding and analysis, it generates themes which lead to determining the various dimensions of this transformation process. The obtained insights and the dimensions guide the design of the *Interactive Data Transformation Interface* (IDTI) used in a design workshop setting to test and gain further insights about the method developed.

The dimensions of the developed transformation method are presented in the following table.

Table 7.1 Dimensions of the Transformation of Personally Meaningful Data into Three-Dimensional Forms:

Main dimensions	Definition
Clarity	Determined by the extent of the transformation is understandable by the participant.
Aesthetics	Determined by the visual characteristics and connotations of the artifact that is created as a result of the transformation method.
Meaning	Determined by the connection of the data source (sound recording) to participant memories.
Social Clarity	Determined by the understandability of the artifact and transformation by outsiders.
Permanence	Determined by how the transformation process makes the memory and the connected sound more permanent.
Accessibility	Determined by the ease of use of the transformation process, the degree of usability of the process unattended.

In the following sections, research questions and answers of this thesis to those questions are presented while also relating them to the dimensions presented in Table 7.1 above.

7.1 Revisiting Research Questions

7.1.1 Q1: What are the main design approaches for meaning and value and what would be the role of *memories and personalization* in creating personally meaningful and valuable artifacts?

Throughout the thesis, the term artifact has been specifically used to focus on the personal meaning and value of the artifacts rather than the financial value that might be related to products. Therefore, this study and the developed transformation method consistently use a cylindrical object that is *personalized with memory-connected data* coming from the participants to *focus on the meaning and value coming from the memories and the process* rather than those that might come from the artifact's function.

In order to develop meaningful and valuable artifacts, the ways they become meaningful are explored. There are different sources and kinds of meaning and value in artifacts: *cultural meaning, biography of objects, common history, symbolic meaning, private* and *public meaning*.

Mugge (2007) explains different ways for artifacts to become meaningful in her study, and from those, meaning sources below fall into this study's focus:

- Identity expression
- Representation of interpersonal ties
- Evoking of enjoyment
- Symbols for personal history
- Symbols for cultural-religious meanings
- Symbols for human qualities and personalities

When the artifact has symbolic meanings that are not present in any other artifact, then it becomes irreplaceable (Schifferstein & Zwartkruis-Pelgrim, 2008). A common history and work with an artifact make its relation to its possessor unique and irreplaceable (Raz, 2001).

Memories play a significant role in developing meaning and value in artifacts because they help to create emotional and personal connections to the artifact. When an artifact is associated with memories, it becomes a representation of the possessor's personal history and experiences, which can increase their attachment and emotional bonding to the artifact. This is especially true for souvenirs and heirlooms, which are often acquired to remember a specific experience, place, or event. Additionally, the embodiment of memories in an artifact can happen in the cognitive domain, where the artifact serves as a trigger for personal and shared memories, or in the physical domain, where the artifact shows physical signs of events or experiences that intensify the remembrance of those memories. Therefore, incorporating memories into the design of an artifact can increase its meaning and value for the possessor. Memories, in particular, is one of the design strategies in emotionally durable design (Chapman, 2012) and have the potential to create meaning and connection between the artifact and the user.

Emotionally durable design (EDD) is a user-centric approach that aims to increase the longevity of products and reduce waste by understanding the emotional factors that contribute to the consumption and disposal of these products. EDD seeks to create products that are desired to be kept for their emotional, as well as physical, lifetime. Strategies for establishing emotional longevity in products include creating memories, pleasure, enjoyment, self-expression, usability, sensory design, appearance, utility and reliability, product personality, and group affiliation.

The meaning and value of an artifact can be affected by the time spent (and memories related to them) with it and the shared history and work invested in it. Artifacts that are connected with memories can provide a sense of continuity for the self and create value through the meanings generated by the union of memories associated with the artifact. Heirlooms, or treasured possessions that are passed down through generations can illustrate the potential for memories to create meaning and value when embedded in artifacts. However, designing heirlooms can be challenging as the ways in which an artifact achieves heirloom status is highly idiosyncratic and depends on the meanings and memories it holds for different people. Artifacts can also serve as memory cues, triggering the recall of specific memories or events. Personalization, or the ability to customize an artifact with personal meanings and memories, can increase the emotional value of the artifact and facilitate the creation of a unique identity.

7.1.2 Q2: How can data in the form of sound be transformed into artifacts by adopting the *data physicalization* approach? What would be the *nature of user involvement* in creating personally meaningful and valuable artifacts?

While trying to find ways to transform sound into meaningful artifacts, the focus of the examples search was very blurred. Since I was mainly interested in sound and the memories connected to it, I was searching for sound visualization examples. However, while searching for creative applications related to sound visualizations, I came across the *data physicalization* field.

Data physicalization involves creating physical representations of data to aid in various cognitive processes, such as communication, learning, problem-solving, and decision-making Jansen et al. (2015, p. 3230). These physicalizations use tangible displays to represent numerical and abstract concepts, which can help with reasoning, remembering, and communicating these concepts (Dragicevic, Yansen, Moere, 2019, p. 127). They also serve as tangible or external memories and support remembering and reflection through multiple senses (Karyda, Lucero & Mekler, 2021). Data physicalizations can evoke emotional responses, allow more freedom for information encoding in a perceivable form (Dragicevic et al., 2019, p. 127)., and enable data to live in the physical world (Chiang, 2018). They can create a more engaging and memorable experience (Vande Moere, 2008, p.469), even if they do not convey detailed information. They can introduce an emotional connection (Wang et al., 2019) through different materials. The combination of making and collecting artifacts with the tangible nature of data can create more engaging experiences and deepen the connection and attachment to the artifact (Mugge, 2007). Data physicalizations can also have a self-expressiveness value for people, allowing them to express their identities and create a sense of ownership (Butz et al., 2017, p. 86).

This realization and the related literature enabled me to see the sound as a type of data and use the *embodiment* and *data mapping* concepts (2.7.2 Embodiment in the Representation of Data in Physical Artifacts) in the data physicalization literature to explain how the transformation from sound to artifact happens. The *embodiment* of virtual and physical components in data-oriented artifacts is an important aspect of data physicalization. This involves making abstract concepts more visible and tangible using *data mapping*, which translates data into representations using familiar metaphors. *Data mapping* aims to help people understand unfamiliar concepts by relating them to something familiar.

According to Zhao & Moere (2008) and Moere & Patel (2009), the embodiment model has three different modes. *Indexical, iconic, and symbolic* relationships define the distance between the data (signified) and the representation (signifier). The distance increases from indexical to symbolic relationships, making the understandability of the physicalization harder. In other words, symbolic relationships require an explanation to be understood by the perceiver. However, it is the most flexible embodiment type since any artifact can be substituted for any data as long as a description establishes a symbolic relationship between them.

As I argued in the previous paragraphs, data physicalization involves creating physical representations of abstract data connections. Thus, the principles and techniques from this field can be applied to product design to connect memories (data) with artifacts. Sound data, in particular, can be a particularly rich source of data for designing meaningful and valuable artifacts, as it is widely available and can be quantified, digitized, and sensed with relative ease (Bijsterveld & Dijck, 2009). Sound data can also be multisensory when transformed into visuals and forms, enhancing the overall experience. Sound, as a data source, can potentially contain an individual's memories and emotional associations. By using sound as a starting point for design, individuals can create artifacts that have a deeper personal meaning and significance for them, as illustrated in the design workshop in this study.

Since this thesis is concerned with a more foundational understanding of a transformation method that can be used in creating meaningful and valuable artifacts, the *symbolic* relationship appeared to be the most flexible option among them. Because *if a method could be developed to create meaningful symbolic relationships with one kind of data, then it can be applied to many different types of data*. However, indexical and iconic relationships require a tailor-made approach for each artifact-data connection since the conceptual relationship between them would require a different approach. Moere & Patel (2009) gives an additional example of symbolic representations as abstract symbolic data sculptures, mainly more aesthetically pleasing artifacts with sculptural qualities.

However, with the symbolic relationship approach, there was a problem with the understandability of transforming meaningful data (sound) into an artifact form. *Since the conceptual connection between the data and the form is loose, a description has to coexist with the artifact*. This problem is solved after exploring related examples and their meaning generation potentials in Chapter 2, section 2.9, Data Physicalization Examples.

In section 2.9, I have explored *data physicalization* applications and their implications on meaning creation and understandability by the users. I used the main difference between the explored examples from the perspective of this thesis as a way of categorizing them: the nature of participation of the user. There are various examples, from art-based exploration projects to advertising and Kickstarter projects to academic papers. I approached them from a user's perspective and discussed how meaningful those examples are from the perspective of meaning creation and understandability by the user. I realized that understandability is very closely related to the nature of user involvement in the process of transformation, which resulted in three different categories of participation:

- Inactive Participation: Observer (2.9.1)

- Deferred Active Participation (2.9.2)
- Real-time Active Participation (2.9.3)

Inactive Participation: Observer category contains examples mainly from artistic explorations and design studio projects. The main characteristic of this category is the user is the observer in all these examples. S/he has no chance to be involved in the process. In some cases, even the explanation is not there. However, as seen in *Sound Surfaces* and *Samba Stool* projects, the designers/artists also felt the need to prepare explanatory videos to communicate what is happening in their work. The users in the examples in this category can only participate cognitively by meaning-making.

The *Deferred Active Participation* category contains examples in which the user can participate in the creation of the artifact. However, s/he sees the results of his/her performance in a deferred manner. The examples in this category are collected from data physicalization, HCI, and TUI literature, an iPhone application, and an awareness campaign for Parkinson's disease. The main difference between the examples in this category and the previous is that the processes used in these examples allow the participation of the user with his/her personal data. However, there is a disconnect between the input data and the output artifact. *This disconnect prevents the user from making a cognitive connection between his/her data with the artifact*. Of course, there are explanations and presentations about the result. However, the user has to trust that some sophisticated technology has made the outcoming artifact without the participation and control of the user. This disconnect and shutting the participant off from *the moment of transformation* (2.9.4.2 Moment of Translation) causes a severance in meaning transfer. For example, the *Aura Pendant* application (Figure 2.12, page 69) that generates personal accessories from the user's voice and heartbeat data illustrate the argued severance very well in distancing the user from the generation of the artifact. The user records his/her data, and after s/he passes to the next step to see the generated pendant, s/he is faced with a loading screen-like interface, which generates the artifact in the background without letting the user see it. Then, out of nowhere, the artifact appears on the screen without being able to understand (2.9.4.1 Understandability/Clarity of Translation) how and why these intricate forms are generated.

The understandability of data from the resulting artifact is greater in another example from the same category. The *Fantibles* (Figure 2.16, page 75) research project (Andres et al., 2016), conducted in India, aimed to create physical artifacts for fans of cricket teams to commemorate and reminisce about matches. The researchers designed a method to transform match data and Twitter data into 3D-printed artifacts called Fantibles, which combined the match scores with participants' tweets about the match and their excitement levels. These artifacts allowed frequent engagement with memories of the match and personalization and self-expression for the participants. The inclusion of tweets on the artifacts triggered self-reflection and facilitated remembering significant match moments according to their emotions. Although the user in this process did not see how the transformation occurred, there is a significant difference between the Aura App example and this: the understandability of data from the resulting artifact. Although both examples use abstract representations of data as an artifact, the user does not have clues about how to decode the data on the pendant and make a meaningful connection between the data and the artifact. However, the Fantibles artifacts connect match scores with tweet amount and relate them with each other in the artifacts so that a viewer with a brief explanation of what that artifact represents can make meaning out of the artifacts.

Real-time Active Participation category includes examples from various fields, such as design studio works, research studies, and commercial services. Under this category, I have gathered examples allowing the user to participate in the creation process and see the results of his/her actions, either in real-time or near real-time. This *allows the user to understand how the system behaves while establishing trust in the system's working mechanism that allows the construction of ways for interpreting the resulting artifacts*. However, the degree of interpretation ability gained from the system differs from one example to another. When multiple data sources are used, as in the *Love Project* (Figure 2.23, page 88) example, although the artifacts are generated in real-time, *the complexity of the form can hinder further decoding of any connection to the data from the form due to a limited perception of the user*. Several examples in the category use different lengths of data to personalize the artifact. For example, Encode Ring (Figure 2.26, page 96) uses very short sound recordings (three seconds) to create waveform rings. The short duration of the data allows different words in a voice recording to be understandable even by following the variations on the artifact surface. Also, it allows the user immediately see the transformation of the recorded audio into an artifact while providing an opportunity to play the audio in sync with a scanning line over the ring form, showing which part of the audio recording corresponds to which part of the artifact. From the examples I have gathered, it is possible to argue that there is an optimum amount for the length or amount of data that can be used on an artifact. *In order to create a meaningful connection between data and the artifact in the process of data physicalization, it is important to consider the amount of data being used and the length of time it covers. The data can be more effectively translated into a tangible artifact if the data has many variations and distinctions. However, suppose the data is too dense or covers a long period. In that case, it may become difficult to recognize the distinguishing features in the resulting artifact, making the generation of meaning more difficult. It is, therefore, essential to find a balance between distinguishable feature densities so that they do not start to disappear as the data amount or length is increased*.

Another example from the real-time active participation category is the *Data Things* (Figure 2.24, page 91) study by Bowers & Nissen (2015) which involves transforming motion data of crocheting performances into laser-cut and etched artifacts that illustrate the motion data. In the first iteration of the study, the researchers took the motion data from the sensors attached to the crochet hooks, created the visualization artifacts, and handed them to the participants. Since being severed from the generation process, the participants had difficulty understanding the representations. Upon user requests, the researchers prepared another study iteration with real-time visualization of their movements on the computer screen.

Seeing the motion data translated into a form in real time allowed participants to explore the connection between their movements and the resulting forms. One participant slowed down or stopped moving their hook to see how the generated form responded to their behavior. This shows that participants were interested in understanding how their movements were translated and that real-time feedback helps with this understanding. Also, involving the participants in the design and making process creates a sense of belonging and helps generate meaning from the resulting artifacts and their process. *It also makes the resulting artifacts more familiar and easier to understand, as participants can see which parts of the data are connected to which parts of the artifact*. *Therefore, being part of the data translation process increases the legibility of the resulting artifact*.

Among the explored examples, the *Interactive Fabrication* (Figure 2.28, page 98) research by Willis et al. (2011) best illustrates the significance of decreasing the distance between input data and its physicalization. The authors (ibid.) aim to *close the gap between digital tools and materials in design and manufacturing by using real-time interfaces* to materialize the results of actions in the final artifact immediately. They have developed a system that translates sound frequencies captured by a microphone into bent wire artifacts in real-time. This process allows users to have a direct, quasi-tactile connection between their input (sound) and the resulting artifact (bent wire), creating a strong connection between the data and the final product. Decreasing the delay in time and metaphorical distance between the input data (sound) and the output artifact (bent wire) strengthens the connection between the two ends of the transformation process. This is similar to giving form to material directly through hammering, where the hammer represents the sound. Decreasing the delay between the tool and its effect strengthens the connection between data and form. Therefore, *digital interfaces create an augmentation for the physical tool that can transform any type of data into any type of artifact.*

As I argued before mentioning the data physicalization examples I explored, the symbolic relationship between the data and artifact approach requires a description of the connection between them. The examples I explored and insights I have acquired from their discussions from the perspective of meaning and value generation provided me with a way to solve this description problem by using a real-time transformation process that involves the user in the transformation moment. In that way, as in the examples discussed above, the user can extract the related meanings by himself/herself since the meaning is made in the participant's mind, who owns the memory/data (Andres et al., 2016).

7.1.3 Q3: How can personal data (in particular: sound) be transformed into meaningful and valuable artifacts through research through a co-designing approach?

- **What are the means of transforming personally meaningful sound data into artifacts?**

Guided by the literature review and inspired by the examples explored, I have designed the transformation process for the primary research (Chapter 3) to explore the implications of using memory-connected sound recordings as a source of meaning and value by using research through a co-designing approach. After conducting semi-structured interviews with the users in the primary study, I used thematic coding and analysis (Chapter 4) to find emerging themes from meaning and value generation perspectives. These themes and related insights from the user interviews in primary studies (*4.1 Primary Study Findings: Themes and Categories*) are then used to develop considerations and suggestions (*5.1 Suggested Developments for the Transformation Process*) for a next iteration of the transformation process that I conducted later as a design (Chapter 6).

Primary Research

During the primary research design, the main aim was to design a prototype or working interface for the transformation method, test it with users, and use insights from that study to develop and test the next version of the transformation method.

Thus, without any programming experience, I decided to use available tools to create a prototype method.

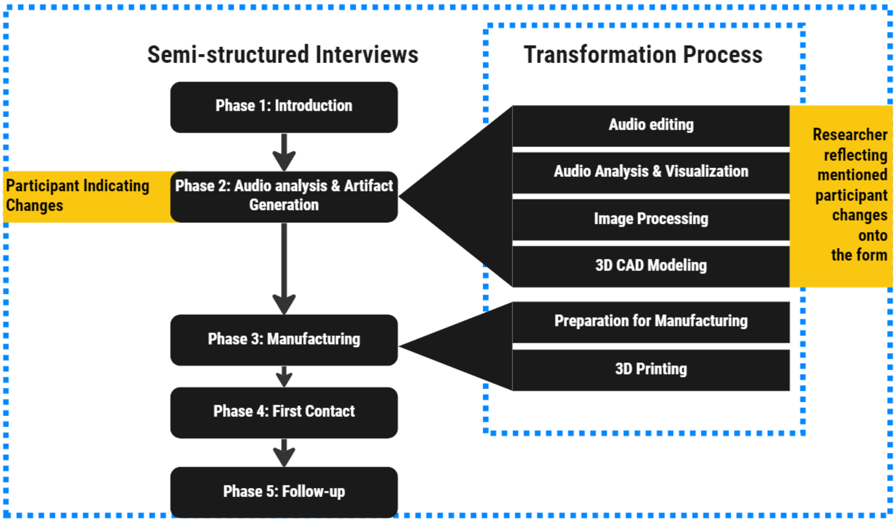


Figure 7.1 Primary research phases and processes.

) that involved a manual transformation process consisting of *audio editing*, *audio analysis and visualization*, *image processing*, *3D CAD modeling*, *preparation for manufacturing*, and *3D printing steps* (Figure 7.1). In this research design, participants participate in all stages of the study but as passive observers in most stages and participate during phase two, in which they state their preferences regarding the generation of the artifact from their sound recordings. They state their preferences to the researcher, me, and I do the necessary changes and preparations in different software (explained in detail in sections 3.1 and 0). The phases of semi-structured interviews are summarized below:

Phase One: This involves an introduction to the process. The participant is asked to find a meaningful audio recording that will be transformed into a tangible artifact. The maximum length of the recording is 10 seconds, and it should evoke emotions when listened to. The recording can be a person's voice, a melody, an ambient sound, or a recording from the past or present. If the recording is longer, it can be cropped during the study. The participant is also informed that a video recording can be used, and its audio can be extracted. After the introduction, the participant is presented with examples of the transformation process.

Phase Two: This phase involves personalization and form-generation processes. The participants are asked questions about their audio file selection, and the audio files are cropped if needed. The audio file is then opened in audio analysis software, which generates a spectrogram image of the audio. The participant is asked about the connections between the sound and the image generated. The image is then translated into a 3D object, with bright areas in the spectrogram image becoming bumps on the artifact's surface and dark areas becoming flat. The participant is asked about their preferences for the resulting artifact, and any necessary adjustments are made.

Phase Three: The 3D model is printed.

Phase Four: The finished artifact is presented, and the participant is asked about his/her reactions and the artifact's meaning.

Phase Five: The study concludes with a discussion about the participant's overall experience and any suggestions for improvement.

During phase two, I observed that the representation of sound with a spectrogram image and using that image on the generation of the artifact played a crucial role in the understandability of the process. During the generation of those elements, I explained what that image represents and how it is translated into the artifact's surface. After the participants got hold of the process and the translation of sound into an image and then onto a form, they started to think in terms of this system. Thus, the method became successful as a vehicle for meaning transfer from sound to form. However, this type of comprehension required many explanations and introduced delays in updating the form since it involved many steps in between.

After the interviews were completed and analyzed (recapped in the following questions in more detail), it is seen that the prototype transformation process used in the primary research had some flow issues preventing the participant from actively participating in the decision-making process. S/he always needed the researcher to realize the ideas and preferences that s/he has. This caused friction points in the process and meaning transfer from sound data to the artifact, which is discussed in more detail in 4.2 *Primary Study Overview*. New suggestions for improving the transformation method are discussed in more detail in 5.1 *Suggested Developments for the Transformation Process*.

The insights from the primary research resulted in the following areas of improvement for the interactive interface that I developed for the design workshop study:

- Decrease researcher intervention
- Increase participant involvement and lead experimentation
- Easy selection of different sound sources
- Function-specific material selection
- Homogeneous sound data distribution across the surface
- Audio data orientation selection
- Parametric surface properties
- Easy switching between audio files
- Real-time transformation of sound to an artifact
- Real-time playback of sound
- Allow more dramatic changes on the artifact surface
- Allow more control over the form of the artifact
- Adjustable audio duration and section selection
- Requesting audio with intense meaning

One of the main aims for the next version of the transformation method was to design and implement it so that the transformation between the playback of the sound and form becomes instantaneous. This way, the perception of form being shaped by the sound would become very strong. For that, I have tried different methods; however, they all had some delays between sound playback and form generation. I have finally attained this real-time playback between sound and form generation and created an interface that I named *Interactive Data Transformation Interface* (IDTI).

It is important to note that there are nearly three years between the completion of primary research and its next version, an interactive interface that the participants can use by themselves. During this period, I gained experience creating custom interfaces through visual programming and tried several solutions before deciding on this method (5.2 *Software Trials*).

Design Workshop

The testing of the IDTI that was developed after my primary research took place at a workshop that was held as a part of the *National Design Research Conference* in 2020. The workshop was organized by the Department of Industrial Design at Middle East Technical University and lasted from September 8th to 10th. It was held remotely due to the COVID-19 pandemic. Due to the remote nature of the workshop, I needed to overcome another challenge, which was making it possible for a participant to interact with the interface I developed with near-zero latency. I solved that problem with game streaming software and conducted nine different user sessions that resulted in nine different artifacts.

The workshop had three main parts. The first part was a general introduction that all the participants attended. The second part consisted of individual participant sessions, where I interviewed each participant through one-to-one remote connections at different times. After finishing all of the sessions, a group discussion meeting was held where all of the participants shared their experiences with creating their artifacts and discussed the process.

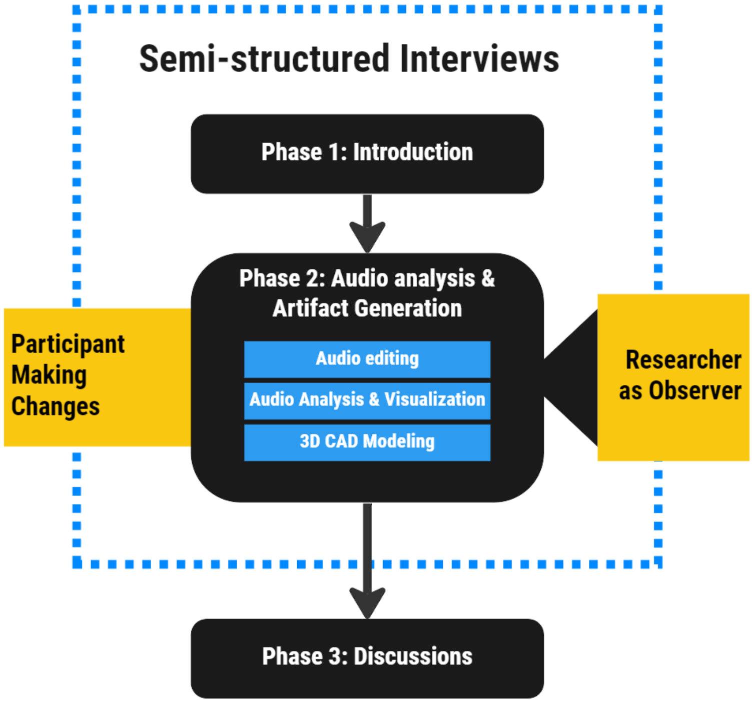


Figure 7.2 Design workshop phases and processes.

The main difference in the transformation process between the primary research and the design workshop is the participant's type of involvement in the process. At first, the participants could only indicate their preferences to the researcher, using the researcher as their agent. So the researcher's role in the previous study was to facilitate and realize the transformation of sound into an artifact. In contrast, in the second transformation method, the participant becomes the one who actively makes the changes, and the researcher is passively observing the user and making necessary guidance when needed. Also, the audio editing, audio analysis & visualization, and 3D CAD modeling steps are integrated into phase 2 of the design workshop to create a more coherent and uninterrupted flow for the participant.

In summary, a participatory co-design process is developed to transform sound into meaningful and valuable artifacts. This process allows the participant to reflect different properties of sound data onto a virtual form that responds to the changes in user preferences and audio frequencies in real-time. This real-time responsiveness ensures a stronger connection between the sound data and the artifact, eliminating the need for explanations. Thus, the involvement and witnessing of the participant in the real-time generation of an artifact based on sound frequency data establish a path to form creation from sound data.

- **What are the design dimensions for enabling the transformation of sound into meaningful and valuable artifacts?**

After conducting the primary research, I transcribed the interview recordings and conducted a research analysis by using thematic coding (Chapter 4). The analysis leads to six main dimensions: *meaning, clarity, accessibility, aesthetics, social clarity,* and *permanence* of transformation. The main dimensions and their properties are presented in Figure 7.3 on the next page, followed by detailed explanations of each dimension and its properties.

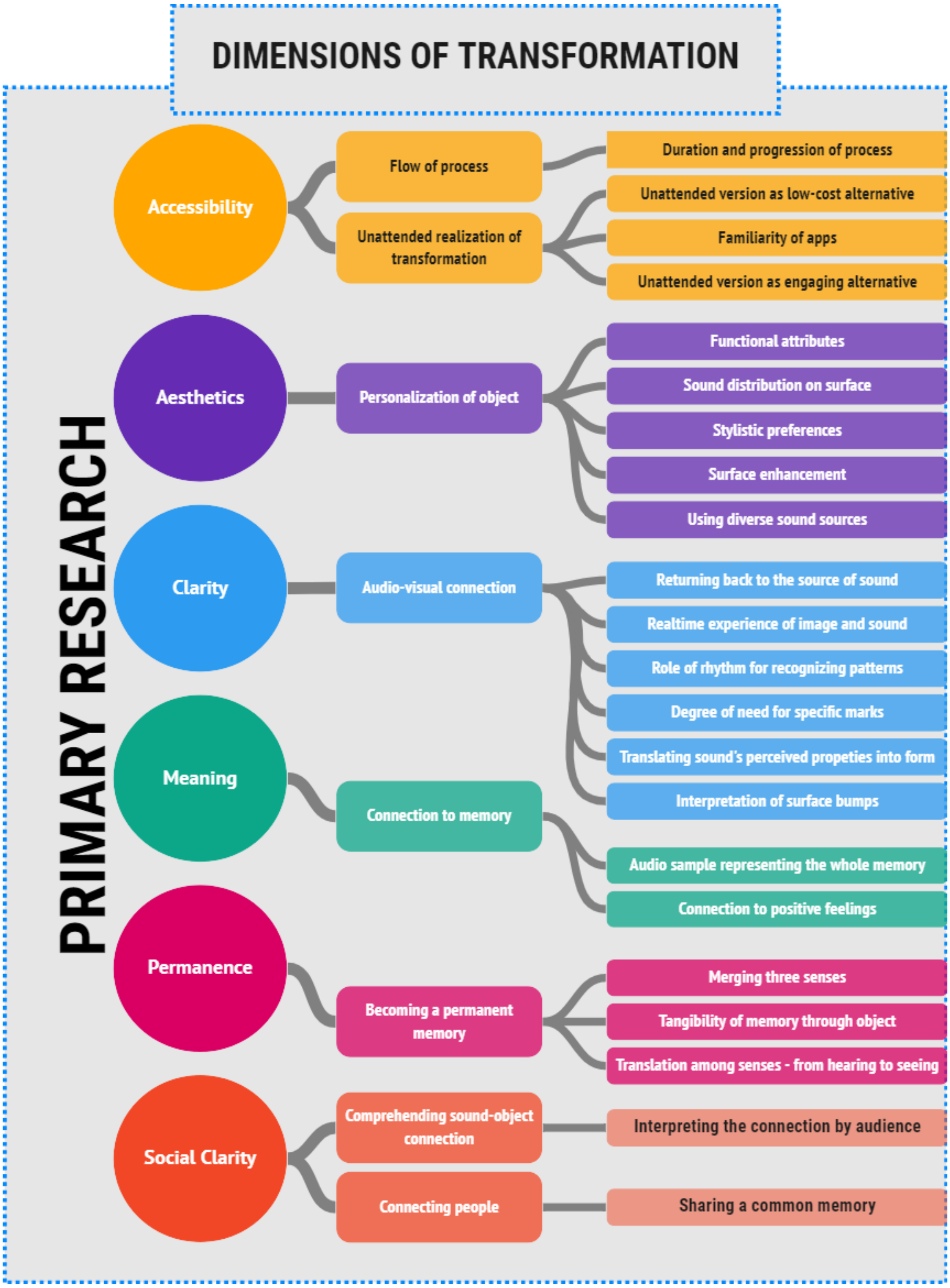


Figure 7.3 Dimensions of the transformation method.

Meaning of transformation

The *meaning of transformation* refers to the significance and connection to memory that participants have with the sound file they bring for transformation. One subcategory, *connection to memory*, includes the property of an audio sample representing the whole memory. Participants generally do not need a long audio sample to represent the memory; the most recognizable part of the audio file may be sufficient. Another subcategory, *connection to positive feelings*, covers participants choosing an audio recording that is connected to positive feelings and has personal significance to them. All participants chose recordings that had some personal significance to them and were often associated with positive feelings. P1 chose an audio recording of her life motto, P2 chose her daughter's first words, P3 chose a song from her wedding, P4 chose a piece of music that was symbolically important to a music foundation he is involved with, and P5 chose the final theme song from a computer game he played as a child. The participants emphasized the importance of the connection between the audio recording and the resulting artifact.

The transformation process itself can also have meaning for participants, with some finding it therapeutic and a way to remember and honor important events or people. Overall, the meaning of transformation involves the *emotional and personal significance* of the audio recording and its connection to memory and positive feelings.

Clarity of transformation

The *clarity of transformation* refers to how well participants understand the process of transforming a sound file into a physical form or artifact. This includes the connection between the audio and visual elements, such as the relationship between bumps on the artifact surface and features of the audio recording. Some participants may need specific marks, such as the beginning and end of the recording, in order to better understand the transformation. The interpretation of the surface bumps on the artifact and the real-time experience of the image and sound can also impact the clarity of the transformation. The ability to return to the source of the sound and the role of rhythm in recognizing patterns are additional factors that can contribute to the clarity of the transformation process. The perceived properties of the sound, such as pitch and volume, can also be translated into the form of the artifact in a way that enhances understanding. Overall, the clarity of transformation involves making the process of transforming sound into a physical form clear and understandable for the participants.

The *degree of need for specific marks* property refers to the importance of being able to recognize certain moments or features on the surface of the artifact created through the transformation process. This can include the beginning and end of the sound recording, as well as specific moments or words within the recording. The spectrogram image used in the transformation process can help participants understand the bumps on the artifact surface and their connection to the audio, but some audio recordings may require additional guidance, particularly if the composition is dense when transformed into an artifact. Some participants may not feel a strong need for specific marks, such as the beginning and end of a recording, especially if it is a song that they are familiar with and enjoy listening to repeatedly. Others may place more importance on clearly identifying the beginning and end of a recording, particularly if it is a speech or has discrete sections. The transformation process should consider these differences in preference and offer options for marking the beginning and end of a recording and the option to use different forms, such as a circular shape for looping recordings.

The *interpretation of surface bumps* property refers to how well participants can understand and recognize specific moments or features in the audio recording through the bumps or features on the artifact's surface created through the transformation process. Some participants may be more focused on specific details and able to connect bumps on the surface to specific moments in the audio. In contrast, others may be more interested in the overall appearance of the artifact and less concerned with specific details. The spectrogram image can help guide interpretation, but individual preferences and cognitive processes can also affect how well participants interpret the surface bumps. Some participants may need more guidance or support in understanding the relationship between the audio and the physical form, while others may be able to make these connections more easily. The transformation process should consider these differences in order to support a wide range of interpretations and understanding of the surface bumps on the artifact.

One unexpected outcome from the analysis of the participant responses pointed out that once the participant understands the connection between the sound, image, and form, s/he may feel that it is unnecessary to search for every detail in the sound and find their corresponding shapes. The transformation process can then move into a new *personalization space* where the connection between the audio and artifact has already been established. However, the participant may continue to change the artifact's appearance, such as different materials, dimensions, and form changes, to satisfy their personal expression and aesthetic needs. These changes do not seem to affect the connection between the sound and artifact made during the real-time transformation experience. On the contrary, participant three, in the primary research, introducing personal preferences related to the aesthetics of the artifact is interpreted as “making covers” to a song. These insights led to a suggestion for the design workshop interface to allow more dramatic changes over the form and appearance of the artifact form.

Under the *real-time experience of sound and image* property, participant responses on the importance of understanding the transformation process and establishing an audio-visual connection are gathered. Some participants struggled to initially connect the sound with the image (in the primary research). However, after listening to the sound and seeing the spectrogram image in real-time, they could find connections between empty spaces and pauses in the sound. Some participants could literally read the words recorded on the artifact's surface, while others relied on the spectrogram image to make the connection. One participant found the transformation process exciting and "magical," while another saw the real-time transformation as the most exciting part of the process. All participants understood the meaning of bright and dark spots in the spectrogram image and their relationship to sound frequency and time. Some participants spent less time trying to match visuals and sound and more time discovering new parts that matched exactly. Overall, the real-time experience of sound and its transformation into an artifact helped the participants understand and connect the audio and visual aspects of the process.

Participant 1 (P1) initially had difficulty connecting the sound with the image. However, as she listens to the sound and sees the spectrogram image in real-time, she finds connections between the empty spaces and pauses in her speech. She discovers that every word has a pattern and can literally read the words from the artifact's surface. P2 tries to understand the spectrogram image and the transformation process and connects the white parts in the image to the bumps in the 3D form. However, she states that she cannot connect the sound to the 3D form without the spectrogram image. P3 also cannot directly connect the 3D form with the sound but finds the transformation process exciting and mentions the "one-to-one transformation" phase in which the sound is transformed into the spectrogram image. P4 finds the transformation of sound into 3D artifacts to be "magical" and thinks the resulting artifact will be enjoyable. He notes that in this process, sound becomes physical and can be interpreted in that way, rather than just listening to or reading about it in two dimensions. He examines the spectrogram image, repeats explanations about its meaning, and understands the relationship between sound frequency and time. After believing in the real-time transformation, he spends less time trying to match visuals and sound and more time discovering new parts that match exactly. P5 believes that the transformation process allows participants to see changes in real-time, and he suggests that this technology could be used in manufacturing. He notes the resulting artifact reminds him of the song rather than its creation moment and that the study's implications may be affected by variables such as the position and brightness of the image.

Overall, the participants show a range of reactions to the transformation process, from difficulty understanding it initially to excitement. The transformation of sound into a visual representation, or spectrogram image, was found to be an important aspect of the process of understanding the transformation of sound into a 3D artifact. Participants (P1, P2, P3, P4, and P5 in the primary research) found it helpful to see the real-time playback of the sound with the corresponding spectrogram image, as it helped them to understand how the transformation took place and create a connection between the sound and the resulting artifact. The spectrogram image played a central role in the visual connection between sound and form, and participants later translated the image onto the artifact and mentally translated the visuals into 3D forms. The experience of being present and involved in the transformation process was also found to be a crucial aspect of the study, as it helped to create a connection between the audio, the symbolic meaning of the audio, the artifact, and the participant.

When the participants can observe the real-time transformation of sound into a visual representation, it helps them *understand how the transformation occurs and creates a grounded, experiential understanding of the connection between the two*. *The initial visual representation of the sound forms the foundation of an "original" perception of the sound for the participant*. W*hat they see first when the transformation takes place is particularly impactful*.

Regarding the understandability of the connection between sound, spectrogram visual (in primary research), and later directly the artifact surface (design workshop), the presence of a complex sound with many simultaneous frequencies can create difficulties in evaluating two different sensorial domains at the same time. To overcome that difficulty, the spectrogram image was edited in participant four's session (primary research) so that some bright areas were darkened. That allowed only the most audible parts of the sound recording to be visible on the spectrogram image. Another similar situation occurred with the design workshop's participant four in which she brought a recording mainly consisting of city noise that made it very hard to create visually distinctive areas on the artifact surface. Since there was no spectrogram image phase in the design workshops, the frequency analyzer of Cinema 4D was used to select distinctive frequencies in the sound recording. Still, these insights reveal that *the content and type of sound data have a significant role in understanding the connection between sound and the artifact.*

Related to the *returning back to the source of sound* property, participants (P1, P2, P3, P5) express a desire for a way to access the original audio recording through the artifact. P1 thinks the artifact should have some explanation of its content, while P3 suggests that the artifact could play the sound with the press of a button. P5 suggests a player device that can "release the sound locked inside the artifact." These comments highlight the importance of maintaining the audio-visual connection and making the artifact more understandable, especially for strangers who cannot guess the connection between the artifact and the original sound.

Participant comments on the *role of rhythm in recognizing patterns* property suggest that recognizing patterns in the sound, such as rhythms or pauses, helps participants understand the connection between the sound and the resulting artifact. Once they understand this connection, they may focus on personalizing the artifact's appearance rather than trying to understand it further. The transformation process should allow for more flexibility in terms of the artifact's appearance, including the use of different materials, dimensions, and form changes, without affecting the connection between the sound and the artifact.

Under the *translating sound's perceived properties into form* property, participants (P2, P3) attempted to match their perceptions of sound with their perceptions of the generated form of the artifact. P2 related the visual properties of the form to the visual properties of her daughter's voice and suggested that the form of the artifact should be chosen according to the selected sound. P3 connected the surface characteristics of the artifact with the feeling the song gave her and suggested that the form could be modified according to her perception of the song. P5 stated that the visual representation of the sound on the artifact did not immediately remind him of the feelings and emotions the song evoked but instead reminded him of the song's progression. This process of connecting the form of the artifact with the perceived properties of the sound is classified as a symbolic representation.

Accessibility of transformation

The *Accessibility of Transformation* category in the user studies refers to the ease and convenience of the transformation process. The subcategories and properties within the Accessibility of Transformation category focus on the participants' experiences and interpretations of the study and the ability to conduct the transformation process independently.

In the *flow of process* subcategory, the participants described the *duration and progression of the transformation process*. They found the process easy to follow and smooth, but they were not eager to wait for the manufacturing phase, which took three to five hours to complete. P4 thought the manufacturing phase was expensive and preferred to watch a video of it rather than attend it in person due to his busy schedule. P4 also expressed interest in the overall process and how the artifact might fit into his daily life, possibly as a conversation piece. P1, on the other hand, found the process short and was fascinated by the ability to customize an artifact to her preferences within a relatively short period. The participants suggested improvements to the transformation process, such as providing more information about the process, providing more control over the form, and reducing manufacturing time. They also suggested using different materials and adding more customization options.

The property of an *unattended version as an engaging alternative* covers participants' thoughts on the potential for the unattended version to generate a stronger artifact-participant relationship, with some participants suggesting that an *interactive* and *self-conductible* transformation process would increase their engagement allowing more *personalized* artifacts. Participants also discussed the potential practical benefits and drawbacks of the transformation process, with some stating that they do not see a practical benefit in being able to conduct the process independently. Suggestions for improving the transformation process include providing more interactive and step-by-step guidance for participants and incorporating an application that allows for more personalized and interactive form generation.

In summary, the unattended version of the transformation process has the potential to be more engaging and accessible for participants. Some participants want to be able to conduct the process themselves, seeing it as faster, cheaper, and more independent. To increase the accessibility of the transformation process, it could be helpful to design an interface that allows participants to complete the process on their own, including recording or selecting the sound, modifying the form, and manufacturing the artifact. This could involve a parametric interface with sliders for adjusting various features of the form.

Aesthetics of transformation

The category "Aesthetics of Transformation" covers participant comments about the form and function of the resulting artifact, including functional attributes, the distribution of sound data across the artifact form, stylistic attributes, and the connection of surface smoothness and bumps with the participant interpretation. The subcategory "Personalization of artifact" focuses on the ways in which participants personalize the form of an artifact through function, appearance, sound data composition, surface properties (smoothness and bumps), and sound sources.

The *functional attributes* property covers participants' comments about trying to find use cases for the resulting artifact, offering different materials and form choices. All the participants search for practical use cases for emerging artifacts throughout the transformation process. Some participants (P1, P2, P5) mention that the artifact is also valuable because of the data source used in the transformation process.

P1 suggests that the form or function of the artifact and the content/meaning of the sound can be connected. P2 thinks that the artifact can be used for decorative purposes but is unsure about the quality of the visual appearance of the artifact. P3 wants to use the artifact as a pencil holder and suggests using different artifact forms that can be more functional, such as jewelry, bracelets, pendants, a picture frame, a computer case, a bookcase, a flowerpot, a speaker, or a watch. P4 does not see any functional use for the artifact but sees it as a replacement medium for listening to music. P5 suggests using the artifact as a wall panel for decoration or as a table surface.

During the transformation process, participants provided feedback on the placement of sound data on the artifact's surface regarding *surface enhancement* property. P1 and P3 preferred higher bump amounts, with P1 expressing concern about the "value loss" of simple recordings when the composition was changed. P4 preferred the time axis to be mapped to the Z-axis. In contrast, P5 initially preferred the time axis around the cylinder but ultimately chose the vertical axis as time and the cylinder perimeter as frequency distribution. Participants preferred the sound data to be spread evenly across the surface and for the time axis to be clearly visible. They also expressed a preference for the option to modify the orientation of the sound data and for the inclusion of a visual representation of the audio recording.

Using diverse sound sources property is about the participant's desire to personalize the form of the resulting artifact by trying various sound sources and quickly seeing the results. P1 provided several examples of what she would create using the transformation process, including personalized gifts and artifacts created from family memories and actors' performances. P3 expressed interest in using the process with other sounds, such as audio and video recordings of her grandmother.

Social clarity of transformation

The "Social clarity of transformation" category of the study covers participants' comments about how the resulting artifact would be interpreted in a social context. The category is divided into two subcategories: "Connecting people," which focuses on the idea of artifacts creating a connection between people who share a common memory, and "Comprehending the sound-artifact connection," which refers to participants' understanding of the connection between the sound and the resulting artifact.

The *Connecting People* subcategory of the *Social Clarity of Transformation* dimension focuses on how the artifact connects people through shared memories. The *Sharing a Common Memory* property covers participants' comments about the artifact representing something shared between multiple people. P5 sees the artifact as a way to give a meaningful gift to his lover, and P2 plans to pass the artifact down to her daughter as a shared memory. To improve the transformation process, the process should be clear to someone who has not seen it, and a self-explanation method should be integrated to enhance communication of the process to outsiders and increase social clarity of transformation.

The Comprehending the Sound-Artifact Connection subcategory refers to participants constructing a connection between the sound and the resulting artifact. P3 sees the artifact as a physical manifestation of the sound, and P4 thinks the artifact can be used as a replacement medium for listening to music. P1 believes the form or function of the artifact and the content/meaning of the sound can be connected. To improve the transformation process, providing more information about the process and the relationship between sound and artifact could help participants comprehend the connection better. The *Interpreting the Connection by an Audience* property covers participants' comments about how an audience might interpret the connection between the sound and artifact. P2 and P3 think an audience would need to know about the process to understand the artifact, and P4 thinks the artifact can be used as a conversation starter, calling the 3D-printed artifact as a “curious object.” To improve the transformation process, providing more information about the process and the relationship between sound and artifact could help an audience interpret the connection better.

Permanence of transformation

The category of *permanence of transformation* covers participants' comments about how the transformation process makes the sound, which is connected to a memory, more permanent. The subcategory of *becoming a permanent memory* discusses how the transformation of sound into a physical artifact affects the concept of permanence. The properties of this subcategory include the *tangibility of memory through the artifac*t, the *translation of senses from hearing to seeing*, and multisensoriality.

Under *the tangibility of memory through artifact* property, the participants argued that transforming sound into a physical artifact made the sound more permanent and valuable. They believed the physical artifact was more durable and less prone to being lost than a digital recording. The participants also felt that the transformation process added a new dimension to the sound, making it more tangible and perceivable through multiple senses. The transformation of sound into a physical artifact was seen as a way to make memories more permanent and to create a lasting connection with others. Some participants likened the resulting artifact to relics or heirlooms, indicating their belief in its lasting value.

Participants in the study believed that transforming sound into a physical artifact made it more permanent and valuable. In the primary research, P1 argued that the physical existence of the sound as an artifact made it more valuable, and P3 and P5 connected the artifact's permanence with its value. P3 mentioned that the transformation process adds a different dimension to the sound and makes it more permanent by creating a physical dimension for it to exist in. The physical artifact becomes a reminder of the sound and the connected memory. Participants also believed that the transformation process translated the sense of hearing into the sense of sight, making the sound more tangible and permanent. They also found that the multisensory experience of seeing, touching, and hearing the artifact enhanced the persistence of the memory and made it more memorable. The transformation process was seen as a way to make something intangible and ephemeral, like sound, more tangible and permanent.

Design Workshop

Based on the dimensions of transformation developed in the primary research, I developed an *interactive data transformation interface* (IDTI) and tested it in a real-life setting through a design workshop. Figure 7.4 shows the dimensions coming from primary studies and the prominent properties and insights that the design workshop provided, illustrated in the blue column.

The main difference between the design workshop and the primary study is the researcher's and the participant's roles. In the primary research, the participant was the change indicator, and the researcher was the reflector of that change on the software. In the design workshop and IDTI, the participant is empowered with an interactive and parametric interface that lets the making of changes on the artifact and sound data through several sliders. The difference can be understood better by comparing Figure 7.1 and Figure 7.2 on pages 316 and 320, respectively.

The insights from the design workshop (blue column in Figure 7.4) are discussed in the following paragraphs under the names of the six main dimensions of transformation.

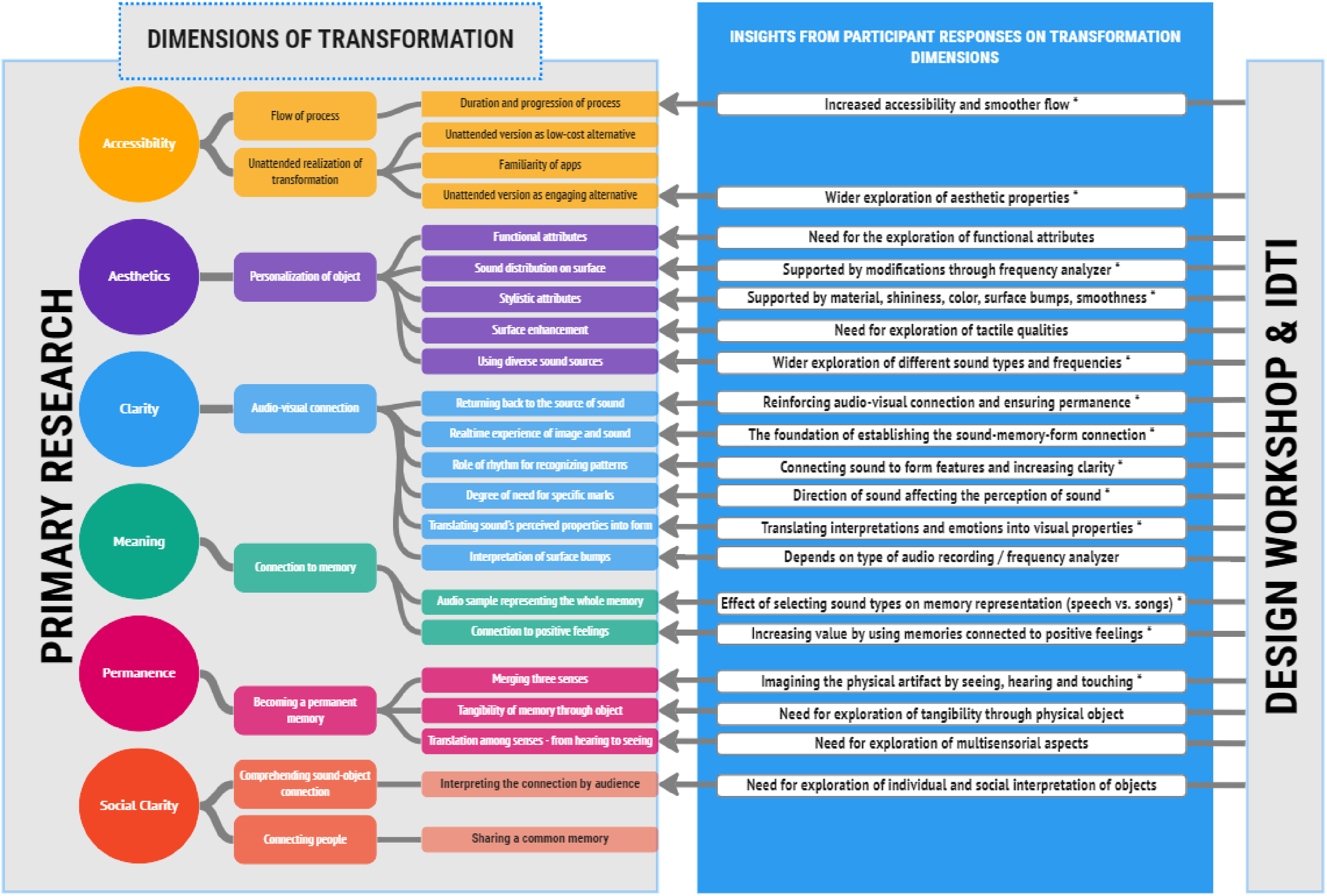


Figure 7.4 Dimensions of transformation and insights from the design workshop.

Accessibility of transformation

There is a significant increase in the *accessibility of transformation* process compared to the primary research studies, which also showed up in the participant responses by receiving nearly no suggestions about the interface. Many participants found the process to be clear and easy to understand, with clear instructions and a user-friendly interface. Some participants suggested adding more expressive controls like sketching and painting or introducing some unpredictability to the form-generation process, while others argued that having too many options can be overwhelming and divert the user from memory. Overall, the transformation process was seen as accessible and easy to navigate, with the clear instructions and layout of the interface helping to facilitate the personalization of the artifact.

Better flow and increased accessibility of the transformation process allowed the participants to explore a wider range of design options. Because of the long time intervals between the screenshots of user sessions, some of the form explorations cannot be seen in the provided figures. However, some participants explored very high displacement amounts, very sharp and smooth surfaces, and many different colors over several seconds, letting them see what they liked and what they did not.

Aesthetics of transformation

Because of the increasing accessibility of the transformation process, participants no longer needed to communicate with the researcher about each change they wanted to try. This agency of the participant significantly increased design explorations through the interface.

There were two perspectives during the personalization of the virtual form. One is changing the form according to the sound data, emphasizing certain features of sound. The other is changing the form according to the meaning coming from the memories related to sound. Some participants found it difficult to balance the aesthetic preferences of the resulting form with the meaning of the sound that they were making from memory. Aesthetics was seen as an important factor in the selection of sounds by many participants, while others focused more on the personal significance or emotional impact of the sound. There was a range of views on the function of sound in the transformation process, with some seeing it as central and others as secondary.

In some cases, the sound and the form seemed to complement each other, with the sound emphasizing certain aspects of the form. This is when this complementary situation creates an *emotional resonance* in the participants. It is argued that *when the meaning-wise and aesthetics-wise preferences resonate with each other*, this causes an increase in the value and meaning of the resulting artifact while creating greater satisfaction in the participant.

The aesthetics of the transformation process were seen as being strongly connected to the meaning of the transformation, which came from the meaning of the sound memory for the participant. Therefore, the insights coming from the meaning and aesthetics of transformation have connection points with each other, as seen from the emotional resonance mentioned above.

The function of sound in the transformation is that it constructs the bridge that connects the sound and memory by aesthetically altering the virtual base form, the cylinder. Although participants can change the deformation amount of sound on the cylinder, some participants (P1,P6, P7 in design workshop) mention that they cannot change the sound-related features completely, referring *that the sound data create a domain that is untouchable by the participant and this appears to be that untouchable domain which establishes the connection to the memory*. Some participants mentioned that the sound data created a starting point for them to reflect their aesthetic preferences.

Another function-related discussion was the lacking functionality of the cylinder form. This was also an issue of discussion in the previous study. However, the design workshop introduced more intense questions on this issue. That is probably due to the demographics of the workshop participants, who were dominantly from an industrial design background.

Some participants expressed concerns about getting away from the original form, while others saw it as a way to reflect their own preferences. The initial representation of the sound data was seen as important, as it created an "original" interpretation for the participant. Modifying the form also caused some participants to shift their focus away from memory and towards product design. Many participants found the cylindrical form of the artifact to be too rigid and limiting. They preferred a more organic shape. In the form selection process, the participants considered the direction of the time dimension on the surface, with *radial progression associated with cyclical events and vertical progression with specific beginnings and ends*. The aesthetic qualities of the surface, such as texture richness, diversity, and significance, were also important factors in the selection process. All participants wanted significant features (bumpy and flat areas that are clearly distinguishable) on the surface to help them connect the sound with the artifact form, but some preferred more significant features while others preferred less.

Clarity of transformation

Being able to experience the generation of the form in real-time increased the clarity of the transformation process since the need to create a spectrogram image first and communicate how that works to the participants took time and mental processing. Implementing that spectrogram analysis into the transformation process itself established the connection between the sound and/or memory for the participants.

Different sound recordings caused different surface features on the virtual form during the generation of the virtual form, as expected. However, the recordings with very homogeneous sounds were harder for the participants to connect with the surface features of the cylinder form. In those instances, the frequency analyzer feature of the interface is shown to the participants, allowing them to select the desired frequency range that can have a dramatic effect on the surface of the form. The selection of the frequency range required trial and error. However, it created excitement in many participants, as if they had discovered a hidden feature, while also creating relief since some of them found it hard to recognize the connection between form and sound. Therefore, selecting which part of the data is used on the object increased the *clarity of the transformation* by emphasizing desired frequencies. Similarly, rhythmic sounds created a similar effect on the participants, facilitating the perception of the connection between the sound and surface features.

One of the properties that are highly prominent in the design workshop was *the degree of need for specific marks*, which is about the direction of the time on the artifact surface. The participants that preferred looping impressions selected radial form, whereas those that wanted discrete beginning and ending selected the vertical alignment. This direction selection was highly connected to aesthetic preferences since changing the direction also significantly changed the surface bumps' visual distribution.

Another significant one among participant responses was *translating sound's perceived properties into form* property. This property also had strong connections to the meaning and aesthetics of transformation since the participant's decisions were made in conjunction with the visual appearance of the surface details and the meaning and emotions coming from the associated memories.

In the primary research, when talking about the 3D printed artifact, there was a desire to hear the sound again and to *return to the source of the sound*. The design workshop also received feedback for this property, highlighting that it would reinforce the audio-visual connection and increase the memories' permanence while introducing a possibility to increase the artifact's social clarity.

Social clarity of transformation

The understandability of the generated artifacts by an outsider seems not possible to the majority of the participants. However, none of the participants seemed concerned with this. This personalization process is regarded as highly subjective and personal by the participants. Because of this, they might accept the creation of meaning and value only in their minds from the beginning. One insight on this dimension comes from two different participant comments from the primary research. One of the participants commented on the manufactured artifact and stated that it becomes something between two people. At the same time, another called the manufactured artifact a “curious object” and “conversation starter.” The private meanings of the artifacts are also mentioned in the literature. Therefore, the social clarity of the method can have some unexplored potential from the perspective of meaning and value generation.

Permanence of transformation

Due to the COVID-19 pandemic, remote nature, and duration of the workshop, tangible artifacts could not be a part of the workshop. However, participants seeing the virtual forms made from different materials on the screen and probing questions allowed them to imagine to some extent what would happen if they were made as tangible objects. All participants believe that transforming sound into a physical form helps increase the related memory's lasting nature. This happens in several ways. One is by making the memory more durable through its transformation into a tangible object (P5 in the design workshop). The other is by displaying the memory in a way that allows it to be constantly seen and remembered, reinforcing it in memory (P1, P5 in the design workshop). Sound is often perceived as ephemeral, but converting memories related to hearing into a visual form makes them more permanent. When asked about the difference between a manufactured artifact and a photograph in terms of memories, P6 (in the design workshop) compares the two and says that photographs are two-dimensional and confined to frames, giving the feeling of a finished and old event. In contrast, *the three-dimensional artifact lives in the environment and has multiple faces, allowing for more interpretation*. Almost all the participants also mentioned that seeing and hearing the form and sound together (multisensorial) is much more effective, which also relates to the lasting nature of the memory.

Meaning of transformation

Many participants chose sounds that had personal significance or evoked strong emotions, while others focused more on the sound's technical aspects. The resulting artifact's meaning and value were seen as closely connected to the personal significance of the sound recording. The participants who brought recordings without strong connections to memories had difficulty giving meaning to the artifact and the process at the beginning. However, as the workshop progressed and they invested time and effort, the result started to gain meaning through self-reflection and expression of their identities through their preferences. The emotions evoked by the sound recording were also translated into the resulting artifact, which became a representation and reminder of the participant's emotions for the sound. The process also allowed for the creation of tangible representations of personal memories that may not have mementos. These artifacts could contain a different layer for meaning-making compared to more quantitative representations like photographs.

- **How does the active participation of people in the design process (i.e., selecting intangible sources, transforming this source into a form, and getting feedback for the user experience regarding the process and outcome) impact the creation and understanding of meaning for the process and the resulting artifact?**

During the design workshop studies, participant responses show that the resulting artifact has two dimensions for meaning and value. The first one is expected to be coming from memory-related sound data. However, several factors, like the nature of the selected sound recording, whether a personally strong memory is connected to it, and the perception of the transformation method by the participant, affected the value of the sound data significantly. Some of the participants (P4, P8 in the design workshop) who did not give meaning and value to the recording that much in the beginning started to value the form as they gained control over the artifact by being able to select different frequencies of sound. However, the second dimension for value and meaning has been the sole involvement of the participant in the process and reflection of his/her preferences in the final form, no matter how meaningful the sound data is for them. This result is consistent with co-design, meaning, value, and memory-related literature that are explored in the literature review part of this thesis.

It is also observed that participation in the process starts to become a part of the memory related to the artifact. Thus, the artifact becomes tangible proof of the participant's *invested time and effort, identity, self-expression,* and *creativity*. Thus, user participation dramatically enhances the perceived value of the process and outcome. One of the primary study participants, P5, gave clues about this outcome when he mentioned that without his participation in the process, he would not have accepted the final artifact.

One approach to using personally meaningful data, such as sound, to design a transformation process for creating personally meaningful artifacts is to involve users in the co-design process. Co-design, which involves designers and non-designers working together in the design development process (Sanders & Stappers, 2008), can empower users by giving them agency in the design process. It can also spark conversations supporting multiple ideas rather than imposing a single one.

Involving users in the design process of an artifact can increase its value and meaning, which is especially true when co-designing within a participatory design framework. Bingham, Green, and Porter (2017) suggest that objects connected to meaningful data can trigger memories and create a stronger emotional attachment to the product, potentially increasing its lifespan. However, designers must consider the types of data to include and how they will affect the form and function of the product while still maintaining aesthetic coherence.

7.2 Contribution of the Dissertation

7.2.1 Theoretical Contribution:

In this thesis, I developed and presented six different dimensions for transforming sonic memories, which are accepted as personally meaningful data, into meaningful and valuable artifact forms that the users of the method want to keep and even pass on to loved ones. While doing so, the artifact form remained a cylinder to see if the process would successfully create meaning and value even in a functionless and meaningless form. Having succeeded in creating meaning and value, I now can present evidence-based proof that this method even works on a generic artifact so that it can be applied to different artifact forms with functional attributes. Coming from a design background, I sometimes found it hard to prevent the inner urge to try functional objects in the process and completely understood the participants' desire to make this cylinder a functional object. However, I hope that insisting on this cylinder can lay the foundations for many use cases that can introduce novel ways of using it. It should be noted that these dimensions are the foundations of this transformation from data to artifact. Therefore, new dimensions based on the transformation to different kinds of artifacts can emerge.

As mentioned in the Introduction chapter (Figure 1.2), this thesis gathers information from different fields for the following related concepts

- Industrial design: where this research originates and the results to be used in
- Human-computer interaction: determining the interaction ways and principles with data and digital artifacts
- Emotionally durable design and personalization: in the creation of meaning, emotional bonding, and ways of establishing longevity
- Data physicalization: in ways for transforming the data (memories) into artifacts
- Psychology: Creation of meaning and value, and memory

- Codesign: In the design of a participatory design method

By building upon the knowledge in the areas mentioned above, this thesis presents a process that engages the person who uses it to create personally meaningful artifacts.

The developed transformation method provides meaning through *memories*, *self-expression*, and *self-identity*, which are also sources for increasing products' *emotional durability*, as argued in section 2.4.2., which is closely linked with product longevity. Although this thesis does not aim to measure the emotional durability of the artifacts generated, it provides a novel way for incorporating memories in creating meaning and value in products. As a result, it provides a route for enabling product longevity.

Within data physicalization, this study contributes to the field by providing insights into what happens to the meaning of the data during the translation from intangible data to tangible artifacts. The main contribution of the thesis to the product design field is a novel way of creating meaning in products before manufacturing takes place, thus *creating a path for design to consider personal data as a material for design*. In doing so and creating a path for meaning-generation before the manufacturing phase, the method developed also provides the opportunity for innovative design solutions to establish longevity through the emotional bonds already built into the product.

7.2.2 Practice-Based Contribution:

As mentioned in the theoretical contribution part, the method developed in the thesis aims to lay the foundations for a path that enables the usage of personally meaningful data as design material. Although the presented example in this study focuses on a functionless artifact, the main aim is to extrapolate the generated knowledge from this generic artifact to a broader setting in design practice.

In this study and data physicalization examples, most manufactured artifacts seem to be no more than experimental objects. However, with the proper use of post-processes and more advanced additive manufacturing techniques, they may be used together with manufacturing systems even today. This brings the question of the practical applications of such methods.

The *research through codesign* approach and the *Interactive Data Transformation Interface* (IDTI) can be used as a tool for researchers, designers, and users with different focal areas. From the researcher's perspective, the method contributes as a data collection tool that allows a predetermined set of features to be tested in real-life scenarios. From the designer's perspective, it allows a designer to develop a system that lets his/her design intents be transformed into a parametrized system that can create meaning and value by being further personalized with user data and input. From the regular user perspective, the IDTI creates an empowering tool that enables the creation of personally meaningful artifacts by using personally relevant data.

I have presented the foundations of an initial model that allows the creation of meaning over an empty physical form by incorporating personally meaningful data and sound. I believe that this method, and the tools that can be designed around these presented dimensions of transformation, can be used not only in designing standalone artifacts/products but also can be integrated into existing personalization methods and systems.

The Role of Interactive Data Transformation Interface

The developed interface used in the design workshop in this thesis is designed as a method for discovering the dimensions of a transformation route of personally meaningful data (sound data connected to autobiographical memories) into artifacts. The aim of unearthing such a route is to create a method that helps the creation of meaningful products with the help of personally meaningful data. Thus, rather than the interface developed in this study, the main contribution to the practice is how such transformation processes can be utilized to create personally meaningful and valuable products. As mentioned before, instead of a functional product, an abstract form has been consistently used in the studies to understand if the proposed methods can create meaning and value in such an object. Since it is seen that the method allows the creation of such meaning, then this interface has fulfilled its main purpose, and now more advanced methods can be used in future studies. Also, the user experience can be designed from the bottom up by adopting *research through co-design approach*. Therefore, *six dimensions of transformation* stand as the main contribution of this thesis to the practice. The proposed transformation method guides designers and design researchers on how new tools can be developed and incorporated to create meaningful products. In other words, the process developed is software independent.

Integration with Manufacturing

From the beginning of the thesis, the main aim was to understand how the meaning transfer occurs between data and the artifact by developing a tool for that transformation to create meaningful artifacts. After developing the IDTI and completing two field studies, that understanding can now be integrated into conventional and emerging manufacturing practices. Digital manufacturing techniques like additive manufacturing started to diffuse into our daily lives. It is already widely used in dental and medical industries where bespoke production brings high value (Alpay, 2012). In the last years, Adidas has partnered with Carbon (a company that provides 3D printers for high-volume production) to produce the midsoles of their shoes for athletes (Zastrow, 2020). With developing materials and improving techniques in additive manufacturing, the creation of bespoke products will be more and more widespread in different product categories. Expanding emerging technologies into new product categories will introduce more possibilities to use methods, as developed in this thesis, in new areas. Even for conventional manufacturing methods, this method can be integrated into existing personalization tools and platforms, such as designing and creating parts of a larger product with many parts manufactured with conventional techniques but user-facing parts with additive manufacturing.

7.2.3 Contribution to the Design Research Method:

In this thesis, a participatory design process is adopted and implemented in a remote workshop by *research through a codesigning approach* (Bakırlıoğlu, 2017). While involving users in an interactive and delay-critical personalization method, several tools and approaches have been used. Using low-latency streaming and remote access for the interaction method, two-way recording of video and audio communications, and recording the interaction performance of the participants have been used in the implementation and documentation of the workshop. Moreover, a three-dimensional interaction model based on the developed dimensions of transformation has been developed prior to the design workshop through a node-based programming environment.

The role of the researcher in the mentioned research context has also been multifaceted. In the primary research, the role of the *researcher* starts with being the *designer* of the study, then transforms into being the *facilitator* and *observer* in the research. Then in the second study, the design workshop, the researcher becomes the *designer* of a computational parametric interface while also using the research insights from the previous study to determine the parameters of the interface. Then during the design workshop, the researcher becomes the *observer* only, conducting semi-structured interviews. This continuously changing role as a researcher helped me give better-informed decisions while designing the design workshop based on my previous experience in primary research.

7.3 Limitations and Further Studies

During the stages of this research, the duration of studies, the way they were conducted, the demographics, and physical and technological possibilities present limitations on this study, which can inspire further studies.

Sampling and Demographics

In the primary research phase, I specifically chose participants that do not have CAD literacy to prevent participant comments related to the used software. In the design workshop, however, the complete opposite was present since all the participants were design-oriented people who were dominantly from industrial design backgrounds. Similarly, the demographics were very different from each other. Primary research had a wider age range between 25-75, while the design workshop was 21-40. The gender was very skewed in the design workshop, with all participants female, while the primary study had two males vs. three females. Since the general sample sizes of both studies are not high enough to make generalizations, it is hard to generalize the information statistically. However, further studies can be conducted with different age groups and/or on a broader scale since the two oldest participants in each user study had some difficulties making sense of the process. Age can be a determining factor in the understandability of the process, but more importantly, this brings the next limitation of the study: memory types.

Sound-Memory Connection

The participants in the studies brought different types of sound recordings. Some of them had connections to important personal memories, and some of them did not. There seems to be a correlation between the sound's connection to memory and the meaning it generates in the final artifact. However, there is insufficient sampling to provide solid evidence for this effect. Therefore, studies comparing the transformation of different data types can provide insights into which memories might provide more opportunities for meaning and value creation.

Usability of the Interface

Since all of the participants who tried the interface in the design workshop were designers, the demographics of the workshop setting might have hindered some feedback related to the usability of the interface developed. The focus of the second version of the interface used in the workshop was not on the user interface and the experience but rather on providing ways for a more interactive experience that empowers the user to manifest his/her ideas into the final form and see the implications of that empowerment. Furthermore, the interface used is mainly made within the constraints of the Cinema 4D environment. Therefore a complete redesign of the interface was not possible, nor was how the user interacts with it. These limitations in the design of the transformation method open a path for further explorations on its interface design and how the user should experience the overall personalization process. The data physicalization examples discussed in chapter two presented some experiences designed from the beginning like a ritual. Therefore, the user experience design for creating meaning in personal products might consider such examples while creating the experience.

As mentioned above, one of the design workshop's limitations was the participants' demographics. In the primary studies, the participants were specifically selected out of people who did not have 3D modeling experience. However, the design workshop participants came from a design background, and most had 3D modeling experience. This type of demographics provided easier adaptation to the interface and might have prevented any interface-related feedback. Especially navigating in the viewport can normally require some experience with three-dimensional software. Since there was no information about the user profile during the development of the interface, I designed the system with restrictions that prevent the user from losing the artifact while rotating the viewport. For example, wherever the user clicks to rotate the viewport, the object is constrained to the center of the screen. Similarly, zooming in and out also keeps the object at the center. Although the study's focus was not the interface's usability, *its ease of use has connections with the accessibility of transformation*. Therefore, the usability of the interface and the provided parameters can be further tested with participants from non-design-related backgrounds and provide valuable feedback on adopting such a transformation method on a broader audience. The usability of the method and interface can ensure other future research can be conducted on broader audiences.

Using an Already Established 3D Software

Within the constraints of this research, I had to use some existing tools in primary research. However, I created a custom interface (within Cinema 4D software) in the design workshop studies. Even though I managed to create custom functions and implement computational methods that enabled the automatic realization of certain functions determined in previous stages of the study, areas such as user interface design, the overall flow of the process, and certain functionalities remained within the constraints of the Cinema 4D software. While doing so, I tried to arrange the functions and their accessibility in the interface as intuitively as possible from the user's perspective. Coming from a graphic design background and being experienced in the interaction design of software interfaces helped me create a usable interface. However, no matter how well thought out, the constraints of an already established interface of Cinema 4D created limitations for tailoring the interface to an utterly personalization-focused environment. Therefore, further studies can explore the effect of the user experience on the creation of meaning and value while using meaningful data as a design material.

Artificial Intelligence and Machine Learning

Considering the usage of new tools, conversation-based interfaces can provide the potential for further research areas. Toward the completion of this thesis, OpenAI (artificial intelligence research laboratory) released a conversational artificial intelligence language model to the public (ChatGPT). Upon my initial experience with the model, such methods can be incorporated into the functionality of the transformation method so that the user can interact with the form through conversation, which can make the applications of such methods very widespread.

Furthermore, machine learning combined with conversational A.I. can be used to analyze and facilitate meaning-making from the sound recordings by pre-analyzing the data and emphasizing distinctive parts. With such methods, even picking certain sounds in the recording to use them for surface generation selectively becomes possible. Since the developed method is thought of as one of the ways to use data for creating meaningful artifacts, different types of data can be analyzed by A.I. systems, and understandable ways of using them can emerge, increasing the impact area of the research.

Surface Generation Method

During the software trials stage for the development of the IDTI, I iterated through many surface generation methods using sound data. However, in order not to overcomplicate the visual appearance of the three-dimensional model and decrease the understandability of the connection between the data and the form (like in the *Love Project* example in the Data Physicalization examples) I decided to use a single method: sound frequencies causing surface bumps on a predetermined shape. This constraint limited the form generation possibilities of the interface. Although this has not been an issue with the participants, from the product design perspective, more surface generation methods, such as particle and physics simulations and generative lattices, can be explored further to create more aesthetically pleasing results.

COVID-19 and Remote Workshop

As mentioned in the previous sections, I had to conduct the design workshop remotely due to the COVID-19 pandemic measures. This presented some limitations. However, I think that it also showed that an interactive remote workshop was possible with the challenges overcome. The main limitation was evaluating the artifact's physicality as I did in primary research by manufacturing the generated form as a 3D-printed physical object, handing it to the participant, and conducting an additional semi-structured interview. That part of the primary study is missing in the design workshop, which I think posed some decrease in insights related to the artifact's physicality. However, adding material options to the interface facilitated imagining the material properties of the artifact. Although it was not the focus of this research, it presents another further study area: materials.

Testing Emotional Durability

Due to the impossibility of the tangible experience of the artifacts in the remote design workshop, and the inability to conduct follow-up interviews, the developed transformation method needs further explorations and longitudinal studies looking at the aspects of the sustainability of the meaning generated through time and usage. Connected to this, to what extent this method can improve the emotional durability of an artifact/product can be explored. Also, the effects of materials and function can be explored in connection with the usage in more extended time frames. Function and materials experience are also mentioned in the following paragraphs.

Function

The limitation in function was a conscious research design choice in the study, and it was an area in which the participants' imaginations ran wild. Therefore, it creates significant opportunities for further research. Testing of the transformation process on functional products might be the way to broader adoption of this method since the usefulness of a cylinder would be questioned a lot, and the real potential can be seen and understood by a narrower audience. One of the further study areas related to functional products would be the creation of a systematic form creation classification that uses different computational methods for form creation from the data. Also, the data I used is mainly sound frequencies plotted over time. However, many other data types, coming from many different wearable sensors and smartphones, are also functions of time. Therefore, exploring other types of data and finding scalable ways of representing them in the form generation process opens another area for further research.

Product categories

While focusing on meaning creation through this transformation process, I have not considered a specific product category during the research. Also, I paid particular attention to keeping my distance from the artifact's functionality since I was trying to understand if such a method successfully establishes a connection between the artifact and its creator. Therefore, this method leaves many areas for further research on the types of product categories this method can be applied to. Still, the apparent categories for providing value and meaning would be types of products that are more related to personal use, that are used for personal expression and the creation of self-identity. Personal accessories, from fashion items such as jewelry, watches, and shoes, are the first items that come to mind. Manufacturers like Adidas, Nike, and Newbalance are already using personalization methods and biometric data obtained from athletes to generate bespoke items tailored to the user. Therefore, there are already pipelines for bespoke data to generate one-off commercial items in these areas. This example can be extended to an area that involves the manifestations of our identities in homes with furniture, lighting, wall panels, and home décor items, which were also mentioned by some of the primary research and design workshop participants. Another area can be automobile design, in which certain car parts, such as the dashboard, outer body, or gear knobs, can be personalized with similar methods. For example, Mini branded cars provided a personalization approach that let Mini users personalize parts of their cars with 3D-printed components (Woodard, 2017). However, for each product type, component and usability-based analysis would be needed, and each application area would need different considerations.

Another newly emerging area that has huge potential from the perspective of personal meaning and value is the virtual worlds and the design of virtual assets to be used in these worlds. The role of designers, especially with expertise in the three-dimensional domain, is expanding into these new realms in which an alternative reality is being created with virtual representations of our items. However, this time, the items designed in these realms can also be detached from physical limitations and manufacturing costs. At the same time, every desired functionality can be *programmed* into the artifact rather than crafting a physical solution to that. Thus, in a world where we start to lose tactility and physical connections with reality, the search for meaning can increase, and areas related to these worlds can be further explored.

Material Selection and Tangibility

In the primary research, I 3D printed them from white ABS plastic after the participants created their virtual forms. The selection of plastic was also significant in terms of preventing any meaning and value from the material properties, as argued in the 3.6.6 *3D Printing section*. Of course, plastic material also has its connotations; however, at least it was a common selection for the material. The participants reflected on the artifact's material properties during the primary research and design workshop. Especially in the design workshop, when the participants were allowed to modify the material properties of the artifact, a great deal of personalization was made in the material domain, having direct connections with sound and memory. Therefore, studies exploring the relationship with data, material, and kinaesthetic properties of the artifact, its material experience, and their effects on meaning and longevity seem to be promising areas for further studies.

Final Words

I believe the artifacts we own and want to own need deeper meanings than the artificial needs that we are bombarded with. I hope this design research approach, along with the proposed method and dimensions, can be one of the ways we manifest ourselves in this world in a more meaningful, sustainable, and memorable way.

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APPENDICES

A. Exploratory Research Interview Protocol

Phase 1: Introduction

I request from you an audio recording -that is going to be transformed into a tangible artifact- of at most ten seconds length that reminds you of someone some place or something and/or evokes some emotions when you listen to. This audio recording can be a melody, voice of a person or people, an ambient sound, a sound that belongs to past or that has been created nowadays, or a recording that has been recorded in any way that comes to your mind.

If that audio recording is longer that ten seconds or is a sound related with a video recording, I can help you here to edit and trim it. If it is possible, I want the original of that sound.

Now I am going to show you what kind of artifacts and forms can come out of this transformation process. Please feel free to ask any questions that may come to your mind.

[Demonstrate by showing examples of artifact surfaces that are prior to the transformation and after.]

I will be pleased if you could bring the audio recording I requested from you as soon as possible. When you decide on the recording, we can talk on the phone for setting up a meeting for the next session.

Phase 2: Audio Analysis and Artifact Personalization

Exploration of the selected recording

- Can you tell me about the audio recording you have selected?
- What is the reason for choosing this recording?
- What do you think about the visualization process that I've introduced you in our previous meeting?

Now, we are going to examine the audio recording you have chosen with a special software that transforms sound into an image like in the examples I have shown in our previous meeting. In the image you are going to see, the bright areas mean that there is a sound there, and the place of the bright area in the direction of Y-axis tells us about the pitch of the sound. The horizontal axis represents time. Therefore, the bright areas that appear on top of each other mean treble and bass sounds that are heard at the same time. Human voice, music instruments, ambient sounds cause different images to form here. Even two different people saying the same thing will appear differently in this image.

[Open the audio file with Sonic Visualizer]

- Is there any relationship between the audio file you brought and the visualization you see here? If there is in which areas? Why?
- If you do not think there is a relationship, what problems do you think are present? Do you have any suggestions concerning this? If so, what are they?
- What do you think about the transformation of the audio you brought into an image?

Exploration of the transformation

[Export the spectrogram image with Sonic Visualizer and open it in Photoshop. Place and stretch the file into a 2048 pixel x 2048 pixel composition and save the file.]

Now I am completing the image processing that is required to transform your audio recording onto the surface of the artifact. The image that you see here is a mapping technique similar to a topographical mapping as if we are looking to a terrain from the top. The bright areas show the hills and the dark areas represent flat areas.

In the next stage, the sounds in the recording will transform into hills and the silent parts will remain flat.

Transformation of the image into third dimension

In the previous stage, we have transformed the sound into a two-dimensional image. Now we are going to reflect this image onto a three-dimensional geometry.

[Show the normal cylindrical shape]

Shortly, the bright areas in the image file will transform bumps on the surface of the cylinder while the dark areas will remain flat. This image file will reform the regular cylinder.

[Open the CAD file, assign the image file onto the cylinder as displacement a map, and show the resulting model to the participant.]

The surface of the artifact that you see now has been reformed according the audio recording that you brought. The audio mark that you see on the surface of the artifact you seen in the screen may have some very sharp spots. For this artifact to be manufactured, these sharp parts should be smoothed. We are going to establish this with the help of Adobe Photoshop.

[Add Gaussian Blur effect in Photoshop and resave the file. Show the updated model in Modo]

If you prefer, we can make some changes on the resulting artifact such as surface displacement (bumpiness), increase or decrease the smoothness. Do you prefer the current state of the model or do you want to make any changes? If yes, what what do you want to change? Why?

[After completing the changes, ask for confirmation and pass onto the following questions.]

- What do you think about the transformation of your audio mark into a three dimensional artifact?
- Do you see any corresponding points between the image that you saw in the previous stage and the artifact that you have seen here? If yes, which parts? Why?
- If you think there are no relationships or corresponding points, why? What kind of problems do you think there are? Do you have any suggestions concerning this? If yes, what are they?
- Do you think there is any relationship between the sound that you gave and the artifact that you've seen here? If yes, what is it? Why?

- If you think there is no relationship, why? What kind of problems do you think there are? Do you have any suggestions concerning this? If yes, what are they?

[After the artifact takes its final form, export the model in STL format. Open the file in the Voxelizer program and prepare it for 3D printing.]

Phase 3: Manufacturing

In this stage, we are going to manufacture the artifact that we have created with your audio mark with the help of a 3D printer. Do you want to watch a portion or whole of this stage? Why?

What do you think about the transformation of your audio mark into a tangible artifact?

Phase 4: First Contact

- How did you feel and what did you think when you first handled the artifact that carries your audio mark?
- What do you think about the artifact that you handle and its relation to the audio mark that you gave in the beginning?
- To what extent they correspond / relate to each other?
- What do you think about the necessity of this correspondence/relation?
- What kind of transformation in terms of meaning has taken place when it transformed into a physical artifact? Has it gained any new meaning? If yes, what is it?
- When you think about the whole process, what are the things that you want to change? Why?
- When you think about all of the stages, what are your suggestions to improve this process? Why?

Phase 5: Follow-up interview

- Where is the artifact now? Why is it there?
- Have you handled the artifact since our last meeting?
- Has anything changed since the day that you handled the artifact first?
- Do you want to keep this artifact that has your audio mark? Have you assigned

any function to it?

- Would you want to reach to the sound recording that you gave through an internet address that only you have access to?
- What do you think about the process of transformation of your audio mark into a three-dimensional tangible artifact and your personal experience?
- When you look back, do you have any suggestions to improve the process?

B. Summary of Suggestions for the Next Version of the Transformation Process

The following table summarizes the suggestions for improving the transformation process by changing the design of the transformation process. Recommendations with a check mark illustrate that they are implemented in the next version of the process. On the other hand, the others are difficult to achieve within the study's timeframe or are not of primary importance. After the summary of the suggestions table, recommendations and their ways of implementation are explained. Check marks in Table 7.2's last column indicate the suggestion is decided to be implemented, and the flags indicate that implementation seemed to be not feasible within the constraints of the study timeline.

Table 7.2 Suggestions for improvement of the transformation process

Categories	Subcategory	Properties	Suggestions for improvement	Definition	Developed in the next version
Accessibility	Flow of process	Duration and progression of the process	Decrease researcher intervention	Decrease researcher intervention	✓
			Manufacturing process video	Enable participants to see the manufacturing phase through a time-lapse video of the printing process	

Table 7.2 (Continued)

	Unattended realization of transformation	The familiarity of the programs used	Integration of a progress bar	Integrate a progress bar to communicate what done and what is next in the process to strengthen the step-by-step progression of the study	
		Low-cost alternative for the attended version		---	
		Stronger connection with the artifact	Increase participant involvement and let experimentation	To increase engagement and let experimentation, an interactive interface can be designed for the participants to lead the personalization of form by themselves, enable a better reflection of personal preferences, eliminate the concern of being judged, increase the sense of identity, facilitate experimentation with different surface and form alternatives.	✓
			Easy selection of different sound sources	Next version of the process should let easy selection of different sound sources to increase engagement and let participants easily and quickly see how other sound sources come out in the process.	✓
Aesthetics	Personalization of artifact	Functionalization of the artifact	Function-specific material selection.	Usage function specific material selection in the transformation process can be integrated into the interface.	✓
			The emphasis of ephemeral to permanent transformation	The transformation process should be emphasized as converting something ephemeral to permanent.	
				The social function of the process should be investigated	
			Different sized template artifacts	Different sized template artifacts can be presented to the participants in the process to get feedback about different use cases	

Table 7.2 (Continued)

		Sound distribution across the artifact surface	Homogeneous sound data distribution across the surface.	Audio data should be automatically adjusted to fit the entire surface before showing the result to the participant to provide a more homogeneous distribution across the surface.	✓
			Audio data orientation selection	Audio data orientation should be easily adjustable in the interface	✓
		Stylistic preferences	Meaning specific material selection	Other material types should be presented to the participants that can enhance the meaning and increase the value given to the artifact through its material selection.	
		Surface enhancement	Audio normalization	A method of normalizing the amount of displacement on the artifact surface should be developed to prevent dissatisfactory initial results in which the surface is too much deformed or not enough deformed.	
			Parametric surface properties	Participants should be enabled and encouraged to play with the artifact by themselves since they do not know how far they can go with the deformations on the surface of the artifact.	✓
		Use of different sound sources	Easy switching between audio files	Next version of the process should allow easy swapping of different recordings that would enable the participants to see the results of their actions real-time.	✓
Clarity	Audio-visual connection	Beginning and ending of sound/looping non-looping	Audio section selection	The next version of the process should let the participant decide on the audio section, a way of emphasizing beginning and the end of the recording should be developed	✓
		Degree of need for specific marks	Realtime transformation of sound to an artifact	Eliminate the spectrogram phase and directly transform audio to artifact form to decrease cognitive processing, increase the clarity of the transformation process, and construct a stronger audio-visual connection.	✓

Table 7.2 (Continued)

				The density of audio visualization should be balanced to prevent too crowded compositions that make it hard to interpret separate marks on the surface of the artifact.	
		Real-time experience of transformation moment	Realtime playback of sound	Realtime playback of sound should be realized on the artifact surface to eliminate the need for a spectrogram image	✓
			Making the transformation process a part of the memory	The participant decisions during the transformation process, evolution of the form with the sound should become a part of the presented memory	⚑
		Returning back to sound	Reaching the sound recording through the artifact	The original sound recording should be reachable through a QR code integrated onto the artifact surface.	⚑
		Role of rhythmic sounds for recognizing connection patterns between sound and artifact form	Allow more dramatic changes on the artifact surface	The transformation process should allow more formal deformation and changes related to the appearance of the artifact.	✓
		Translating perceived properties of sound to artifact form	Allow more control over the form of the artifact	Participants should be allowed more control over the form of the artifact	✓
				Surface editing definitions such as louder, softer, quiet, pure can be tested for different types of audio instead of "bump amount" and "surface smoothness."	
Meaning	Connection to memory	Audio sample part as a representation of whole memory	Adjustable audio duration and section	The duration and section of the audio should be adjustable by the participant	✓
		Connection to positive feelings	Requesting audio with intense personal meaning	When requesting audio from the participants, it should be emphasized that the selected audio recording should have a strong personal meaning for the participant.	✓

Table 7.2 (Continued)

Permanence	Becoming a permanent memory	Tangibility of artifact	The sound should be reachable by using the artifact	The sound should be reachable by using the artifact	
				Durable materials should be presented as an option	
Social clarity	Connecting people	Sharing a common memory		A presentation of the transformation process should be integrated into the artifact that has the information about what the audio recording is, how it translates onto the artifact surface, how the artifact becomes physical (optional)	
	Sound-artifact connection comprehension	Understandability of the connection between the sound and the artifact by a stranger		A video of a narrative of the transformation process can be embedded into the artifact to tell an outsider about the creation of that artifact. In this narrative scenes from the following stages of the transformation process should be presented: audio selection phase, playing selected sound, real-time translation of sound data onto the artifact surface, final artifact's 3D rendering with a scanline synchronized with audio playback that shows which part of the artifact corresponds to the selected audio, 3d printing phase of the artifact.	

C. Thematic Analysis Example Participant Responses

Example participant responses and coded categories are presented in the table in the next page.

Table 14 Category definitions and examples from the user studies conducted with 5 participants

<table>
<thead>
<tr><th>Categories</th><th>Description</th><th>Sub Category</th><th>Description</th><th>Properties</th><th>Description</th><th>Example Response</th><th>P #</th><th>Example Response Summary</th><th>Insight</th></tr>
</thead>
<tbody>
<tr>
<td rowspan="4">Accessibility of transformation</td>
<td rowspan="4">This category covers participant comments that are about the transformation process itself such as the length of the process, the ease of the transformation process and their implications.</td>
<td>Flow of process</td>
<td>How the transformation process progresses from the perspective of the participant. Is it boring? Is something unpleasant happened?</td>
<td>Duration and progression of process</td>
<td>Overall experience of the transformation process concerning length and the way of its progression</td>
<td>P1 | Şu anda benim elime verilen şeyin, bu kadar zorlanmadan elime gelmesi olağan üstü bir şey. Zorlanmadım, hiçbir şey yapmadım. Kaydettin, grafiği gösterdin, bastın, basılışını gösterdin, elime geldi. Yani bu süreç çok kısa geldi bana.</td>
<td>1</td>
<td>P1 is fascinated by the ease of the manufacturing of such a special artifact without any friction. This sound to artifact transformation period has been very fast and short for her.</td>
<td>Although the manufacturing phases is long to participate, the shortness of virtual to physical artifact stage fascinates the participant and feels very empowering.</td>
</tr>
<tr>
<td rowspan="3">Unattended realization of transformation</td>
<td rowspan="3">The possibility of participant making the transformation all by himself/herself and its benefits. What would happen if the participant was able to do this transformation without any outside intervention?</td>
<td>Familiarity of apps</td>
<td>Participants' interpretation of the apps used in the transformation process</td>
<td>P1 | … Öneri adı altında bir şeyi zannetmiyorum çünkü o kadar böyle adım adım gösterdiniz ki yapılışını sanki her şey çok… alsam yaparmışım gibi geliyor. Fakat bu programlara hakikaten kullanabilir olmak buradaki en önemli etken. Yani bilmiyorum. Öneride o yüzden bulunamıyorum.</td>
<td>1</td>
<td>P1 does not think there are problems in the process. The process is shown to her in such a step by step manner that P1 thinks as if P1 can do the same process by herself. P1 thinks that being able to use these programs is the most important thing here. Because of that P1 cannot make any recommendations.</td>
<td>The different programs used in the process (Modo, Sonic Visualizer, Photoshop, Audition) are very strange to the participant that P1 cannot make any suggestions since P1 does not know or understand how that process works. However, the step by step nature of the process helps her to feel as if P1 is also able to do the same thing by herself.</td>
</tr>
<tr>
<td>Unattended version as low-cost alternative</td>
<td>Being able to realize the process unattended would make the process cheaper and quicker</td>
<td>P3 | ...diyelim ki bir şey yapmak istiyorum başkasına bağımlıysan bu daha geç olur ama kendim yaparsam daha hızlı, tık diye yaparım... Onun için bence daha çok daha ucuza mâl olsun daha hızlı yapayım.</td>
<td>3</td>
<td>She wants to be able to make this process by herself because of being faster and without bound by another person. Also she thinks that it might be cheaper.</td>
<td>Transformation process involving the researcher implies to the participant that the process can be expensive and dependant on another person.</td>
</tr>
<tr>
<td>Unattended version as engaging alternative</td>
<td>Being able to make the transformation unattended establishes e stronger connection between the artifact created and the participant.</td>
<td>P5 | Customizable bir sey hep daha degerli oluyor. Benlik hissi yarattigi icin. Idea falan, o yuzden cok guzel bir yol olabilir. Bunun icin mesela application'i kaydettigin sesi gonderiyorsun Efe'ye gonderiyorsun Efe basiyor sana bunu kargoyla yolluyor gibi bir sey. O customize kisminda sen de bulundugun zaman ozellesebilir. Progress de ozellesebilir, son urun de. Bak ben yaptim gibi.</td>
<td>5</td>
<td>He thinks maybe it would be better for people to do this process by themselves in an application, that would let them to be able to think better. Something that is customisable is always more valuable. Because it creates the sense of identity</td>
<td>If the participants were given an app that they could do this process by themselves, it could let people to “think better” and completely tweak the artifact as they want. Maybe because there is not an intervener into the process, being done something “all by themselves” can strengthen the sense of identity and belonging.</td>
</tr>
<tr>
<td>Aesthetics of transformation</td>
<td>This category covers form and function related participant intervention.</td>
<td>Personalization of artifact</td>
<td>The ways participant uses to personalize the form of an artifact such as function, appearance, composition.</td>
<td>Functional attributes</td>
<td>Participant's trying to find use cases for the resulting artifact offering different materials and form choices</td>
<td>P1 | Belki özel bir ünitenin etrafına, yani bunu böyle değil de atıyorum bir kalemlik halinde, masa üstü sürekli çalışan bir insanın elinin altında ve benden ona dilekler, bir mesaj. Yani iyilik ve doğruluk adına bir mesaj. Mesela düşünsene, bunun çok güzel basılmış bir fotoğrafı ya da atıyorum evinde çok sevdiğin bir hayvanın var. … Köpeğinin görüntüsünü basıp, bir de altında onun sesini kaydediyorsun. Doğmuş çocuğun var. Fotoğrafını çekiyorsun, bilmem ne yapıyorsun, onu koyuyorsun. Altında da işte bunu basıyorsun. …. Ya da çok önemli bir projeyle uğraşıyorsun. O projenin ana, temel şeylerini basıyorsun ve masanın üzerine koyuyorsun. … Ne</td>
<td>1</td>
<td>P1 wants to print anything that comes into her mind and distribute the things to people P1 loves. A decorative table ornament that will have wishes of P1s and her message. P1 gives other gift ideas concerning kids, pets, important projects, wall panels out of Brahms, Bach or Perfect strangers. P1 thinks the things that you will do is related with your character. After seeing the usage areas of 3D printing, P1 thinks that there is no limit to this.</td>
<td>The period at which the participant spends from start to finish might have important effects on the overall experience. The ease of manufacturing and customised artifact creation empowers the user to do other things.</td>
</tr>
</tbody>
</table>

Categories	Description	Sub Category	Description	Properties	Description	Example Response	P #	Example Response Summary	Insight
						bileyim ilim, bilim adına bir noktalarda gelmesini istediğin bir yön çizmek istiyorsan, ona kanalize ediyorsun beynini, onun üzerinde çalışmaya başlıyorsun. …. Mesela bir arkadaşım yemek masası kurmaktan çok hoşlanıyorsa, o masada kullanacağı aksesuarların imal edilip, onların üzerine çeşitli esprili şeylerin basılmasını isterim. Ya da çok ünlü bir müzikhol mesela… Böyle bir şey, dekorasyon da… … Bach'ın ya da Brahms'ın bir eserini ya da Perfect Stranger'ın bir bölümünü ya da … … Yani bunların basılıp duvar kaplamaları haline dönüşmesini isterim. Ya da o kaplamaların içerisindeki birkaç tane tuğlanın onlardan olmasını isterim.			
				Sound distribution on surface	*Participants' preferences and comments about the placement of spectrogram image (and in connection: sound data) on the artifact surface*	P5 | Ses icin bu continuous bir sey gibi ya, silindir, daire hani devamlilik yaratan, hissettiren bir sey. Atiyorum kutuda oyle bir sey yok, her kosesine farkli bakiyorsun. Bunda gayet organik bir yapi var, ses de organik yapi, o yuzden secebilecegin en iyi sekil buyuk ihtimalle silindir ya da dairesel bir sey olacak.	5	He connects the continuity of sound and form. He thinks box does not have such a continuity so best forms would be cylindrical or circular forms according to him.	Circular form is suitable for such kind of continuous inputs like sound (or a song more specifically).
				Stylistic Attributes	*Participants' preferences that are connected with visual appearance of the artifact such as color and style (when "style" is specifically used)*	P5 | Hm hm hmmmm. Yani direkt tekrarlayan his icin soyleyecegim, cunku hic oyle hayatimda gumus altin falan cok … ona karsi bir fetisim olmadi ama… Metal mi yani? P5 | Sonucta onlar da metal ama bir metalin uzerine… ama bu sefer de puruzden kaybetmeye baslayacak. Yok puruz olur yine. P5 | Olur mu? Yani olur olur. P5 | O zaman herhalde agir bir demirden, herhangi bir metalden ya da ne bileyim uzaydan dusmus bi r tas… Metal olmasinin nedeni ne? P5 | Daha dolu gibi boyle. Su mesela soyle baktigim zaman agir bir sey olmasini bekliyorum. O iste aciklayabilecegim bir sey degil tam olarak sozle. Peki metal ve ses arasinda bir bag olabilir mi? Ya da metal ve parcanin senin icin anlami arasinda kurdugun bir sey var mi? P5 | Onun icin degil ama mesela sen onu diyince sey anladim. Ses dalgalari da sonsuzluga giden bir sey ya, metal de gayet dayanikli bir sey ya. Atiyorum altin mesela, currecy'nin kaybolmamasindan insanlarin altin kullanmasi. Ses de yok olmuyor metaller de zor…, yok edilebilen seyler degil yani oyle kolay kolay.	5	He mentions he never had a fetish towards gold and silver. But he wants this to be made from a metal — gives an example of a stone fallen from the sky—, a heavy artifact and still wants it to be matte instead of shiny. He mentions that he is unable to explain his expectation of the artifact being heavier. When asked about a connection between metal and song, and metal and the meaning of song he mentions that metal is a more durable material that is harder to destroy and this can be connected with the material properties with sound's permanence.	Lightness of plastic makes the participant look for another heavier alternative. Also materials can bring new connotations or be used to strengthen permanence feeling of the resulting artifact, thus sound, thus memory.

Categories	Description	Sub Category	Description	Properties	Description	Example Response	P #	Example Response Summary	Insight
				Surface smoothness and bumps	*Participants' preferences about the surface smoothness and bump amount of the resulting form*	P3 | Normalde aslında ses dalgasının aynısını koysak çok betimsiz bir şey olacak. Belki sadece şu kısım gibi olacaktı ve daha böyle görsel olarak farkı, yani görsel ve işitsel duyu farklı işliyor.	3	When the initial spectrogram image is used, the form would be very unnoticable. She thinks if we were to put the same waveform the result would be very dull.	Participant needs further modification according to how s/he wants the artifact form to be interpreted. Lower bumps decrease the noticability of sound on the artifact
				Using diverse sound sources	*Participants who want to customize the form by trying other sound sources quickly and see what comes out of it*	P3 | Tabii bir sürü ses var. Başka sesler... Bence evet müzik sesi tamam. Belki böyle kaybettiğim, çok sevdiğim birinin sesi var elimde, onu yaparsın. Onu hatırlarsın. Bir çok farklı şeyde kullanılabilinir. Bir tanıdığım mesela heykeltraştı. Amatördü, çok profesyonel değildi ama kendi annesinin, babasının heykelini yapmıştı, koymuştu mesela. Esas ses olayını bu şekilde, en çok da müzede ama insan evinde de tutmak ister. Düşünsene mesela anneannemin ses kaydını, videosunu çekmiştik. Onunla ilgili en önemli cümlelerin bir kısmını al ve objeleştir gibi.	3	She wants to try this process again for many other sounds such as her grandmother's audio and video recordings. She would take the most important parts from that video and artifactify them. Also gives examples from a person she knows who makes amateur sculptures of his relatives.	The transformation process encourages the participant to try other sounds that are meaningful and valuable for the participant.
Clarity of transformation	This category covers participants' comments that reveal to what extent the transformation process is clearly understandable by the participants. Also ways for a better understanding of the process making the artifact more meaningful and valuable are included.	Audio-visual connection	*The ways participants connect an audible source (sound) to a visible source (image or form).*	Marking beginning and end	*The importance of being able to recognize the beginning and ending of the sound recording*	P3 | Hani bir demeç olsa belki önemli olur da şarkı olduğu için zaten sevdiğin şarkıları tekrar tekrar çalarsın. Ondan başı sonu burada çok önemsemedim ama atıyorum Atatürk'ün bir sesi olsa onda demeç olsa başta bu nokta önemli olurdu hani orada zaman koyardım	3	She thinks knowing the beginning and end of the recording is not very important since you already play songs you love again and again. But if it were a speech of Atatürk it changes.	P3 connects playing the songs again and again with the looping form of the cylinder. For songs not knowing the beginning and end is not important but if it is an important speech then it matters.
				Need for specific marks	*The importance of recognizability of certain bumps representing specific moments in the audio recording.*	P5 | Bunu seyde de programda bakarken de seyi konusmustuk. Bu dogrudan o sesi bana hatirlatamaz cunku ustunde cok oynadik artik o yumusakligi, last... gibi yumusak gitmek yerine boyle gayet agresiflesti bu. Ama dedigim gibi ben bunun guideline larini gorebiliyorum. Nerede baslayip bittigini buradan tahmin edebiliyorum, eminim yanlis dusundugum noktalar da oluyordur da. Iste benimle obje arasinda oldugu icin onun seyi var. Zilin nerde baslayip trampetin nerde girdigini burdan cozebiliyorum.	5	he can see the "guidelines" of the song on the artifact. Where parts of the song start and end. There might be parts he might be thinking wrongly but it is more important and enough for him to understand where the ringing of the bell starts and how the trumpet progresses.	Artifact's relation with the sound does not always need to be 100% traceable but being able to see some guides that tell the artifact is formed according to the sound is enough for the participant to understand how this transformation takes place.
				Real-time experience of image and sound	*The participants' comments about the realtime playack of the sound file together with the participant and its importance in understanding the process and establishing the audio-visual connection*	P1 | Evet, olayın başlangıcını bildiğin için. Hani oturdun, röportaj yaptın ya. Olayı anlatmasan ve aşamalarını birebir yaşamamış olsan daha anlamsız gelir. Ben burada şu başlangıç ve bitiş olduğunu, yani buradan sesimin patlayarak çıktığını, şunun "ve vicdan"ın olduğu yer olduğunu ve böyle gelip de bittiği noktanın bu olduğunu o görselde düzlem halindeyken bildiğim için, şimdi bunun üstünde de okuyabiliyorum. O yüzden, çok daha etkileyici.	1	P1 thinks that if P1 was not told about the initial stages throughout the study, the result would be less meaningful. P1 can literally read the words that P1 recorded from the surface of the artifact since P1 knows what corresponds to what. Because of that this is much more impressive for her. P1 thinks of a family that record their kids' voices in spirals as a perfect gift.	Seeing how the spectrogram image is formed helps meaning attribution. Being able to spot the things said, or understanding the connections between the parts of the sound and the surface of the artifact increases the meaning of the artifact.

<table>
<tr><th>Categories</th><th>Description</th><th>Sub Category</th><th>Description</th><th>Properties</th><th>Description</th><th>Example Response</th><th>P #</th><th>Example Response Summary</th><th>Insight</th></tr>
<tr><td rowspan="3"></td><td rowspan="3"></td><td rowspan="3"></td><td rowspan="3"></td><td>Returning back to the source of sound</td><td>The participants' comments about being able to play the sound they brought through the artifact and its importance in keeping the audio-visual connection while making the artifact more undestandable</td><td>P3 | Öbür türlü buna şey dersin, jeolojik fosilleri yapıyorduk ya onun gibi şuradan kalmış derisi dikenli falan gibi de diyebilirsin ama bunu biliyorsun ki ses dalgasının dönüşümünü ifade ediyor. Yoksa senin sorduğun sorunun en iyi yanıtı şu olurdu: Hiç sesi bilmeyen birisine bunu verdiğinde bunun sesten geldiğini tahmin edebilir mi? Bunu tahmin edemez şu an. Ben öyle düşünüyorum. Onun için bunu sesle ilişkili düşünmemiz lazım. Onda da hakikatten bunun içinden de ses çıkan bir şekilde olsa, daha da farklı şekilde bakıyor olur insan. Hem ekran görüntüsü hem bu iyice bütünleşiyor olur diye düşündüm.</td><td>3</td><td>Form- artifact and sound should have connections to have a meaning according to her. When this artifact is given to a stranger, s/he cannot guess that the form is coming from that sound. Otherwise it is indifferent from geological fossils. We have to think this artifact in relation to sound.</td><td>The connection between the sound and artifact is important for it to be a meaningful artifact. This connection is established through the explanation (story?) of how that artifact is formed.</td></tr>
<tr><td>Role of rhythm for recognizing patterns</td><td>The participants' comments about certain patterned sound recordings with repeating pauses like pauses between words or rhythms such as drums, bass or words etc.</td><td>P3 | Saksafonun inis cikislari bu sarkida cok belli ya onun her bir vurusunu goruyoruz burda...Evet direkt yani gorunuyor, hepsi cikiyor ve ayni tonun uzatmasini goruyoruz. Iliskisi var, kesinlikle. Yani sesi yansitiyor. Eslerin hepsini goruyoruz. Bu sey gibi hatta ilerde olur belki. Hani muzisyenler desifre eder ya notalari bu desifre ediyor.</td><td>3</td><td>Participant sees the connections between sound and image in the saxophone partitions. Rhythms are easier to distinguish for her. Also she mentions we can see all the pauses. She thinks its alike musicians’ decoding of notes.</td><td>Rhythmic parts and pauses enable easier recognition of sound image/form connections.</td></tr>
<tr><td>Translating sound's perceived properties into form</td><td>The participants' effort to modify the surface of the form according to the audial qualities of the sound to visual qualities of the surface. Eg. "Pureness" to soft surfaces, loud parts to higher bumps.</td><td>P3 | O zaman şöyle diyebilirim mesela evet sivri olmuş ama zaten bizim şarkımızda çıkışlar inişler bu şekildeydi ama dinlerken o şarkıyı, o yıpratıcı bir şarkı değil. Keyif veren ve mutluluk veren bir şarkı olduğu için bu çıkışlar gene gözüküp belki yumuşak, yani sivri değil de daha yumuşak gibi olabilir yani bu aralar biraz açılıp, buralar yükseltilebilirdi ama o zaman da nasıl olurdu? Şu araları daha netleşirdi ama o da kullanışlı olmazdı…</td><td>3</td><td>Evaluates the surface properties of the artifact. Connects the surface characteristics with the feeling song gives to her. If it is too sharp, yes there are downs and ups in the song but it is not a wearing song so the surface can be softer. If it was a metal song, it could be sharper but if there is saxophone then can be softer.</td><td>Rather than using the spectrogram image as is, participant prefers to modify the surface properties according to how P3 perceives the song.</td></tr>
<tr><td rowspan="2">Meaning of transformation</td><td rowspan="2">This category includes participant comments related with the meaning of the sound file they brought and its connection with the memory they have.</td><td rowspan="2">Connection to memory</td><td rowspan="2">The relationship between the sound participant brings and his/her memories about it.</td><td>Audio sample representing the whole memory</td><td>The participants' comments about the meaning of part of a long recording and to what extent it represents the memory as a whole.</td><td>P3 | sarkinin hepsini cok seviyorum ama sarkinin bu kismi sen de bana 10sn limitini verdigin icin dusundum zaten burasi cekiyor sarkinin insani ama senin calismani kolaylastiracaksa uzatabiliriz ama bence intro’su bunun yani.</td><td>3</td><td>For the participant, all of the song is important and meaningful but a 10s portion becomes enough for her since she thinks the intro part is the part that attracts the listener.</td><td>10s portion of the whole sound is enough for the participant since it is the part that attracts the listener.</td></tr>
<tr><td>Connection to positive feelings</td><td>The comments of the participant related with the reasons behind his/her choice of audio recording.</td><td>P3 | Bahsedeyim, yani sevdiğim bir sarki. Kaydı secme nedenin ne? - Kaydı secme nedenim ne zaman dinlesem bana gercekten enerjik ve iyi duygular hissettiren bir parca olması. Ayni zamanda benim icin özel ve anlamlı günlerde de bir video oluşturuyorsak ya da farklı bir sekilde kullanıyorsak mutlaka bu parçayı tercih ediyorum.... Çünkü her kosulda gercekten enerjisini yansitiyor ve cok iyi hissetmemi sagliyor. Yani verdigi iyi hislerden dolayı.</td><td>3</td><td>Participant selects a song that she loves, makes her happy, evokes energetic and good emotions whenever she listens to it. She prefers this song when she is making a video that has a special meaning for her. Although she mentions that she does not know the meaning of the song (in French), after looking it up on the internet, the meaning of the song title (je voux, I love you, she found a wrong translations since je veux means “I want”), she thinks that this is very suitable.</td><td>Participant prefers memories connected with positive feelings, events etc.</td></tr>
</table>

Categories	Description	Sub Category	Description	Properties	Description	Example Response	P #	Example Response Summary	Insight
Permanence of transformation	This category covers comments about how the transformation process makes the memory connected sound more permanent.	Becoming a permanent memory	*Transformation of sound, which is considered as a kind of memory that is ephemeral, into a physical artifact and become permanent.*	Tangibility of memory through artifact	*The participants' comments about the transformation of the sound into a solid artifact and its connection with the concept of permanence.*	P5 | Aha ben bunu bunu yaptim, sevginin karsiligi budur falan. Hayir o degildir de, elinde somutlastirabiliyorsun. Somutlastiramadigimiz seyi somutlastirmis olamanin verdigi kucuk mutluluklar oluyor. ......Soyle, anlam acisindan az once verdigim cevap gibi, orda gordugumle burda gordugum arasinda bir fark yok ama boyle dokunabildigim bir sey olmasi her zaman daha iyi. Yani dijital ortamda 0-1 den gayri bir sey var artik burda. Bu bir obje yani. Oyle bir cloud'un icinde gorunmeyen mecazi bir yerde, oyle bir space'te degil. Baya artik, aha iste, tugra gibi duruyor burda. O acidan daha fazla kiymete biniyor olmasi ondan kaynakli.	5	Transforming sound into artifact brings the happiness of making things concrete that normally we cannot.	.
				Translation among senses	*The participants' interpretations about the changes happening when something that can only be heard is transformed into something that can be seen and the way it adds to the memory's permanence*	P3 | İşte o gün de konuştuğumuz gibi kalıcı bir anlamı oluyor, ses uçup gidiyor gibi oluyor çoğu zaman. Sesi kapattığında duymuyor oluyorsun ama bu her zaman burada oluyor ve o sesin sana çağrıştırdığı şeyleri aslında hatırlatıyor oluyor.	3	The sound transforms into a permanent reminding artifact that remains there even when the sound is not playing. And that artifact reminds the memories the sound recall.	The transformation of sound into an artifact makes the presence of sound permanent even when the sound is not there.
				Multisensoriality	*Participants' comments about how the experience becomes a multisensory one and how that makes the experience more memorable*	P3 | Ona baktığında hep o sesle görüntü ilişkisini kuran bir şey olmuş oluyor daimi olarak. Çok boyutlu düşündüğünde öğrenmede bile ses, görsel, yazı derler ya. Burada da en çok akılda kalıcıdır bir şeyi öğrenirken ya da anlarken. Burada da bir şeyi hatırlarken aklında bir tablo var ve burada elinde dokunabildiğin bir obje var, ses var. Hepsini bütünleştirebildiğin bir şey aslında.	3	The artifact becomes a visual connector between the sound and form. This unifies 3 senses, a scene that you remember, an artifact you can touch, and sound. This makes the memory more memorable. The artifact for her is like a toy from her childhood that you cannot throw away because when you look at them you feel good and remember past times. An artifact that makes people feel however that sound makes them feel.	The transformation process addresses multiple senses, touching, seeing and hearing. Artifact becomes an emotional trigger recalling the memories and emotions that the sound reminds. Multisensoriality of the final artifact increases the persistence of the memory.
Social clarity of transformation	This category covers participants' comments related with their ideas about how the resulting artifact would be interpreted by a stranger who has not seen the process.	Connecting people	*Artifact becoming a connection between people that share the same memory.*	Sharing a common memory	*The Participants' comments about the artifact becoming a symbolizer or something that is shared between many people.*	P5 | senin yaptigin gorsel benim karsiya anlattigim kadar var. Cunku ben atiyorum sen baskilari gosterdin ya 3D, ben bunu bilmeyen birisine verdigim zaman ustune aciklama yapmam gerekiyor o da ikimizin arasnida bir sir olarak bile kalabilir. ....Yani, 2 insan arasinda ya da bir grup arasinda. Hani aslen total olarak bir grup icin bir sey represent ettigi zaman, bir seyi o insanlara animsatip anlattigi zaman sanki daha seyi ortaya cikacak gibi oluyor bunun Yani bu tekil, tamam OKAY bu benim objem ama hani buna anlam yuklemis bir grup icin daha baska olabilir. Onlarin sembolu olabilir, aitlik aidiye, ait hissetmelerini saglaya bir bag vardir aralarinda. Bu da belki onu pekistirecek bir obje olabilir. Cunku her seyde var yani atiyorum her dinin bile kitabi var, takimin logosu var gibi. Oyle bir sey hissettirdi simdi, ilk aklima gelen sey bu oldu.	5	He thinks that he needs to make an explanation after giving the artifact to somebody. After that explanation, it can even remain as a secret between two people. It depends on the perspectice. If the person wants to have an exclusive feeling then it turns into that. Or It can be a door handle or another thing.	The resulting form becomes understandable to the extent that it can be explained to someone who has not seen the process. It can be used to give an exclusivity feeling.

<table>
<tr><th>Categories</th><th>Description</th><th>Sub Category</th><th>Description</th><th>Properties</th><th>Description</th><th>Example Response</th><th>P #</th><th>Example Response Summary</th><th>Insight</th></tr>
<tr><td></td><td></td><td>Comprehending sound-artifact connection</td><td>The understandability of the existence of a connection between the artifact and sound.</td><td>Interpreting the connection by audience</td><td>The participant's comments, concerns and solutions about the artifact's understandability by strangers.</td><td>P5 | Ama soyle bir durum da var, ben bu objeyi gordugum zaman icerisindeki anlam zaten benim ona yukledigim bir anlam. Ben bunu kime verirsem vereyim, bak bunun icinde bu sarki var dedigim zaman hadi len diyecek bana, o yuzden bu benim. Bana ait bir sey. O yuzden bu gorseli benim secmis olmam, bunu dogrudan ben seciyorum o yuzden sesle arasindaki bag benim kafamda. Yani kisiyle obje arasinda.
.... - Bu şeyin nasıl olduğunu anlattım. Başta hani bu 3d printerı hiç duymamış. Anlattığımda tam anlamadı.. Bunlar ses dalgaları falan dedim, nasıl yani ses dalgası falan dedi. Üstüne Outlaws'ı, last gunfight ı ondan sonra üstüne sesin temsili olan bir şeyle falan diye… Bu prosesi anlattım, nerden başladığını nerede bittiğini falan anlattım.
Öyle anlatınca ne dediler?
- Anladı, artı olarak hoşuna gitti. Önceki konuşmamızda mı tam hatırlamıyorum da, hediye olarak çok fazla potansiyeli var diye bir şey demiştim. Annemde de gördüm onu. Herhalde yaptırırdı.</td><td>5</td><td>He thinks when the artifact is shown to a stranger and explained that this is the song he likes a lot, people will not see that. Because of also this, he thinks modifying the appearance of the artifact by the person is important since the connection between the artifact and sound is in his mind. In other words between the artifact and the person.</td><td>The connection between the sound only exists in the mind of the participant and it is not much possible to communicate that connection to a stranger.. Because of this participant does not have any concern about changing the initial appearance of the artifact.</td></tr>
</table>

D. E-Mail Sent to the Design Workshop Participants

Merhabalar,

Çalıştaya kaydınız için teşekkürler. Çalıştay tamamen uzaktan bağlantı ile gerçekleşeceğinden o gün geldiğinde sürecin sorunsuz ilerleyebilmesi için gerekli olan bilgileri aşağıda bulabilirsiniz:

Çalıştaya katılabilmeniz için https://www.efealpay.com/utak2020 adresinde yer alan "Veri Girişi" butonuna tıklayarak açılan sayfadaki formu doldurmanız gerekmektedir. Kolay ve hızlı iletişim sağlayabilmek adına geçici olarak bir Whatsapp grubu kurulacaktır ve ona dahil olup olmak istemediğinizi belirtilen formda işaretleyebilirsiniz.

Katılımcılardan kendileri için bir anısı olan ve duygusal açıdan güçlü öneme sahip, **en fazla 10 saniye** uzunluğunda bir **ses kaydını** mp3, wav veya aiff dosyası halinde en geç **4 Eylül Cuma günü saat 17:30'a kadar** yukarıda belirtilen formdaki ilgili alana ("ses kaydı seçimi") yüklemeleri beklenmektedir. Aynı formda bu ses kaydını **neden seçtiklerini ve onlar için önemini anlatan kısa bir açıklama** yazmaları beklenmektedir. Ses kaydı müzikal bir kayıt olabileceği gibi cep telefonlarındaki ses kaydetme özelliği ile ya da başka bir şekilde yapılmış kayıtlar da olabilir. Gönderilecek kayıt bir video kaydı da olabilir. Ancak bu durumda katılımcının bu video dosyasındaki hangi saniyeler arasındaki sesi kullanmak istediğini belirtmesi gerekmektedir. Eğer seçtiğiniz ses dosyasını kırpmakta sorun yaşarsanız gönderdiğiniz dosyada hangi saniyeler arasını (en fazla 10 saniyelik bir aralık olabilir) kullanmak istediğinizi de belirtebilirsiniz.

Çalıştayda sizden beklenenler:

- Parsec (https://parsecgaming.com) ve Zoom (http://zoom.us) yazılımları kurulu, webcam'e ve mikrofona sahip bir bilgisayar.

- Kulaklık (çalıştay sırasında kullanılacak seslerin konuşma seslerine karışmaması için kulaklık kullanmanız gerekmektedir)
- Kararlı/kesintisiz bir Internet bağlantısı

5 Eylül Cumartesi günü 14.00-16.00 saatleri arasında tüm katılımcılarla bir bağlantı testi yapılacaktır. Eğer katılamama durumunuz varsa önceden bilgi vermeniz beklenmektedir. Zoom bağlantısı Cuma günü ayrı bir mail ile paylaşılacaktır.

Çalıştay ile ilgili bilgilendirme ve izin formunu ilişikte (consent form.docx) bulabilirsiniz. Aklınıza takılan herhangi bir soru olursa çekinmeden sorabilirsiniz.

Katılımınız için tekrar teşekkürler!

Cumartesi günü bağlantı testinde görüşmek üzere,

Efe Alpay

E. Design Workshop Consent Form

Orta Doğu Teknik Üniversitesi (ODTÜ) Mimarlık Fakültesi
Endüstri Ürünleri Tasarımı Bölümü

Eylül 2020

Görüşme için katılımcı izin formu:

Bu çalıştay, ODTÜ Endüstri Ürünleri Tasarımı Bölümü'ünde yürütülmekte olan Efe Alpay'ın doktora tez çalışması kapsamında yapılmaktadır. **Araştırmanın amacı birlikte tasarım yaklaşımıyla kullanıcılar için özel anlam ve değeri olan seslerin nesnelere dönüştürülmesi amacıyla ürün anlamını güçlendiren kişiye özel yeni bir süreç önerisi geliştirmektir.** Görüşme sırasında elde edilen veriler yalnızca bilimsel amaçlarla, tasarım sürecinde, tez çalışmasında, bilimsel yayınlarda ve sunuşlarda kullanılacaktır. Katılımcıların kimlik bilgileri saklı tutulacaktır. Konuşulanları ve süreci daha sonra tam olarak hatırlayabilmek ve gözden geçirebilmek için görüşme kaydedilecektir. Görüşme sırasında ekran görüntüleri, konuşmalar ve webcam görüntüleri kaydedilecektir. Tüm çalışma üç aşamada gerçekleşecektir. İlk aşamada süre tanıtılacak, ikinci aşamada ana çalışma ve ilgili görüşme gerçekleştirilecek, üçüncü aşamada da süreçle ilgili sunum ve geri bildirimler olacaktır.

Bu çalıştaya katılarak yapılacak araştırma konusunda size verilen bilgiyi anladığınızı ve görüşme yapılmasını onayladığınızı belirtmiş oluyorsunuz. Çalışmaya katılmanız yasal haklarınızdan vazgeçtiğiniz anlamına gelmemektedir; ayrıca araştırmacının, katılımcıların, ilgili kişi ve kurumların yasal ve mesleki sorumlulukları devam etmektedir. Çalışmaya katılım gönüllülük esasına dayanır. Araştırma, katılımcılar açısından herhangi bir risk taşımamaktadır. Görüşme sürecinin başlangıcında veya herhangi bir aşamasında açıklama yapılmasını veya bilgi verilmesini isteyebilirsiniz. İstediğiniz zaman gerekçe belirtmeksizin görüşmenin durdurulmasını talep edebilirsiniz. Araştırmaya katkıda bulunduğunuz için teşekkür ederiz.

Katılımcının adı soyadı İmza Tarih

Araştırmadan sorumlu araştırmacı ve öğretim elemanı:

Efe Alpay Doç. Dr. Çağla Doğan

ODTÜ Mimarlık Fakültesi Endüstri Ürünleri Tasarımı Bölümü Tel: 0312 210 22 14

Bu formun bir kopyası katılımcıya verilmelidir.

F. Pre-Workshop Preparations Protocol

Installation of the necessary software

[Parsec]

Parsec yazılımını aşağıdaki web sitesinden indirin / Download Parsec from the web page: https://parsecgaming.com/downloads/

Parsec programını bilgisayarınıza yükleyin ve aşağıdaki bağlantıdan bir hesap oluşturun. / Install Parsec on your computer and create an account at https://parsecgaming.com/signup/

Bilgisayarınıza yükledikten sonra Parsec'i çalıştırın ve oluşturduğunuz hesap bilgileri ile giriş yapın. / Open Parsec that is installed on your computer and login with the account information you have created.

[Zoom]

Aşağıdaki adreste "Sign up, it's free" bağlantısına tıklayarak yeni bir hesap oluşturun. / Create an account by clicking Sign Up, It's Free button on the web page: https://zoom.us/

Aynı web sayfasından Zoom uygulamasını indirin ve bilgisayarınıza yükleyin. / Download and install Zoom application from the same web page.

Video konferans ve program kullanımı açısından sorun yaratmamak adına mikrofonlu bir kulaklık kullandığınızdan emin olun. Notebooklarda olan dahili mikrofonlar kullanılan yöntemde yankılanma sorunlarına neden olduğundan kullanılamamaktadır. / Make sure that you have headphones with microphones. Please do not use the internal speaker and microphone on your computer since that will cause problems in the legibility of the communication and recording process.

You can watch a tutorial video explaining the steps above in the following link: [youtube video link here]

Çalıştay uzaktan bağlantı ile gerçekleştirilecek olduğundan, çalıştay günü gelmeden sizinle iletişime geçilerek bağlantının sorunsuz çalıştığının teyit edilmesi gerekmektedir. Bu nedenle aşağıdaki takvim bağlantısından size uyan bir aralığı seçmeniz durumunda kararlaştırılan tarih ve zamanda sizinle iletişime geçilecektir. Ancak öncesinde yukarıda belirtilmiş olan yazılımların bilgisayarınıza kurulmuş olması ve hesap oluşturmuş olmanız önemlidir. / Since the workshop will be held via remote connection, you should be contacted before the workshop day arrives to confirm that the connection is working smoothly. Therefore, if you choose a suitable interval from the calendar link below, you will be contacted on the agreed date and time. However, it is important that the above-mentioned software is installed on your computer and that you have created an account.

[https://boomerangcalendar.com]

Protocol for pre-workshop connection test

Send a zoom meeting and Parsec links via e-mail to the participant at the predetermined date by boomerang calendar.

Start the zoom meeting.

Start screen recording on the host computer via OBS screen recording service.

Ask the participant to connect to the researcher computer through the Parsec link.

If the connection is established, open the Cinema 4D interface to let the user try the interface.

Adjust the window that displays the participant camera so that it can be recorded to the OBS video capture.

Check if the participant hears the sound file when s/he hits play.

Check if -while the sound is being played- the participant hears the researcher talking.

If working fine, gather internet connection information (service provider, speed, system info, connection type -wifi, ethernet or hotspot-) and end test session.

If there are problems with the connection, gather system and internet connection information and try a 10 minutes troubleshooting session. If nothing can be solved or the source of the problem can not be found, abort session and eliminate the candidate from the final participant list (maybe they can participate in the presentations and discussions phase?).

After the test, make sure that the screen recording has all the necessary sounds and visuals recorded without problems.

User audio setup

After receiving the audio file from the participant, load the file into the scene.

Adjust the viewports and control panel on the screen so that the participant is faced with a simple interface rather than the Cinema 4D's complex interface.

G. Design Workshop Protocol

Bu süreçte sizden beklenen aklınızdan geçenleri sesli olarak dile getirerek seçmiş olduğunuz ses kaydını ekranda gördüğünüz modeli kişiselleştirmek için kullanmanızdır. Yapacağınız seçimlerde veya değişikliklerde neyi düşünerek bu değişiklikleri yaptığınızı belirtmeniz araştırma için önem taşımaktadır. / *In this process, what is expected of you is to use the audio recording you have chosen to personalize the model you see on the screen by expressing what is on your mind. It is important for the research that you state what you think about in the choices or changes you will make.*

Bana seçmiş olduğunuz ses dosyasından bahsedebilir misiniz? / *Can you tell me about the audio file you chose?*

Özellikle bu kaydı seçmenizin nedeni veya nedenleri neydi? / *What was the reason or reasons for choosing this particular record?*

Seçtiğiniz sesin ne gibi özellikleri var? Sesinizi bir kaç sıfat kullanarak tanımlasaydınız hangi kelimeleri kullanırdınız? / *What features does the sound you choose have? If you could describe your voice using a few adjectives, what words would you use?*

Introduction of the customization interface

[Viewport window]

Bu alanda ses ile özelleştireceğimiz nesneyi istediğiniz açıdan görebilirsiniz. / In this area, you can see the object that we will personalize with sound from any angle.

[Viewport zoom and rotate buttons]

Sağ üst köşede bulunan bu butona basıp sürükleyerek nesneye yaklaşıp uzaklaşabilir ve bu butona basılı tutup sağa sola çekerek nesneyi farklı açılardan görebilirsiniz. / You can move closer and further away from the object by pressing and dragging this button in the upper right corner, and you can see the object from different angles by keeping this button pressed and pulling it left and right.

[Parametric Interface – Surface properties]

Bu alanda ise seçmiş olduğunuz ses kaydının nesne üzerindeki etkisini değiştirebileceğiniz kontroller yer almaktadır. Sesin nesne üzerinde neden olduğu kabartı miktarını, yüzeyin yumuşaklığı gibi değişkenleri bu çubukları kaydırarak isteğinize göre ayarlayabilirsiniz. / In this area, there are controls where you can change the effect of the sound recording you have selected on the object. You can adjust the variables such as the amount of relief caused by the sound on the object and the softness of the surface by sliding these bars according to your desire.

[Parametric Interface — Orientation of time]

Buradaki butonlar ile sesin nesne üzerinde hangi yönde ilerleyeceğini seçebilirsiniz. / With the buttons here, you can choose in which direction the sound will move on the object.

[Parametric Interface — Material Selection]

Nesnenin görünümünü buradaki malzeme seçimini değiştirerek istediğiniz gibi değiştirebilirsiniz. / You can change the appearance of the object as you wish by changing the material selection here.

[Start-stop the transformation]

Buradaki oynatma tuşuna bastığınızda ses dosyanız çalmaya başlayacak ve ekranda gördüğünüz nesne gerçek zamanlı olarak sese göre değişmeye başlayacaktır. Bu tuşa bastığınızda ses kaydınızı da kulaklıklarınızdan duyabiliyor olmanız gerekir. Eğer sesi duymakta bir sorun yaşarsanız sorunu lütfen araştırmacıya bildirin. / When you press the play button here, your audio file will start playing and the object you see on the screen will start to change in real time according to the sound. When you press this button, you should be able to hear your audio recording through your headphones. If you have a problem hearing the sound, please report the problem to the researcher.

Oynat tuşuna bastığınızda ses çalmaya ve yüzey sese göre şekil değiştirmeye başlar. Tekrar bastığınızda oynatma işlemi durur. / When you press the play button, the sound starts to play and the surface changes shape according to the sound. Press it again and playback stops.

[Selection of audio section]

Buradaki çubuğun ortasına tıklayıp sürükleyerek sağa ya da sola doğru kaydırdığınızda ses dosyanızın hangi bölümünün nesne üzerinde kullanılacağını seçebilirsiniz. Bunu işlevi getirdiğiniz ses kaydının başını ortasını ya da herhangi başka bir bölümünü seçmek içmek için kullanabilirsiniz. Örneğin ses dosyanız bir müzikse, parçanın başlangıcı yerine isterseniz özellikle nakarat kısmından bir bölümünü kullanmayı tercih edebilirsiniz. Ya da birinin konuşma kaydıysa o kayıtta söylenen sözlerden sizin için anlamı en çok olan kısmını kullanmayı tercih edebilirsiniz. / By clicking and dragging the middle of the bar here, you can select which part of your audio file will be used on the object when you slide it to the right or left. You can use this function to select the beginning, middle or any other part of the audio recording you have brought in. For example, if your audio file is a piece of music, you can choose to use a part of the chorus instead of the beginning of the track. Or, if it is a recording of someone's speech, you can choose to use the part of the words spoken in that recording that has the most meaning to you.

[Control is handed to the participant]

Şimdi daha önce gösterdiğim gibi oynatma tuşuna basarak sesin formu nasıl şekillendirdiğini görebilir ve form üzerinde dilediğiniz değişiklikleri yapabilirsiniz. / *Now you can see how the sound shapes the form by pressing the play button as I showed you before, and you can make any changes you want on the form.*

[Katılımcı arabirimde çalışmaya başlar] / *[The participant starts to work on the interface]*

[Bir süre katılmcının yapılabilecekleri üzerinde konuştuktan sonra katılımcıyı kendi haline bırak Hangi değişiklikleri neden yaptığını, yaparken anlatmasını hatırlat] / *[Leave the participant alone after discussing what can be done for a while. Remind them to tell what changes they made and why.]*

Ses kaydı ile nesne / sonuç arasındaki ilişkiyi nasıl değerlendirirsiniz? Hangi bölgelerin bağlantılı olduğunu düşünüyorsunuz, tek tek göstererek lütfen nedenlerini açıklayın? / *How would you evaluate the relationship between the sound recording and the object/result? Which regions do you think are connected, please explain why by showing one by one?*

Birbirleriyle ne ölçüde ilişkililer? Neden? "Çok alakalı = 7" "Hiç alakası yok = 1" derecelendirin / *To what extent are they related to each other? Why? Rate "completely relevant = 7" "no relevance = 1"*

Category: Accessibility of transformation

Sub-categories: Flow of the process, Unattended realization of transformation

Bu arayüz, nesnenizi sesle özelleştirmenize / kişiselleştirmenize ne ölçüde izin veriyor? Özelleştirme sürecinizde ne tür kesintiler olmuş olabilir? Neden? / *To what extent does this interface allow you to customize/personalize your object with sound? What interruptions might have occurred in your privatization process? Why?*

Burada sunulan özelleştirme seçenekleri ne ölçüde yeterlidir? Yeterli değilse neden? Neleri tercih ederdiniz? Neden? Kişiselleştirme seçeneklerini nasıl değerlendiriyorsunuz? / *To what extent are the personalization options presented here adequate? If not enough, why? What would you prefer? Why is that? How do you evaluate the personalization options?*

Kişisel tercihleriniz son forma ne ölçüde yansıtılıyor? Bu deneyimi iyileştirmek için tercihleriniz veya öneriniz ne olurdu? / *To what extent are your personal preferences reflected in the final form? What would be your preferences or suggestion to improve this experience?*

Kişiselleştirme seçeneklerini nasıl değerlendiriyorsunuz? Burada sunulan özelleştirme seçenekleri (tek tek üzerinden geçerek) ne ölçüde yeterlidir? Yeterli değilse neden? Neleri tercih ederdiniz? Neden? / *How do you evaluate the personalization options? To what extent are the personalization options presented here (going through them one by one) sufficient? If not enough, why? What would you prefer? Why?*

Category: Aesthetics of transformation

Sub-categories: Personalization of object

Functionalization of object

Size göre, oluşturduğunuz formu farklı malzemelerden yapılmış olarak görmenin etkileri neler? / *In your opinion, what are the effects of seeing the form you have created as made of different materials?*

Sound distribution across the object surface

Ses kaydının başını ve sonunu form yüzeyinde ne açıklıkta görebiliyorsunuz? Neden? Nesne yüzeyindeki ses dağılımıyla eşleşen ses özellikleri nelerdir? / *How clearly can you see the beginning and end of the sound recording on the form surface? Why? What are the sound properties that match the sound distribution on the object surface?*

Vertical or horizontal orientation for clarity and meaning – Zaman algısı ile ilgili olarak ses kaydının form yüzeyinde ilerleme yönü olarak neden bunu tercih ettiniz? Sizce sesin form üzerinde ilerleyiş yönü anlam ve anlaşılabilirlik açısından ne ifade ediyor? / *Regarding the perception of time, why did you choose this as the direction of progress on the form surface of the sound recording? What do you think the direction of sound on form means in terms of meaning and intelligibility?*

Surface enhancement

Form properties and aesthetics of transformation – Seçtiğiniz sesin özellikleriyle, oluşturduğunuz formun hangi özellikleri (pürüzsüz, yükseklik genişlik, kabarıklık) uyuşuyor? Neden? / *What features (smoothness, height, width, surface bumps) of the form you create match the characteristics of the sound you have chosen? Why?*

Material choice and attributed features for clarity and meaning – Seçtiğiniz sesin özellikleriyle, seçtiğiniz malzemenin hangi özellikleri (opaklık, şeffaflık ve yansıma veya metalik özellikler) uyuşuyor? Neden? / *What properties (opacity, transparency and reflection or metallic properties) of the material you choose match the properties of the sound you have chosen? Why?*

Category: Clarity of transformation

Sub-categories: Audio-visual connection

The selection of the time frame of sound for clarity –

Kullanmak istediğiniz sesin uzunluğuna nasıl karar veriyorsunuz? / *How do you decide the length of the sound you want to use?*

The perception of the real-time for clarity –

Sesin forma dönüşümü işleminde gerçek zamanlı algısına sizce ne ölçüde ulaşıldı? Bu nesne ses tarafından şekillendirildi ne ölçüde denebilir? / *To what extent do you think the sound has transformed into a form in real-time? To what extent can this object be said to have been shaped by sound?*

Bu süreçte sesin fonksiyonu var mı? Ne olabilir? Neden? / *Does sound have a function in this process? What could it be? Why?*

Form üzerindeki ses çalma ve yüzey deformasyonları ne ölçüde birbirine bağlıdır? Lütfen bu bağlantının algılanan gücünü değerlendirin: 1(çok zayıf) – 7 (çok güçlü) Bu puanı vermenizdeki etkenler nedir? / *To what extent are the sound playback and surface deformations on the form interdependent? Please rate the perceived strength of this link: 1 (very weak) – 7 (very strong) What factors contributed to your rating?*

Bu bağlantının gücü dönüşümün anlaşılabilirliğini sizce nasıl etkiler? / *How do you think the strength of this connection affects the intelligibility of the transformation?*

Bu forma baktığınızda hangisini daha çok hatırlayacağınızı düşünüyorsunuz: / *Which one do you think you will remember more when you look at this form:*

a) Seçtiğiniz sesi ve onun anımsattıklarını / *The voice you have chosen and what it reminds*

b) Bugün gerçekleştirmiş olduğunuz bu dönüşüm sürecinin kendisini / *This transformation process you have accomplished today*

c) ikisi de / *both*

Neden? Eğer cevap C ise lütfen iki şıkkı da ayrı ayır 1'den (kesinlikle hatırlamam) 7'ye (kesinlikle hatırlarım) kadar puanlayın / *Why? If the answer is C, please rate both of them separately from 1 (I definitely do not remember) to 7 (I definitely remember)*

Category: Clarity of transformation, Permanence of transformation

Sub-categories: Audio-visual connection, becoming a permanent memory

Geçmişinizle ilgili bir ses kaydına bir nesne aracılığıyla ulaşmanın etkileri neler olabilir? / *What are the effects of accessing a voice recording of your past through an object?*

Sesin görsel bir forma ve bir nesneye dönüşmesi, kalıcılık kavramıyla ne ölçüde ve nasıl ilişkili olabilir? / *To what extent and how can the transformation of sound into a visual form and object be related to the concept of permanence?*

Bu form sizin için neyi sembolize ediyor? Neden? / *What does this form symbolize for you? Why?*

Bu form ne ölçüde sesin ait olduğu anıları temsil ediyor? / *To what extent does this form represent memories to which the sound belongs?*

Bu formun verdiğiniz sesle ilişkisi bu forma ne ölçüde bir değer ve anlam kazandırıyor? / *To what extent does the relationship of this form with the sound you give add value and meaning to this form?*

Bu nesneyi fiziksel ve somut bir biçimde görmek ister misiniz? Neden? / *Would you like to see this object in physical and tangible form? Why?*

Nesne kalıcılıkla nası ilişkili olabilir? / *How can the object relate to persistence?*

Bu formu üretildikten sonra saklamak ister misiniz? Neden? / *Do you want to save this form after it is produced? Why?*

Bu nesne vasıtasıyla ses kaydına tekrar dönebilseniz sizin için ne ifade ederdi? / *What would it mean to you if you could go back to the sound recording through this object?*

Altında QR kod olsa ne ifade ederdi? / *What would it mean if there was a QR code underneath?*

Başka biri buna baktığında ne düşünürdü? / *What would someone else think when they looked at this?*

[son yorumlar] / *[last comments]*

Oluşturmuş olduğunuz forma ve onu oluşturma sürecine dönüp baktığınızda bu dönüşüm süreci ile ilgili ne düşünüyorsunuz? Ne gibi önerileriniz olabilir? / *When you look back on the form you have created and the process of creating it, what do you think about this transformation process? What suggestions can you have?*

CURRICULUM VITAE

PERSONAL INFORMATION

Surname, Name	: Alpay, Efe
E-mail	: efe.alpay@gmail.com
Website	: efealpay.com

EDUCATION

Degree	Institution	Year of Graduation
MSc	METU Industrial Design	2012
BFA	Bilkent University Graphic Design	2006
High School	TED Ankara College, Ankara	2002
IB	International Baccalaureate	2002

FOREIGN LANGUAGES

Bilingual Diploma English

RESEARCH INTERESTS

generative design, 3D printing, design for interaction, computer-human interfaces, data physicalization, exhibition design

AWARDS & SCHOLARSHIPS

2017	Falling Walls Lab Ankara Winner 1st Ranking Presentation (Breaking the wall of Reminiscing in the digital age)
2002 – 2006	Bilkent University Full Tuition Scholarship
2002	2nd ranking project in TUBİTAK National High-school Research Projects Competition in Chemistry

PROFESSIONAL EXPERIENCE

2019–Present	Part-time instructor at Bilkent University Graphic Design Department Course Title: Computational design methods

2015 - 2022	Creative Director (Reo-Tek Inc.)
2013 - 2014	Design Consultation for Interactive Interfaces and Immersive Experiences for Reo-Tek Inc.
2008 - Present	Co-Founder (Mirror Fabbrica) In conjunction with thesis research, a specialized application of 3D printing on mirrors and glass is developed
2007	Bassam Hage Photography Concept development, Graphic design, web design and photography
2005-2006	Co-Founder of Tavanarası Media
2004	Ajans Ultra (İstanbul) Internship Graphic design for companies such as Ak Sigorta, Akbank, Turk Telekom, Ülker

PROJECTS

2021-2022	"Digital Studio" for Turkish Electricity Distribution Corporation (TEDAŞ) Project Development and Management, Creative Direction of a project that converts all of the contents of basic electrical training into a cohesive, interactive digital experience that is delivered to the students through interactive, augmented reality and virtual reality technologies.
2020-2021	İstanbul Cinema Museum (Atlas Cinema) Creative direction, conceptual development, project management, product design
2019	"Göbeklitepe, The Gathering" exhibition at Cer Modern Ankara Creative direction, conceptual development, project management, exhibition design, music and sound design, motion graphics and compositing
2018	Berlin ITB Expo Anamorphic Projection Magic Box Installation Creative direction, Interactive interface design, motion graphics, 3d rendering
2017 - 2018	Kayseri Science Center Exhibits Production Creative direction, exhibition unit design, interface and motion design

2015 - 2017	TUBITAK Teydeb 1511 1150195 No'lu Dinozorlar Ve Temel Bilimler Bilişim Ağırlıklı Etkileşimli Sergi Tasarımı Projesi
2015 - 2017	TUBITAK Teydeb 1511 Project Number: 1150193 Buluşlar Dünyasina Yolculuk Ve Buluşlar Tarihi Etkileşimli Sergi Tasarimi Projesi
2016	EXPO Antalya Agriculture and Biodiversity Museum Creative direction, conceptual development, exhibition design, exhibition units design, motion graphics, interaction and interactive interfaces design
2016	Çankırı Museum Interactive Interfaces and Interaction Design

SEMINARS / PRESENTATIONS / WORKSHOPS

2020 September 8-9th	Workshop: 3D Form creation with memory connected sounds, METU UTAK2020, Ankara
2019 April 27th	AR/VR Game Process, University/Industry Collaborations, Cer Modern, Ankara
2019 April 26th	Designing Immersive storytelling experiences, Bilkent University
2018 Sep 14th	Game development process of an educational digital game design for children with participatory design methods. International Design Research Conference, Ankara
2017 Nov. 8th	Reminiscing in the Digital Age. Falling Walls Lab, Berlin (https://www.youtube.com/watch?v=ooX1ihisdmk)
2017 May 17th	Interactive Technologies and User Experience in Science Centers. Turkey Science and Technology Centers Conference
2015 June 3rd	Printing in the Third Dimension TED Ankara College 2nd IT and Technology Fair
2015 May 6th	A Brief Story of My Journey in 3D Printing METU Faculty of Architecture Kubbealti

2014 May 7th	3D printing and Interdisciplinary Applications TED University Fatma-Semih Akbil Culture Center Ahmet Ersan Conference Room
2013 April 25th	3D printing and Interdisciplinary Applications Bilkent University Chemistry Department

EXHIBITIONS:

2021	Don’t Turn a Blind Eye, Light the Dark Yogurtcu Park Exhibition, UN Women & Istanbul Municipality
2019	Step by Step, Light The Dark Segmenler Park Exhibition, UN Women
2017	Contexture V.2 An Experimental Typography Exhibition, 4-28 April 2017, CER Modern
2014	“Lighting - Sustainable Design Explorations”, ID724 Product Design for Sustainability Design Projects, 02-10 April 2014, METU Faculty of Architecture Exhibition Hall.
2013	Objectifying Sound. Praxis Poetics Conference UK Poster presentation
2005	Images and Words TBA

PATENT & UTILITY MODELS

1. TPE Application Number: 2017/12209, 3D Printing Device.