Doctoral Thesis

Rematerializing The Digital: Assessing Tangible Design Interventions in The Home and Workspace

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Abstract

In this study, I identified the roles of rematerializing the digital by designing and developing interactive products through several iterations and by conducting user's usability and (aesthetic and emotional) experience in the office and home. Accurately, the three designed products in the study are presented in a realistic and intriguing direction with four aspects (four digital information, Design for the user environment, actuation for digital information, and cognitive coherence for interaction).

In order to reveal the authentic experiences and needs of the users and to provide practical guidance for designing future rematerialized digital devices, I chose a qualitative user study method by conducting the use of research products in the office and home for a short-term and long-term period. I found not only common usability but also different experiences according to the feature of digital data, form, interaction, usage periods, and use environment. In particular, I identified the value related to the presence of technology embedded independent tangible devices in their space (on their desk). In this section, I identified the value of improving access to information: reducing checking steps, and evoking behavior change. Next related to the changing shape to deliver information, this study suggested the value of premeditating negativity for inducing positive interaction and controversial factors about tangible input. Lastly, this study suggested three ways to revive analog things with the digital device and the method to maximize the practicality of the device by combining related functions. Based on these findings, I also identified eight suggestions for designing the future rematerialized device. I categorized them into three perspectives for functional, interaction, and form design aspects. Through three design iterations, finding, and discussion, I hope that these findings and discussion make new research fields about rematerialization. I also want to give guidance and references for future research.

1. Introduction

Since the conception of smart devices, multi-touch devices, including smartphones, tablets, and others, have overlooked the way we interact with personal data (Vitale et al., 2019). In this process, the smartphone's digital functions have absorbed the features of the analog products that we previously relied on. Consequently, smartphones play the role of a digital carrier. They digitally transmit information and functions of products that were previously used (Van Campenhout et al., 2016). This change has been manifested in several types of intangible digital applications (Redström, 2001). These digital media continuously make creations with a temporal form that exists for a short moment and disappear (Hallnäs et al., 2002). The digitality offers the benefit of accessibility across various environments. It facilitates the accumulation of data in a device or cloud service for a long time (Odom et al., 2012). However, these same characteristics have resulted in issues such as continuous stacking of personal digitized data in storage and difficulties in data management (Vertesi et al., 2016). These challenges have resulted in complexities in the use of digital data and can primarily be attributed to the formless and placeless character of digital content (Odom et al., 2013). Furthermore, since all functions are digitized, product-user interactions and physical and haptic features expectedly disappear (Wensveen et al., 2004).

A growing body of evidence explores the possibility of tangible and materialized data (Odom et al., 2012). Since people live in a physical world, it is natural to explore controlling digital elements with physical interaction (Hornecker, 2011). More recently, researchers have investigated user experiences toward the materialization of digitized personal data (Van Campenhout et al., 2013; Kim et al., 2018). The increasing proliferation of design research in the HCI (human–computer interaction) community calls attention to reviving the physicality of digitized devices. It has led to works exploring how the representation of digitally stored data can more naturally permeate into everyday artifacts with tangible forms and requiring interaction. These studies seek various goals, such as improving access to information (Gaver et al., 2016), increasing usability with novel methods of use (Bennett et al., 2012), and raising expectations to extract information (Chen et al., 2019). These papers focus on merging digital information with tangible forms and interaction. However, among the various types of digital information used in everyday life, areas related to the value of physicality still exist that are far from fully answered.

To address this gap, my research aims to investigate the rematerialization of digital data, values of rematerializing digital information, and usability and experience (aesthetic and emotional) of the user at home and office.

1.1. Research Aim and Scope

1 What are the values of rematerialization in delivering digital information in the home and office environment?

1.1 What is needed to consider designing dematerialized information to the rematerialized device for providing functional usefulness and emotional value?

1.1.1 How can design tangibility for performing the following tasks:

: delivering weather and calendar information in the indoor environment by considering materiality?

: delivering calendar and traffic information together?

: helping with checking and managing emails in the office environment?

1.2 What kind of functional usefulness and (aesthetic and emotional) experiences can rematerializing with digital data provide?

1.2.1 What kinds of functional usefulness can rematerialization provide compared to the digital?

1.2.2 How are people's experiences in placing and utilizing the rematerialized device in the home or office?

In exploring our questions, I developed three rematerialized design iterations using the methodology of research through design (RtD). The first product is a research device called DayCube that physicalizes weather and user schedule information. The second product is called Traffico, which embodies the user schedule and traffic information. The final output, called Maili, facilitates checking email and registering and reconfirming essential emails.

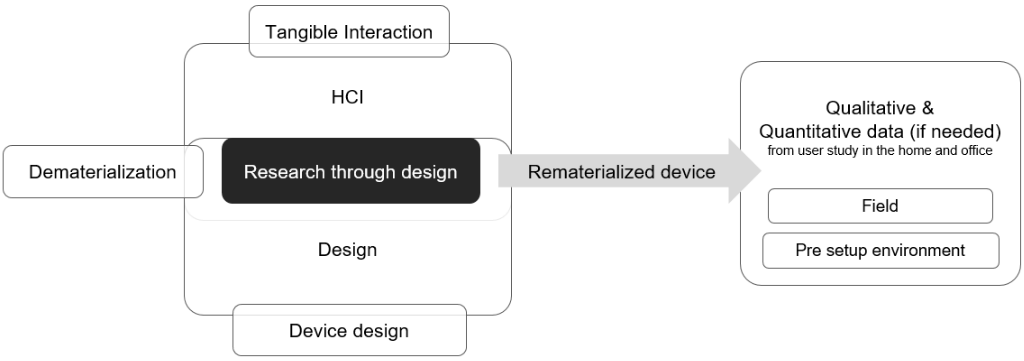

Figure 1.1. Scope of this Research

This study seeks to rematerialize digital information. Digital data in this research refers to functions in the dematerialized state utilized predominantly on the smartphone or computer. We sought to develop a tangible product by combining the HCI and design fields. Our research adapted the device design method used in the design field and the direction and theory of tangible interaction extensively investigated in HCI studies (see Figure 1.1).

Users examine the research prototype in their office or home environments. These user studies purport to reveal the participants' perceptions of the research device's usability. Based on the data obtained through these studies, we understand the value that rematerialized products can achieve with tangibly transferring the digital data.

With these iterations and findings, the purpose of this article is to inform new design examples that can serve as references while providing practical suggestions related to increasing the value of the rematerialized device to designers and researchers who want to design a rematerialized device.

1.2. Approach: Research Through Design

In this study, it was adopted the RtD method. A significant number of articles have been published in recent years on adapting RtD in design and HCI research to search the value of tangibility to the users. Research through design is a method for grasping design knowledge by developing, formulating, and validating a prototype of a device. These prototypes are created of fully working prototypes or paper mockups (Alonso & Keyson, 2005). In this study, it was developed a fully functioning prototype.

When conducting RtD, products are designed to explore the implications of the proposed theory in context. The skills of the designer play an instrumental role in the creation of new products. The problem area is addressed through design skills (Frens, 2006). Gaver mentioned that these researches continuously developed new multiple worlds. These worlds increasingly broaden product lines (Gaver, 2012) and also provide new design development opportunities to designers and practitioners (Koskinen et al., 2013). Nelson and Stolterman (2003) claimed that designers work to construct problems in terms of intentional actions that contribute to a desirable and appropriate state of reality rather than concentrating on problem solving to avoid undesirable states. In line with this, Wiberg (2014) mentioned the importance of RtD in interaction design and stated that designing new interaction is similar to making the future a part of the present, which implies that the future becomes anchored and manifested in the present. Thus, related research commonly states that the RtD focused on a specific situation can open up new areas that have not been revealed. Through this, it can provide suggestions for or serve as a linker to a better future by developing multiple new devices.

RtD can create the following effects. It can recommend a novel design to follow and make suggestions for researchers who want to improve the design (Frens, 2006; Zimmerman et al., 2007). It is desirable to accumulate generalized knowledge and, simultaneously, obtain people's reactions, reconsideration, and fresh perspectives to products. It also has the advantage of creating another world while continuously expanding extra product lines (Gaver, 2012). The new worlds created through RtD have been progressing in various directions. For example, the concept of ludic design can stimulate curiosity and create ludic meaning for the user; several prototypes have been developed with this topic (Gaver et al., 2004; Gaver et al., 2013). Furthermore, many studies have been developed with the RtD method, including the Strong Concept (Höök & Löwgren, 2012) and cultural probes (Gaver et al., 1999). RtD can connect design researchers and practitioners by considering the response to and performance of the designs in the lab, field, and showroom (Koskinen et al., 2013).

Furthermore, most of these existing studies have been conducted in a lab (Bennett et al., 2012; Alonso & Keyson, 2005) or are field studies through installations in public (Quintal et al., 2017) or private spaces. These field studies mostly ranged from one week (Jang et al., 2019) to several months (Odom et al., 2014).

1.2.1. User Study

Field study brought a new system to users and asked (often implicitly) to use the system naturally outside the laboratory, in environments for which the system was designed (Brown et al., 2011). Products developed via RtD are subjected to experimentation in real-life circumstances to figure out the complicated relationship between people and reality. Thus, knowledge about products and creating these devices is obtained (Frens, 2006). The designer-researcher can search for complicated product interaction issues in a realistic user situation. From this, they reflect on the design process and the determinations conducted based on genuine user-interactions with the test prototype (Keyson & Bruns, 2009).

Field studies are suitable for recognizing usability concerns and the primary attractiveness of the device, and the features are determined by the users instantly. However, it usually lasts for an insufficient amount of time and is restricted to involving a small group. The limitations of field studies are that users might rate the system or product high due to the novelty, and it cannot investigate the effects of long-term adjustment and knowledge (Shaer & Hornecker, 2010).

Figure 1.2. Example of a User Study

The specific number of necessary users is challenging to distinguish and depends on the situation. It varies based on many conditions, including variability among users and the number of required user characters (Kujala & Jauppinen, 2004). Holtzblatt and Beyer (1997) proposed that between six and twenty users should be called depending on the investigation’s breadth. Hackos and Redish (1998) suggested five to ten participants. It is feasible to obtain the number of participants required as per this research’s degree of scope. Kujala and Mäntylä (2000) showed that as few as six users might yield practical knowledge for product development.

For gathering data, one research used a combination of quantitative (questionnaire and usage log) and qualitative methods (interview). They found that questionnaires were not as useful as they expected. They surveyed previous papers and found that many field studies used quantitative (usage log) and qualitative method (interview) together (Kujala & Kauppinen, 2004).

Till now, this section has looked at previous examples of RtD research and user studies. Based on this, it was endeavored to develop a rematerialized device from the digital and research user’s perceptions recorded in the user study. The research device in this study is a newly designed product. Therefore, it wanted to record the genuine feelings of users with minimal interference from the researchers. In particular, we were interested in understanding how our products penetrated the user’s environment and are utilized. Field studies are frequently exploited by HCI researchers for this purpose and are particularly useful to find unconstrained and unanticipated use patterns and emotions (Robinson, 1993). I thought it would be more beneficial to install the product as close to the participant’s usage environment as possible or in the environment where the users live or work, rather than using it in a limited environment (see Figure 1.2). Five people were recruited for the study, and their perceptions were gathered through interviews and log data. The target group of user surveys was the 20s and 30s who seemed to be accustomed to access and use of information. The specific target groups were different following each case.

1.3. Thesis Structure

The structure followed and the content described in each section of the study are outlined below.

Section 2 introduces the concept of dematerialization, which is the starting point of this thesis and interactive physical product research based on digital information. Following this, the direction followed in this study is defined.

Section 3 describes the four types of digital information selected in this study, the reasons for selecting them, and the selection criteria for input and output used in the three research prototypes developed in the study.

Sections 4, 5, and 6 describe the research products using calendar and weather information, using calendar and traffic information and using email, respectively. Each section elaborates on the design implementation, user research plan, results, and discussion points for each product.

Section 7 focuses on findings that are common or different among the three cases with respect to usability and emotion. Thereby, the value the rematerialized digital information is able to provide to the user is highlighted.

The discussion points are introduced in Section 8. In line with the subject of this study, the aim is to deliver a reference to researchers looking to conduct rematerialized research or product development in the future.

Finally, in section 9, it will focus on how this research achieved goals and what contributions it made. Specifically, it defines the concept of rematerialization, and bring limitation, and future suggestion for the rematerialized research.

2. Why is Rematerializing Required?

The background literature for this study is introduced here. The concept of dematerialization, which is currently the primary concept of theses and research on the physicalization of digital information in the HCI field is discussed below. Lastly, the concept of rematerializing the digital is proposed.

2.1. Dematerialization

The digitization of physical products as they lose form is called dematerialization. Analog products are overwhelmed with the development of smart products with enormous screens and multi-touch features (such as tablets and smartphones). The development of smart devices for everyday use with multi-touch screen interactions has compounded the dematerialization of physical products and interactions (i.e., music albums, physical books) (Van Campenhout et al., 2016). This change has manifested in several types of intangible digital applications (Redström, 2001).

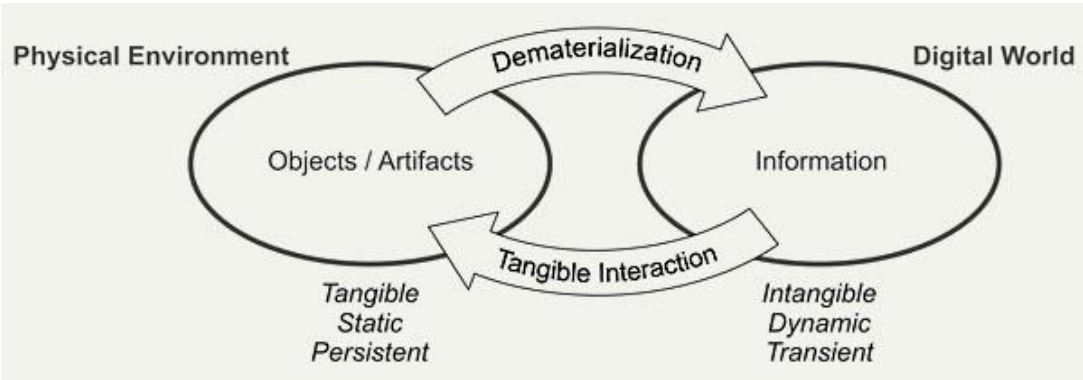

Figure 2.1. Characteristic of Digital and Physical (Van Campenhout et al., 2016)

Digital functions can allow performing various functions simultaneously with minimum effort. For example, we have thousands of albums or photo data in small smartphones. These functions are operated with a multi-touch display with intangible interaction and are in contrast to materialized product interactions with multi-mode sensations (i.e., visual, auditory, and haptic) (Van Campenhout et al., 2019; Redström, 2001). These digital functions also include the feature of the input and output being directly connected. Therefore, it is possible to react following the direct manipulation of the user (Fitzmaurice et al., 1995). These digital media offer the benefit of approachability across various environments (computers, smartphones, and smart tablets) and accumulation of data in a device or cloud service for a long time (Odom et al., 2012).

In Figure 2, the characteristics of the object (tangible things) and information (the digital one) are demonstrated. Information is intangible, dynamic, and transient (Van

Campenhout et al., 2016). For example, users can adjust the volume by turning the dial icon on the screen. However, they cannot feel the tactile characteristics of the physical dials used in radio or speakers. The digital object is transient. Thinking about turning an app on and off on a smartphone, users can repeat that specific feature. Functions disappear on the screen and come out again with just a simple touch. On the other hand, with physical products, the shape of the device remains constant. It does not lose and disappear its form suddenly.

Finally, the digital object is dynamic. A multi-touch screen can perform various functions such as the tasks of dials and buttons on just one digital screen. Tangible products are static. For example, in the case of a chair, it can only work as a chair in which human beings can sit down. It cannot unexpectedly change its form and function as a bicycle. The chair, a tangible product, focuses on only one role. Other researchers have mentioned that digital information is placeless, spaceless, and formless. It implies that it can be connected anywhere, with no physical placement, and reproduced (Odom, 2014).

2.1.1. Issues in Dematerialization

As a result, the many tangible analog products that once populated daily life are disappearing, getting replaced with smart devices that are partly or wholly confined to digital environments and their related interfaces (Van Campenhout et al., 2013). Although these intangible platforms enhance daily life in various practical and supportive ways (Vallgårda & Sokoler, 2010), it also creates limitations. For example, in the product–user interactions, it often loses the physical/haptic character (Wensveen et al., 2004), with tangibility providing more meaningful affordances and interactions (Norman, 1999; Gibson, 2014). The visible shape of the former information carriers such as CD players and books appeared affordances that evoke the acting skills of our body (Gibson, 2014). Interaction with touch-screen devices is limited to button-pushing or a set of standardized gestures on display. Moreover, the past artifacts attracted the perceptual-motor skills of our body, and the current digital devices appeal to our brains' cognitive abilities.

In the functional aspect, these same characteristics have resulted in issues such as the continuous stacking of personal digitized data in storage, causing difficulties in data management (Vertesi et al., 2016). These challenges have resulted in complications for the user in the use of digital data, mainly due to the formless and placeless character of digital content (Odom et al., 2013). Due to this, users tend to forget about what or how much data they have and how they can utilize them. At the same time, due to these characteristics, digital information has a weakness in terms of security. It may be indiscreet, and information may be unintentionally shared compared to physical products (Odom et al., 2012). Due to these issues, researchers have started exploring the possibility of tangible and materialized data.

2.1.2. Turning Point of Dematerialization

Due to this dematerialization, we live in a world where we can shift from tangible products and utilize their functions through simple operations on smartphones and tablets. Given the flexible characteristic of dematerialized information, new types of smart devices and features will continue increasing, threatening the status of remaining products. This is not the first time that functions are being combined into one product. The work that people used to previously perform manually is being integrated into computers, for instance, from drawing to CAD programs. Currently, the culture where functions were united into desktop computing in the past is changing to multi-touch computing (Van Campenhout et al., 2016). Judging from these historical patterns, it appears likely that physical products or methods in our society will gradually disappear further.

This study does not seek to deny the convenience accorded by digital information and functions. However, as we are living in a physical environment, attention is directed to striking a balance between the values of digital information and the physical element and conveying new values to people by combining the two.

2.2. Physical Representation from Dematerialization

In response to dematerialization, endeavors in the HCI community have sought to integrate digital information with the physical environment (Van Campenhout et al., 2016; Ishii & Ullmer, 1997; Vallgårda, 2014). The elements of computer and digital functions are penetrating into various physical devices in our everyday lives (Vallgårda, 2014). Due to this, the existing method of applying a digital function that considers only usability following the adoption of digital functions into the products of users' daily lives needs to be changed (Redström, 2001). Since humans belong to and act in a physical world (Hornecker, 2011), digital features merged with a tangible direction is inevitable and is a natural way to interact with material things (Ishii & Ullmer, 1997).

2.2.1. Value of Merging Tangibility with Digital Information

HCI and design communities have long been exploring how to merge digital information into independent everyday artifacts (Gaver & Höök, 2017; Nam & Kim, 2011;

Gaver, 2012), applying physicality with embedded interaction (Redström, 2001; Vallgårda, 2014) and capitalizing on the characteristics of digital information.

For instance, by utilizing personal data slowly accumulated in physical devices across a user's life (i.e., digital photographs [Chen et al., 2019; Odom et al., 2014], music [Odom et al., 2019]), research has suggested a feasible way to match users with their data. These products carry the advantage of being able to revalidate the value of digital information and increase the user's expectation of verifying the digital information collected by users (Odom et al., 2014). In one study, public data was expressed on a portable device that the user can carry outside. This product enhanced access to information, while naturally increasing interest in local data around users (Gaver et al., 2016). Quintal et al. (2017) developed an exhibition product that helps users to quickly ascertain the power consumption of the product through the physical display. As the amount of digital information and functions increases in our society, such research provides useful evidence on designing physical products in a direction that helps users to reaffirm the value of digital information around them.

Studies have explored practical and exciting applications to deliver digital information tangibly by printing information on paper beyond presenting schedules on display (Jang et al., 2019) and storing family photo data through printing photos on the paper (Bennett et al., 2012). Thus, these studies proposed delivering digital information through physical media.

Alternatively, research is being conducted to develop physical–digital goods in a way that generates value for users beyond functionality (Nam & Kim, 2011; Gaver et al., 2004). In these studies, they proposed a concept called ludic design, in which using the device over time creates emotional value for the user apart from merely providing functional value.

Expressing digital information in a physical direction can be highly beneficial. Ishii mentions that digital information associated with a physical direction is a more intuitive means of collaborating with digital products (Ishii & Ullmer, 1997). Thus, one advantage of tangibility is intuition. It leads to natural use in the physical form; therefore, it is possible to use it immediately with brief explanations. One study developed the input with moving the magnet and paper model. They showed that experiments can be performed instantaneously with or without a brief explanation (Zufferey et al., 2009). Next is improving accessibility. Tangible products hold the advantage of improving accessibility between users and information based on their physical form. Hornecker and Buur mentioned familiarity and affordances from everyday interaction with the actual world lowering the threshold of difficulty for engaging with a system and thereby increasing the likelihood of people using it actively (Hornecker & Buur, 2006). The final benefit is providing hedonic value. A study gauged hedonic value with tangible interaction (Alonso et al., 2005). Alonso et al. (2005) developed a product that plays music when a combination of actions such as shaking are performed while commenting on a situation where music is being digitized and moving away from tangible interaction. Thus, tangible research has explored the extraction of hedonic value with tangible interaction (Alonso et al., 2005), creating pleasure in controlling data physically beyond a practical purpose (Hassenzahl, 2018).

Through this literature review, we searched the vast literature dedicated to bringing tangibility to digital information and the value that tangible devices offer with digital information in delivering and storing information and increasing intuition and accessibility.

2.2.2. Summary and Reflections

Physical form and functions are disappearing into the digital functions of smart devices. There are many advantages which this digitality can afford. Contrarily, the functional and interactive value of physicality is also vanishing. To evoke the value of tangibility again, digital functions are applied to the physical medium for integrating the advantages of reminding the importance of digital information, emphasizing emotional value, improving accessibility, and inducing excitement.

In connection with this issue, this study's novel products aim to pursue a tangible direction that reminds users of the value of digital information and affords functionality and emotional value. This research did not stop at the development of one product. RtD continuously creates new, varied worlds and expands product lines further (Gaver, 2012). It was sought to add a new perspective to the topic of rematerialization through the repeated creation of research products on the same subject. Furthermore, with the creation of this world, it would like to make suggestions that researchers and designers can refer to later.

2.2.3. New Worlds Developed from Tangibility with Digital Information

Among the many attempts related to this research topic, it was identified a few research groups that proceeded similar to this research: 1) utilizing research through design (RTD); 2) creating two or more outputs with a single research topic (creating a new world for a topic); 3) utilizing digital information and functions as parts of the product; 4) independent products (the product itself has inputs and outputs); and 5) test research products using semi-structured interviews or field study methods.

First, Van Campenhout et al. applied rich interaction (Frens, 2006) and suggested the "third stand" for a more appropriate consolidation of digital materials and physical elements

(Van Campenhout et al., 2013; 2016). To merge the flexibility of digital data with the richness of tangibility, Van Campenhout et al. proposed three design requirements called third stand (Van Campenhout et al., 2013; 2016; 2019). First, it seeks harmony of form, function, and action based on a rich interaction framework (Frens, 2006). Second, it focuses on a single function-specific operation linked to the following interaction; and lastly, it considers a collection of dematerialized information as an essential part of its physical structure. The framework emphasizes the merits of digital functions while simultaneously presenting the benefits related to the interactions through the physical form of the device. A few related studies were identified that explore the opportunities for materialized devices through an iterative design process based on the three design requirements. One recent study developed prototypes to provide material components to a dematerialized audio system. This applied digital functionality into diverse physical territories called modules (Van Campenhout et al., 2013). In another case, a physical payment device called EPT (experimental payment terminal) was developed. The creators conducted a user study to gauge value through a lab investigation by comparing their prototype with an existing CPT (commercialized payment terminal) (Van Campenhout et al., 2019).

Second, Bill Gaver proposed the concept of ludic design (Mivielle, 2016). The key to Gaver's argument is meaning-making. The ludic design does not interfere with the improvement of efficiency or problem solving, such as regarding technical, social, or psychological topics. Ludic design is specifically deployed to support meaning building activities. Gaver is wary of design, providing detailed narratives to the users. He opines that it is crucial to develop cultural interpretations or meanings by users from open-ended or ambiguous devices (Gaver et al., 2004). This ludic design concept provided useful evidence for explaining a new perspective that was not available in the existing research, especially related to the participants' emotions regarding the device.

Third, Odom apprehends the characteristics of digital information (Odom et al., 2012) and uses digital information to create tangible products in his graduation thesis and other papers (Odom, 2014). He particularly focuses on digital data (photos and music) that users have used and stored for a long time. In these studies, he mentions the features and problems that users perceived from utilizing accumulated digital data. He sought to find possibilities by radically transforming the digital in a physical direction. Furthermore, his research examines users' emotions through long-term, in-field user studies and semi-structured interviews. However, he does not offer any frameworks for actual device development. Alternatively, he introduces four quality aspects— being inquiry-driven, having perfect finish, being fit, and being independent—for developing a research product with a high degree of maturity that is worthy of in-field research (Odom et al., 2016).

A comparative analysis of the three works is insightful. Van Campenhout et al. proposes a combination of physical interaction with dematerialized information for presenting each strength and new charms between two things. His research is significant because it provides the method of "third stand" that can be adapted for product development. However, that researches conducted an in-lab study to compare with his research prototype and existing commercial product (Van Campenhout et al., 2019) or did not conducted a user study in previous studies (Van Campenhout et al., 2016). At the same time, he offered no reply in developing a working prototype except the paper mockup. Conversely, Odom and Gaver have a similar trend in developing a working research prototype and conducted an in-field user study. Cleary, Odom provides a beneficial summary of the values of radically shifting digital data to a physical product. However, the digital data was limited to information such as photos and music filed over a long time. Gaver created prototypes with a focus on creating meaning. However, the functional aspect is considered necessary for interactive products. This will probably be a disadvantage if applied in a real-world scenario.

2.3. Research Through Rematerializing: Working Proto with Lab and Field Study

Through synthesizing the literature studies mentioned above, my study proceeded in the following directions (Figure 2.2).

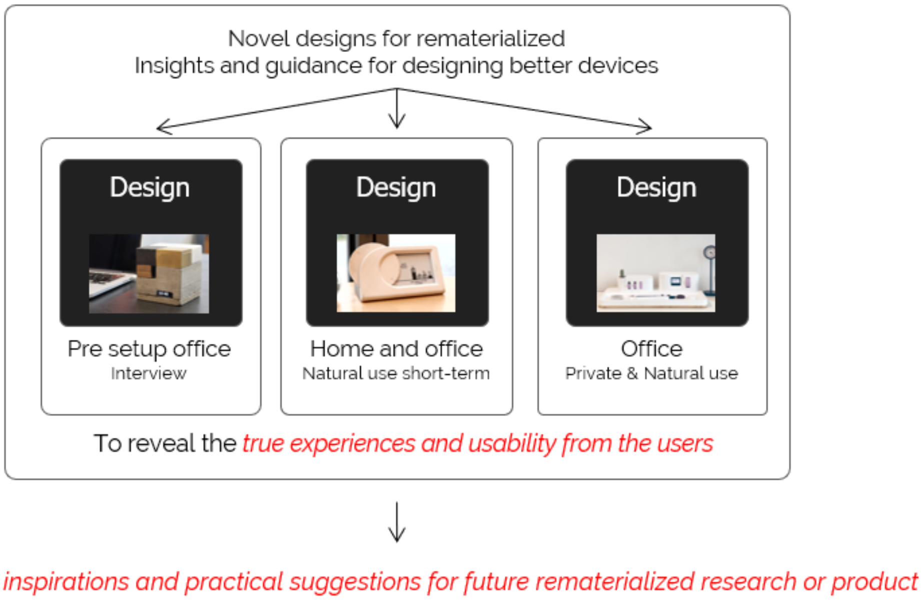

Figure 2.2. Research Through Design in This Research

1) First, rematerialization supposes developing a novel design device that can afford practical functions from digitality and form and interactive design. We also want to ensure intuitive interaction to control digital information and a design well-matched to the specific environment. The development of these devices proceeded with consideration for various features, including the form element of products (Vallgårda, 2014) and the quality of the prototype (Odom et al., 2016). For example, Vallgårda (Vallgårda, 2014) suggested that the form element of the interaction design couples three things: the physical form, including color and size, the temporal form that represents the transformation of the device state, and the interaction gestalt that indicates the movement according to the user's object or environment. Additionally, Frens (2006) describes function, interaction, and form as three elements of interactive products. At the same time, while traditional devices are appropriately linked with those elements, contemporary digital products are becoming more diverse in their forms, while interaction is becoming standardized.

In consideration of these perspectives, the input and output of the tangible interaction applied in this research were designed by considering efficiently expressing and controlling digital information. In the product design, we designed a form that can be well-matched with the user's environment through long term discussions with many design majors. It was selected the digital functions that have not been physicalized or functions that can contribute practical value in the user's environment through a new tangible way based on the literature survey. These selected digital functions are frequently utilized in smart devices and are expected to be useful in the indoor environment. Comprehensively, these devices focused on providing functional usefulness and emotional meaning to the users. The environments in which the product will be adapted is a home and an office. It is because these are the two places that people occupy the longest in their daily life (BLS, 2019). It is highly probable that users place and utilize interactive products in these spaces.

2) This study uses the RtD method to develop a product that can operate independently, including the Internet and electrical component. The independent device referred to in this research is a product that can operate similar to the commercial electronic products we use in daily life and can perform the digital functions. The prototype development sought to develop high-quality devices that can be used without the researcher's intervention during the user study following the guidelines of the research product proposed by Odom et al. (2016).

3) The user study was conducted for at least two days, and two or more interviews were handled to record the user's authentic experience and impressions on

usability. Through two or more interviews, this study wanted to grasp the participant's emotional change. Furthermore, the user's log data was collected as required to reinforce the research data. Moreover, five to ten participants were recruited. Through this user survey, we intend to propose a finding from usability, aesthetic, and emotional experience that users perceived while utilizing the research products. Here, the aesthetic experience is the product's capacity to delight one or more sensory modalities. Emotional experience pertains to emotion psychology and daily language on emotions, including love and disgust, concern and hope, pride, and despair (Desmet & Hekkert, 2007). Through this, we attempted to determine how the design, function, and interaction of the research product affect the user's emotions.

4) Finally, from the findings and discussion points, this study attempts to suggest new possibilities in designing rematerialization. It would also like to propose suggestions for improvement and create a more reliable and rematerialized design based on the user-experience data.

2.4. Summary

Throughout this section, it has been commented on the disappearance of tangible products in society. The newly created digital function has its value, but it has also the disadvantage of excluding the attractive tangibility aspect of physical devices. Much has been written about finding new value by using digital information with tangible products through RtD research in the HCI and design fields.

Based on this current situation, this study combines digital information and physical aspects to produce working research devices with RtD. This study aim to develop a total of three prototypes. It is devoted to finding digital information that has not been physicalized or is expected to bring functional value to the user, designing form and interaction to understand this digital information thoroughly, and designing a working research product that is well-matched and extensively researched in the field. Additionally, qualitative data—such as interview data—and quantitative data—such as log data—are collected through a user study. This study aims to grasp the value that physical products can deliver and the experiences of the users. Lastly, it seeks to offer further references for future researchers and designers.

3. **Aspects of Designing Rematerialization**

3.1. Possibilities of Rematerializing the Digital

3.1.1. Digital Function: How Much is Digitalized?

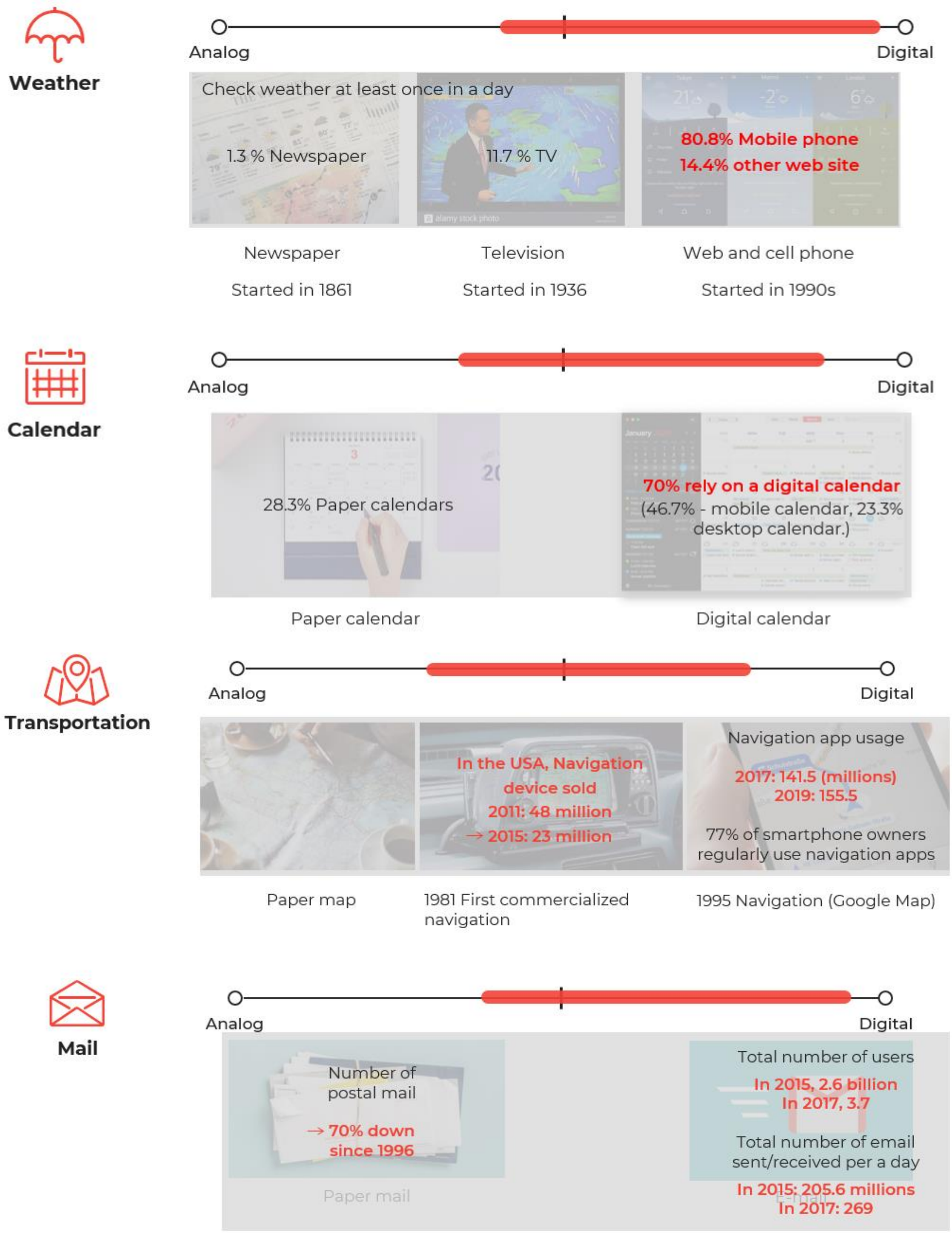

Figure 3.1. Digitalized Function and Analog Function_ What Do People Use?

Figure 3.1 shows how much the digital function in this research is digitized. Moreover, it identifies the analog device in use previously and the extent to which it has vanished now.

Weather: Weather information was previously transmitted through newspapers and television. Weather information started being conveyed in the newspaper in 1861 (Czerski, 2011) and in 1936 via television (BBC, 2009). The web and smartphones followed suit in the 1990s (Henson, 2010). According to a recent study that queried on the tool preferred for checking the weather at least once a day, 80.8% of people responded cited smartphones, 14.4% mentioned the web, 11.7% mentioned televisions, and 1.3% referred to newspapers (Phan et al., 2018). Thus, it is evident that a significant amount of weather information is utilized in a dematerialized manner. The usage rate of analog devices such as newspapers and TV is quite low.

Calendar: Although digital calendars are available, digital and physical (paper) calendars are still used in combination. The exact period of the introduction of digital calendars is not clear. However, according to user pattern, 70% of users organize their schedules with digital calendars, of which 46.7% use mobile phones and 23.3% use desktop computers. Approximately 28.3% use paper calendars and diaries (ECAL, 2018).

Traffic information: Traffic information was verified with a paper map a long time ago, followed by navigation, which is an independent product. Currently, it is confirmed through the map app on smartphones. Currently, paper maps are of limited use for business, travel planning, and education (Baig, 2020).

Considering the map’s digital-tangible device, navigation in automobiles, the first commercialized navigation system for a vehicle was launched in 1981 by Honda (Leite, 2018). However, its usage continues to decrease. It was found that the sales of navigation devices, which amounted to approximately 48 million in 2011, decreased to 23 million in 2015 (Liu, 2018). Contrarily, the usage of map apps continues to rise. In 2017, 141.5 million people used map apps; this increased to 149.6 million in 2018. This amounts to approximately 66.2% of all smartphone users. This increase in use is projected to be about 164.2 million people in 2021 (He, 2019). At the same time, about 77% of users of these map apps regularly utilize the navigation function (Panko, 2018).

Email: Lastly, paper mail was predominantly used in the business field, such as for bills and advertisements. However, in the United States, total paper mail usage has decreased by about 70% since 1996 (OIG, 2017). By contrast, the usage of emails is continually increasing. Ray Tomlinson developed the first email system in 1971 (Swatman, 2015). Present American workers spend about three hours a day using email. Furthermore, many employees check their emails outside of their work (Adobe, 2019). Email users around the world ranged about 2.6 billion in 2015 and sent about 205.6 million emails per day (THE RADICATI GROUP, 2015). In 2017, about 3.7 billion of users were sending and receiving about 269 million emails. This number is expected to increase to about 4.1 billion by 2021 (THE RADICATI GROUP, 2017).

Through this analysis, we discovered that the four functions are mainly used digitally in modern society. Moreover, we analyzed existing literature and commercial devices to understand the existing physical devices that provide these four types of information.

3.1.2. Possibilities of Rematerializing to this Digital Information

Weather

Of previous studies in the interactive design field, Gaver et al. (2013) proposed a ludic design product that can store and display weather information in users' indoor living environments. Simultaneously, his research team noted the growing interest in conveying environmental information. Weather information is one of the most utilized functions through voice feedback in smart IoT home assistants (e.g., Amazon Alexa) (Brittany, 2018). A study mentioned that unpredictable weather affects a person's emotions. Based on this, they presented an experience design installation that combines a physical shape and a video projector as an interior design that allows people to experience various weather conditions in the room (Airaud et al., 2016).

However, little research is available currently on transmitting weather information in an indoor environment into a tangible form. In this regard, the possibility of conveying weather information through physical interaction was considered.

Calendar and transportation

Calendars are utilized as paper products or apps. Surprisingly, while the digital calendar app is used a lot, the analog paper calendar is also utilized extensively (Tungare et al., 2008; Brush et al., 2005). Some studies introduced devices displaying schedules in a physical form (Han, 2017; Lee et al., 2017), focusing on suggesting ambient ways of displaying upcoming schedules. These exciting studies provoke tangible experiences through physical devices, which are often forgotten in the dematerialized world. Besides, many attempts have been made to provide calendar information in a tangible form.

Here, we intend to design a different product. Therefore, information on transportation was included as well. Regarding the visualization of schedules with a transportation option, Dragicevic and Huot (2002) proposed displaying time information for buses and shuttles within a virtual digital clock. In another study, researchers introduced “Intelligent Alarms,” a digital calendar used to set reminders and location-related alarms (Manas, 2008). From these studies, the possibility of displaying transportation information between schedules is identified as a valuable option. However, these researchers focused on proposing intangible interfaces as solutions and rarely represented the two digital information in a physical form.

Email

Since email is used as an essential means of communication in the modern world (Jovicic, 2000), earlier studies of the email were reviewed to improve our understanding of email usage. For example, research was conducted to measure the frequencies of email inbox use over time through a large-scale quantitative study (Alrashed et al., 2018). Other studies explored how individual businesspeople utilize emails in the professional context (Bälter, 1998; Quaresma et al., 2013). Building on these works, further studies have identified challenges in email usage, such as email triage (Neustaedter et al., 2005) and email overload (Whittaker & Sidner, 1996), related to an increasing number and frequency of emails and the challenges in their management. Moreover, other researches illustrated how a smartphone’s email or message alarm leads to negative emotional responses (Pielot et al., 2014). These studies highlight the stress created by email use.

Several methods have been proposed to deal with the above issues. For instance, one study combined mobile text messages to alert users of critical emails (Rector & Hailpern, 2014). Alternatively, another focused on the meeting schedule in users’ emails, developing a system that proactively displays schedules (Zhao et al., 2018). Other researchers have explored utilizing email data with the physical medium through printed emails for people who cannot properly access computer email (Cannata, 2005) or compared the user’s response when checking email through printed text with the computer (Hill & Monk, 2000). Another proposed voice interfaces with a traditional telephone to assist the elderly when sending emails through voice recording (Brewer et al., 2016). One study illustrated the concept of how tangibility in email function supports improved usage through a playful interactive device. It subsequently results in reducing stress (Gaunt et al., 2013). However, in the case of using email as data for physical products, many studies were conducted focusing on improving accessibility. However, research on interactive products that can reflect actual email data and usage has not been conducted extensively.

Through this literature review, we identified the scope, importance, and challenges of contemporary digital information usage and subsequently considered them in the design and development of our design case. Collectively, the strands of research have contributed to understanding how tangible forms can be designed based on the digital data and how ongoing HCI research has started dealing with the application of digital data in tangible, everyday objects.

While this research is promising, there persists the concern of how to convey digital information related to functions physically and any resulting benefits of a materialized approach. There is growing interest in representing digital information with tangible artifacts. Thus, we see opportunities to investigate how the dematerialized digital function can be designed with physical form and interaction and what kinds of value can be delivered with an everyday object to users.

3.2. Design for the Use Environment

When it comes to making products with digital information that users can actually use, it is vital to think about where and how users will use these products.

In particular, when users live with various analog and electronic products in their daily lives, it is necessary to conduct user research in a place consistent with the real user's environment to obtain authentic experience and usability. Function selection, appearance design, and interaction also were proceeded with consideration to suit each environment.

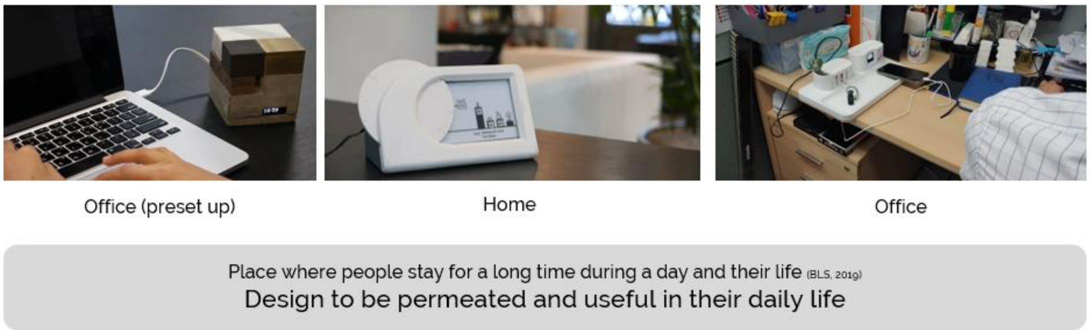

Figure 3.2. Design for the Use Environment

To this end, in this study, three user studies were conducted close to the existing user's environment or directly installed in the user's environment (Figure 3.2). First, it was rented the office environment, installed the product called DayCube in the office, invited users to use the product, and tried to observe the feelings that the product could deliver in the office environment. In design, this device is well-suited in the office environment and combines various materials in a rectangular shape. In function, it provided the weather and schedule information, which is assumed to be useful in the office environment.

The second product was installed in a place of the user's choice irrespective of whether home or office. Since too many color displays populate our daily life, the e-ink display and Jesmonite material were utilized. Jesmonite is a smooth surface and durable material used for sculptors and buildings. Its color can be changed by mixing with dye. Therefore, it can be well matched in indoor environments. Moreover, it provided calendar and transportation information, which is considered to be useful for the indoor situation. Therefore, this user study is conducted in both the home and office.

Finally, the product was placed in the office space where the user was working. It utilized the email function, which is frequently used in the office environment. Moreover, we designed the device with an analog tray, in which the user can place their goods and which is expected to add value in the office. Through user interviews in each of these situations, it wanted to thoroughly grasp the usefulness, convenience, and discomfort the user feels in accepting and using digital information as a physical product.

3.3. Activating Rematerialization for the Digital

3.3.1. Actuation for Digital Information

In this study, the products were designed to deliver digital information in an efficient and interesting direction. Therefore, we designed an output that utilizes actuation to express movement from the research device. It was devoted to physically reflect the characteristics of continually changing digital information.

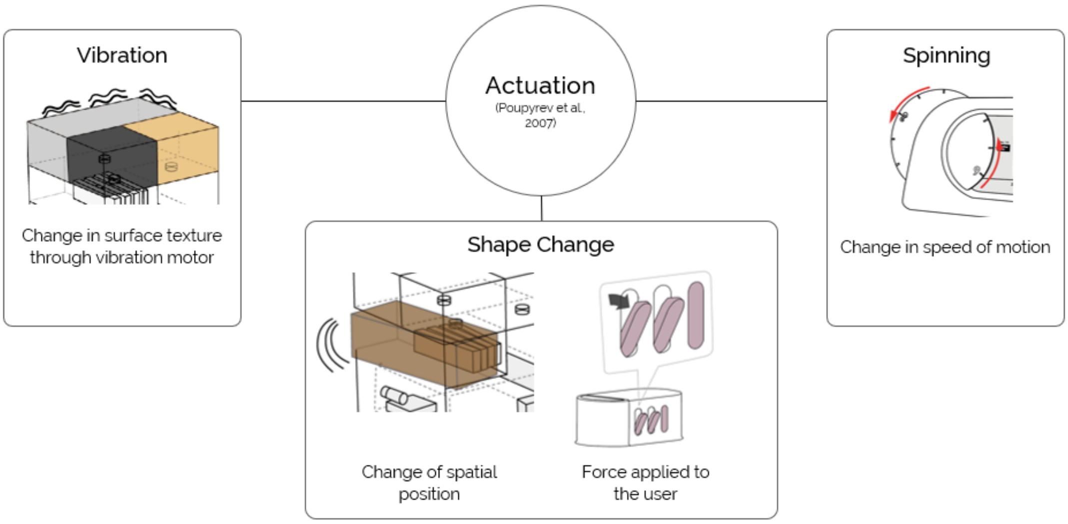

Figure 3.3. Actuation Utilized in Three Pieces of Research

Poupyrev et al. (2007) mentioned a change in spatial position, speed of motion, surface texture, and force applied to the user as the four elements of actuation. In Figure 3.3, we used movement of the wood (DayCube) and movement of the node (Maili) to reflect the change of spatial position. A rotating clock plate considering the characteristics of change in the speed of motion was implemented to the study of Traffico. By matching the change in surface texture, changing the characteristics of the surface through vibrations was used for DayCube. Lastly, by considering the change in force applied, Maili fixed the position of the node when it protrudes forward when users press the node.

3.3.2. Cognitive Coherence for Interaction

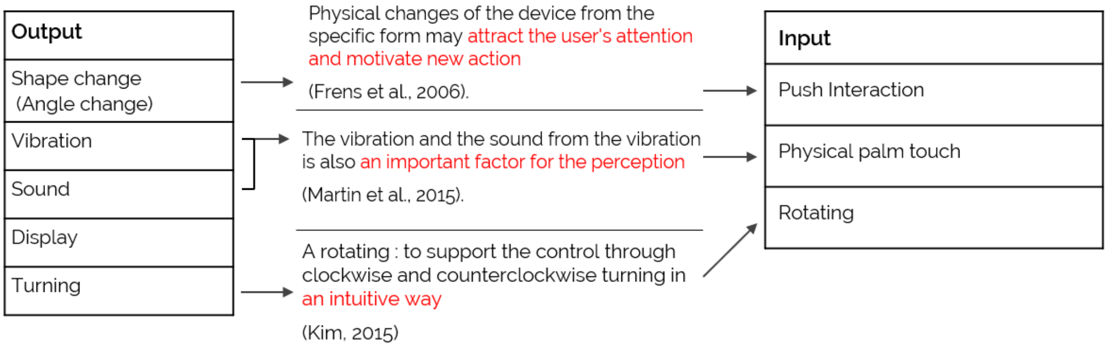

Figure 3.4. Correlation with Output and Input

In this study, it tried to ensure usability in using interactions to verify and control digital information. Therefore, the output that expresses digital information and the input that controls digital information are not independently placed; instead, a connection is designed between input and output. Through this, the method of expressing digital information in the product is intended to naturally induce user input. It was thought that this combination would improve usability by reducing the mental demands of the user interactions and enable cognitive coherence that allows manipulating the product as intended.

In Figure 3.4, shape change was associated with push interaction since it can attract the user's attention and induce action through physical movement (Frens, 2006). Accordingly, product movement allows the user to press the product naturally. Vibration and sound were intended to allow users to perceive the product through their palms or ears since vibrations and the sound of vibration affect the user's perception (Martín et al., 2015). The clock plate provides a natural input for the user to be able to rotate left and right. At the same time, it serves to inform the user of the information in a circular motion (Kim & Eune, 2015).

In the output and input with a connection to digital information used in each three design iterations (Table 3.1 & Table 3.2), this research utilized the output aspect, including the product shape change, vibration (tactile feeling), sound, rotation, and display. Digital information has the characteristic of malleability, which means they can be created, changed, and distributed efficiently and promptly. However, physical objects are rigid and static, which limits their utility (Pangaro et al., 2002). If physical properties, including shape, texture, and position, could be changed, the design vocabulary of tangible user interfaces can be expanded tremendously (Poupyrev et al., 2007) and physical changes of the artifact will serve to attract the user's attention and induce new action (Frens, 2006). Therefore, figuring out the output from actuation can reveal the characteristic of digitality to the tangible.

Table 3.1. Matching with a Digital Function with Output

Output \ Digital Function	Weather	Calendar	Transportation	E-mail
Shape Change		DayCube		Maili
Vibration	DayCube			
Sound	DayCube			
Display	DayCube	DayCube / Traffico	Traffico	Maili
Rotating		Traffico	Traffico	

DayCube Traffico Maili

Specifically, in Table 3.1, a total of five outputs were used. All products used to display to deliver information. With the characteristics of the shape change, DayCube's calendar information and Maili's email information were delivered. The weather information of DayCube was transmitted using vibration and sound of the vibration of materials. Rotating's output was used to convey Traffico's time floating information.

Table 3.2. Matching Digital Functions with Interactions

Input \ Dematerialized information	Weather	Calendar	Transportation	E-mail
Physical palm touch	DayCube			
Rotating		Traffico	Traffico	Maili
Push Interaction				Maili

DayCube Traffico Maili

As given in Table 3.2, these three cases adapted palm touch, rotating interaction, and push interaction. Palm touch was employed to retrieve weather information by touching the surface of the concrete. Rotating interaction is an intuitive interaction used to control the time zone of the calendar. At the same time, the vertical rotation was applied to control the email inbox in Maili. This vertical interaction comes from mouse rotating which we usually use for checking email on the computer. Lastly, the push interaction is utilized to press the node to check email content in Maili.

4. Rematerializing the Calendar and Weather Information: DayCube

An earlier version of this article was delivered at the CHI (Computer-Human Interaction) Conference in Denver, 2017.

4.1. Purpose of Research

4.1.1. Materiality in Interaction Design

This study was conducted to consider materials as part of product properties. Jung and Stolterman (2011) mentioned that it is necessary to consider the form factor when digital technology is adapted into various environments; however, understanding the form is limited and they suggested that material is one element of the form factors. Similarly, in interaction design, the selection of a suitable material is essential in accomplishing the goals of the design (Gross, 2015; Van Kesteren et al., 2007; Fernaeus & Sundström, 2012). Fuchsberger et al. (2014) described that interaction design needs to be involved with materiality and the experience of materials that emerge from interactions with the device. Furthermore, in previous devices, materiality is a crucial element in constituting a product and contributes various visual and haptic experiences to the users (Ashby & Johnson, 2013). The materiality in the product offers consumers the advantage of being easily distinguishable compared to the form design (Saakes, 2006). Thus, the selection of the appropriate material has the advantage of bringing a new interactive direction and can provide hedonic value as well as support to improve usability during the interaction (Kwon et al., 2014). Furthermore, the materiality influences the various stages of the user's evaluation of the product from the performative stage to the sensorial stage (Giaccardi & Karana, 2015).

Building on the body of previous studies, we could discover why materials are essential in interaction design and the value that material can offer to users. Studies in the HCI field have emphasized the importance of materiality for a better understanding of design (Döring, 2016; Giaccardi & Karana, 2015; Jung & Stolterman, 2010; Robles & Wiberg, 2010). In this state, several kinds of research have been proposed in developing tangible devices that combine digital functions with materials to inquire how physical interaction with digital information can be enriched through materiality applied to vital engagement with the device.

4.1.2. Materiality in Delivering Information through Tangible Devices

Wang et al. (2016) proposed "water shadow," which utilizes the characteristic of the concrete material in interactive devices. The interaction works by making the surface color dark when water is put on the concrete and returns it to its original color after the water evaporates. By using this method, they showed the possibility of transmitting information through concrete. Besides, Lee et al. (2017) developed a calendar device designed with concrete and wood called Quietto and Jang et al. (2019) also produced a tangible calendar device that combines the concrete and E-ink display called Monomizo. These two case studies used concrete in designing IoT products through the development of interactive devices and the field deployment study. Regarding other types of materials in tangible interaction, Tsaknaki et al. (2014) investigated the opportunity of leather material by combining with digital functions and digital tools. Also, Ventä-Olkkonen et al. (2014) developed the concept of an ice hotel, which used ice to create interactive touchable walls. Moreover, Schmid et al. (2013) held a workshop with glass material and created a new tangible interaction idea that capitalizes on the material properties.

The above studies have explored the characteristics of materials by combining with digital function or by conducting a series of user studies to understand the user's perception of the material during interactions with the devices. Although the consideration of materiality is an essential factor in designing digital artifacts, more studies are required in terms of how various material properties can play a role in designing an interactive device, focusing on the relationship between the materials and interaction design (Jung & Stolterman, 2010). We also found that there appear to be many other materials (e.g., materials used in modern architecture and art) that have possibilities to be explored by assigning diversified materials to digital features and examining the experience of their visual-haptic value in everyday encounters with the product.

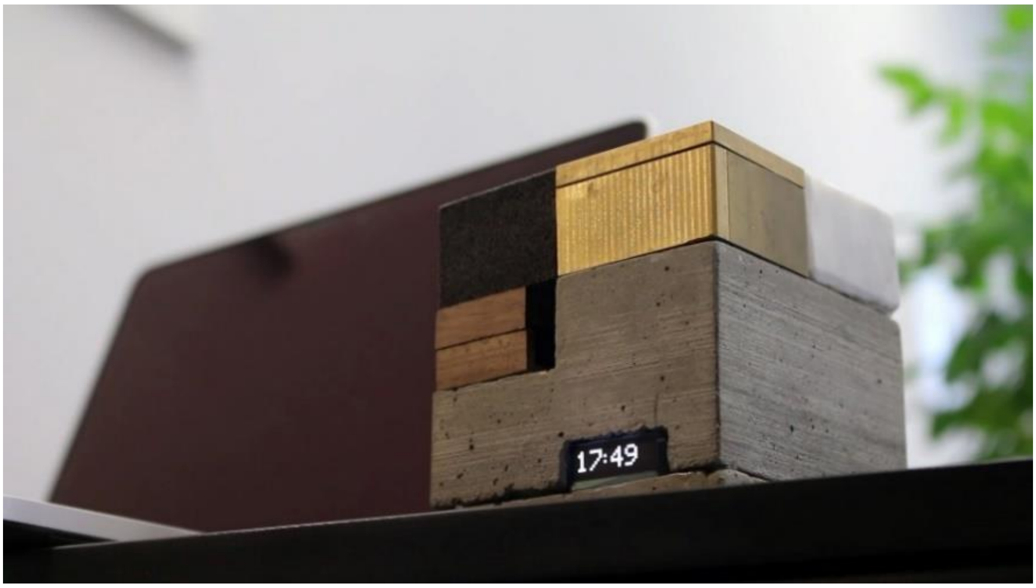

Figure 4.1. DayCube

In this study, we developed an IoT device by not only considering the selection of materials but also the design of the specific IoT functions. For this, we selected five different types of materials and sought to commingle them with two IoT functions. For each material, we singled out various substances, including mixture, metal, and wood. We propose a novel personal daily tangible device called DayCube (Figure 4.1), fabricated and mix-matched through five unique materials: brass, concrete, dyed cork, lumber, and marble. Furthermore, we discuss the possibilities of these materials through our two-day, in-lab user study with ten participants.

4.2. Design of DayCube

4.2.1. Rationales and Approaches to Design DayCube

DayCube is an interactive object for everyday use designed with five different materials: brass, concrete, dyed cork, marble, and lumber. Each material is matched to perform two different functions (schedule and weather) to deliver daily information. To design this, we considered the following issues.

As we focused on the development of interactive objects for indoor use, we analyzed the functions of various interactive devices from the previous studies. We determined to approach our design by applying a new way of representing digital data combining the properties of materials to provide tangible interaction with the data. We chose two functions as the vital information needed during most of our indoor activity—namely, schedule notification and weather information in the area where DayCube is set up.

Gaver et al. (2013) proposed a product of ludic design that can transmit weather information to people in their indoor living environments. Weather information is one of the most utilized functions through voice feedback in smart IoT home assistants (e.g., Amazon Alexa) (Brittany, 2018). Furthermore, many kinds of research are being conducted to propose the possibility of a tangible device bringing Google Calendar data (Lee et al., 2017; Kim et al., 2018). They described the advantages of the physical-digital devices showing users' schedule information archived in digital apps, in particular, its intuitive representation of schedules (Lee et al., 2017) and easy reminding of schedules (Kim et al., 2018). From this, we determined the information on weather and calendar schedules as appropriate digital functions that can be used in an indoor environment. We started designing a way to express these functions with materials for the development of our interactive object "material exploration," which means designing digital devices' forms or functions by analyzing materiality from the early development process. We sought to design our prototype by considering the material properties from the beginning of this study. We utilized mix-matched use of concrete, brass, cork, lumber, and marble as user interfaces of a tangible object.

In designing the device's interaction through those materials, we investigated how existing research has used material properties in designing its tangible interaction with the device. Based on this, we wanted to explore a new direction not only focusing on the texture of the materials but also the sound that each material can generate and the physical movement actuation of materials to deliver digital information. Thus, to convey the weather information in DayCube, we decided to use the vibration and the sound of material from the vibration. Sound data was selected since the sound produced when touching the material is also essential for the perception of material properties (Martín et al., 2015; Wang et al., 2016).

4.2.1.1. Selecting Materials to Connect Interaction with Digital Data

In order to select materials for the DayCube tangible interaction design, we considered the following issues with sensorial and emotional information and meaning, which explains how users can perceive the materials.

First, we selected materials that can be used to adequately express the aesthetic, meaningful, and emotional experience from the object to the user (Desmet & Hekkert, 2007). Based on this, we considered whether the material could suitably portray the digital functions and information with their sensorial and emotional properties. Also, we analyzed the factors of technical issues (manufacturing) and availability (supply) to produce the form and undertake its functional implementation (Karana et al., 2008).

At the initial stage, a group of materials—i.e., plastic, wood, mixtures (concrete, plaster, and Jesmonite), metal, and stone—was primarily selected among materials that can be purchased and implemented. Among them, we excluded plastic because it is widely used in digital and analog products, as well as in the research of existing tangible interactive devices (Hayes & Hogan, 2020).

For the mapping of three weather conditions ability, we chose three different types of materials by considering their possible sensorial and emotional experiences that may be felt by the user. We tested the vibration sound from materials by attaching vibration motors inside materials.

For clear, sunny weather, we picked brass, among other types of metal materials. This was selected to help understand how users may feel when the clear sound generated from the vibration motor combines with the brass material, hoping to represent the sunny weather. We were also inspired by a previous study that used copper in the device's inner surface to receive the sunlight (Gaver et al., 2013). By using the visually reflective feature of unpolished metals, we chose a slightly different metal material (brass) instead of copper. We applied the material's sound to explore the user's perception when used to deliver clear (sunny) weather through an everyday object.

Cork, as a block of synthetic wood, has a rough appearance along with the feeling of disorder due to the inconsistent wood-part composition. We considered this rough sensorial property to be relevant to the contaminated state of the road after rain or snow. Moreover, the vibration sound from the cork material generates a somewhat low and heavy feeling. Thus, due to the cork's sensorial features in its irregular appearance and heavy sound, we wanted to explore how users may perceive the mapping between cork sound and rainy weather.

We have selected the marble material because it is expected to induce emotional value due to its patterns and colors derived from nature. So far, marble material has rarely been adopted to provide tangible interaction with digital information. As the sound generated from marble is less heavy than cork and clearer than brass, we specifically wanted to investigate how the auditory feedback from the marble's vibration sound may relate to representing cloudy weather. Marble is commonly used for indoor and interior design. We also found it interesting to identify the possibilities of utilizing this material in digital interactive objects.

Through this selection of the materials, we wanted to focus on exploring the experience of gathering the current abstract weather information through the materials' sensorial (e.g., sound and appearance) properties in a tangible device.

Furthermore, to alarm users, to indicate upcoming events scheduled in their digital calendar, we used the movement of a wooden block. When determining the electronic actuators in the moving of woodblock, we considered that servo motor or stepper motor is not appropriate because of the sound generated when they are actuated. For this, we utilized shape memory alloy and a flexible 3d-printed module (Walters & McGoran, 2011), which can create the noiseless movement of wood.

The movement of the woodblock was based on its physical actuation with the change in spatial positions of objects (Poupyrev et al., 2007) by deforming the angle of the block made of a particular material. We selected this output interaction to inform upcoming schedule information because, given the rectangular exterior form, physical changes of the device may attract the user's attention and motivate new action (Frens, 2006). Also, Strong and Gaver (1996) suggested three different designs for minimal communication by using the specific modalities that materials can provide. In this, we considered that the familiarity of wood can contribute to curtailing the discomfort perceived when moving.

The capacitive sensor was placed in the concrete, the main body of the product, allowing the surface to be touched for input to provide an unexpected and positive feeling to the user (Lee et al., 2017). Concrete is relatively easy to make large forms through molds. We also expected it to afford proper weight to hold the placement of the product during product–user interaction by using concrete in the lower parts of the device. At the same time, it was presumed to have sufficient durability to be the main body based on the previous studies that utilized concrete as the main body (Lee et al., 2017; Jang et al., 2019).

Table 4.1. Matching Materials with Digital Function

Material	Information	Function	Sensorial Property	Actuation
Concrete	-	Surface touch input (Capacitive sensor)	Touch	-
Wood	Schedule	Alarming through changing the angle	Vision	Shape Memory Alloy
Marble	Weather (Cloudy)	Vibration and sound from the vibration	Touch, Vision, Sound	Vibration motor
Cork	Weather (Rainy and snowy)			
Brass	Weather (Sunny)			

Table 4.1 summarizes how each material’s visual, auditory, and tactile properties match with the digital function of retrieval of weather and schedule information.

Considering the above design aspects, DayCube was created in a cubic form merged with each cuboid material (Figure 4.2). The device’s upper segment is created from marble, dyed black cork, and brass. In the lower segment, there is a lumber-based alarm unit that works by the movement of its body. Lastly, the concrete part contains a touch sensor and a display.

4.2.2. Implementation of Interaction Techniques

Figure 4.2 shows the inner structure of DayCube. By utilizing the Arduino Yun, DayCube is connected to Wi-Fi Internet. Arduino Yun obtains the start time and content of schedules in Google Calendar and the current weather data from Temboo.

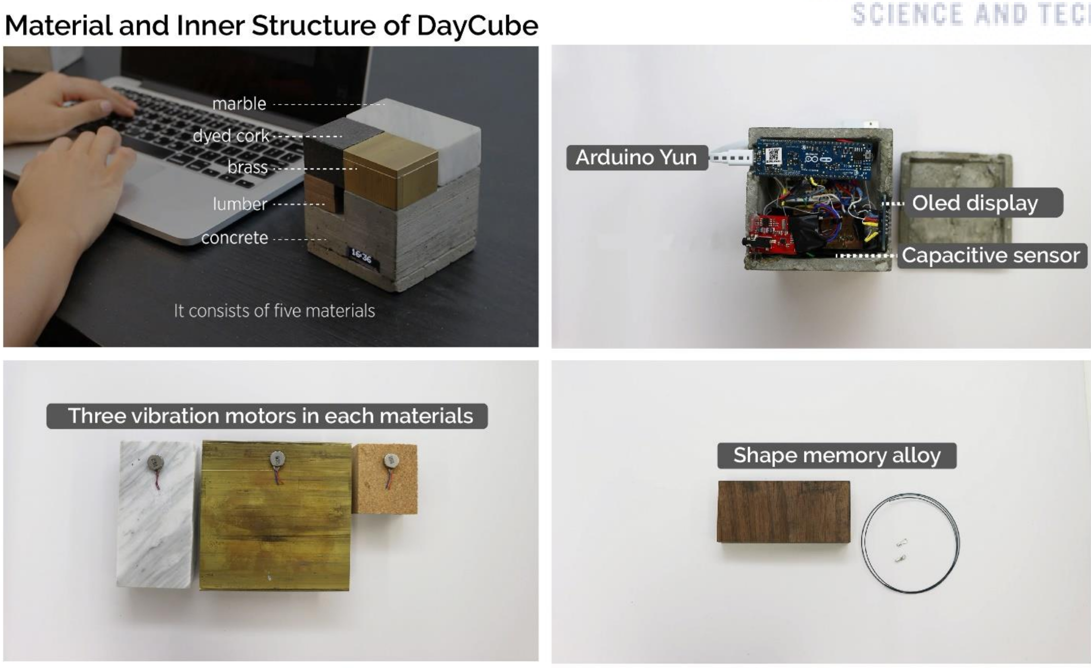

Figure 4.2. Material and Structure of DayCube

4.2.2.1. Presenting Weather through the Oscillation Sounds of Materials

First, the DayCube receives weather information for the current territory when the user touches its concrete surface. For this, a capacitive sensor is coupled with a 2.2 mega-ohm resistor. It is attached inside the concrete body to recognize taps or brushes on the surface.

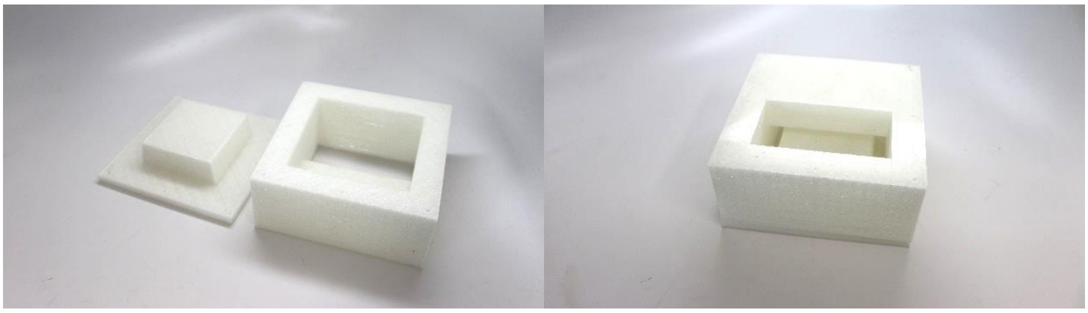

Figure 4.3. Mold for Concrete

Figure 4.3 shows the mold for making the concrete body. We have tested several versions for developing the proper mold, including silicone and acrylic shown in Figure 4.3. First, the acrylic mold (Figure 4.4.a) had an advantage by creating a clear surface. On the other hand, it can only be used once. To use it again, it was necessary to assemble from scratch. In addition, because there is no flexibility in the acrylic, there was a problem that cracks may occur in the process of disassembling the mold. Second, in Figure 4.4.b, the silicone mold had an advantage in flexibility. Therefore, it was easy to dismantle. However, because of this elasticity, there was an issue that the rectangular mold form could not be sustained after pouring the concrete.

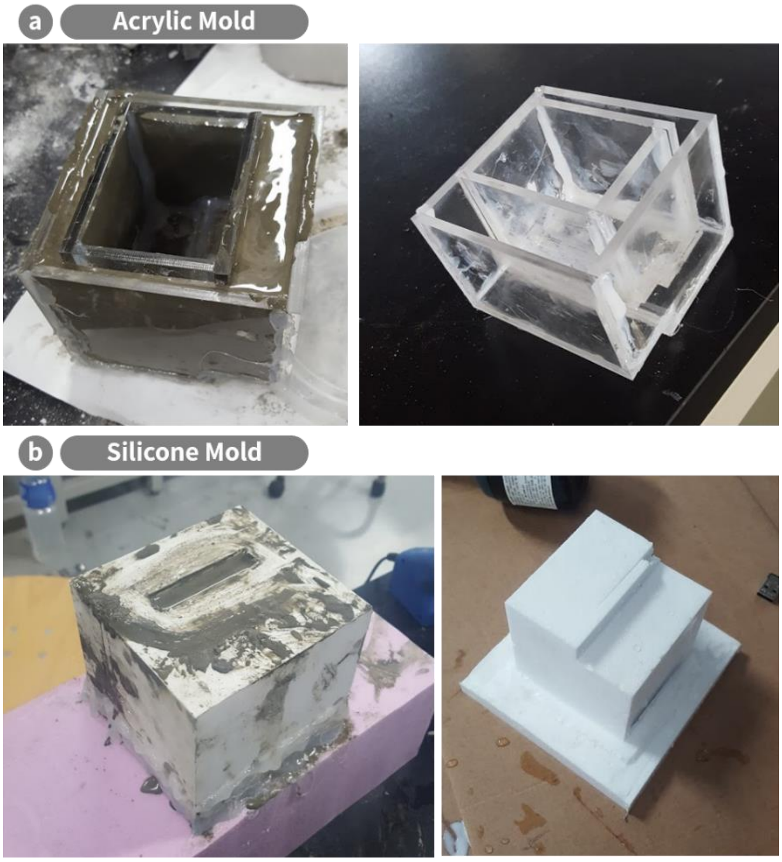

Figure 4.4. Mold Test, a) Acrylic Mold, and b) Silicone Mold

We considered that the silicone mold was suitable. Still, we found a better way to develop the mold. It was the flexible 3D printing in Figure 4.3. The advantages were we could develop a specific size of mold as we wished and we also can produce holes for screws. It could hold the shape of the mold and gave flexibility when disassembling.

When the capacitive sensor detects contact in Figure 4.2, the Arduino Yun acquires weather data for the area from Temboo in real-time. Vibration motors (diameter 10 mm, thickness 2.7 mm) are attached to three materials—dyed cork, marble, and brass—to convey information with a distinct sound due to the oscillation and friction of the separate material components (Figure 4.2).

Inside each of the three materials, we created sufficient space to insert the vibration motors by using a CNC (computerized numerical control) and a drill. The vibration motor moves up and down slightly when it vibrates, colliding with the material to generate sound. In Figure 4.5, the user can hear the sound of material vibration and feel the material vibration for detecting the current weather. Three weather types—sunny, cloudy, and rainy/snowy—were chosen because we considered these to be the weather information which is most effective in preparing ourselves for better everyday activities (e.g., bringing umbrellas or hats).

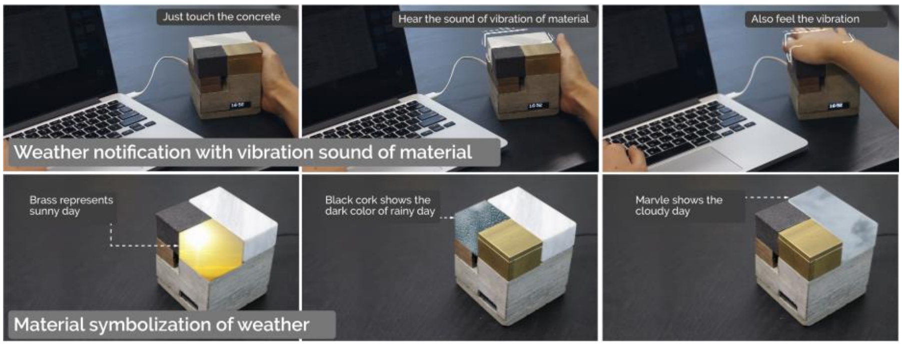

Figure 4.5. Interaction of DayCube: Weather Notification

4.2.2.2. Notifying Users of Upcoming Schedules through Shape Changes

Second, to carry out an upcoming schedule signal through shape changes of the lumber module, we applied four coil-type shape memory alloys (SMAs) (Figure 4.2). A shape-changing actuating unit was devised with regard to Walter's literature (Walters & McGoran, 2011). This module was 3D printed with a flexible material using the Formlabs machine. SMAs are placed to the left and right sides of the module. This module is attached to the inside of the lumber module. SMA's actuation can move the lumber module, which shrinks and expands when electrical stimulation is transmitted to them. Schedule information in the Google Calendar is wirelessly transferred to the SMAs connected to the Arduino Yun. Subsequently, fifteen minutes before the upcoming appointment, the lumber module repetitively and slowly moves to the left and right thrice (Figure 4.6). Additionally, the title and start time of the appointment are shown on the mini display placed on one side of the concrete body.

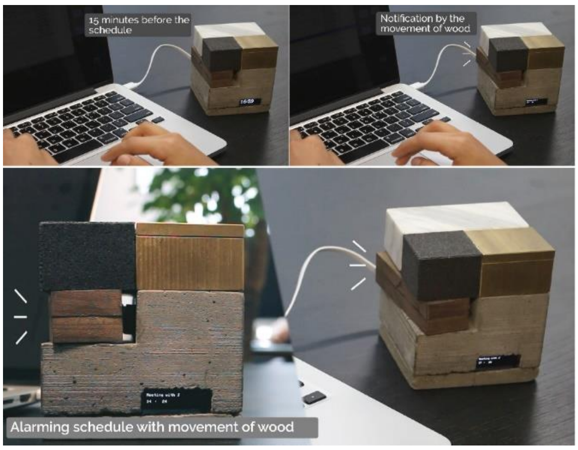

Figure 4.6. Interaction of DayCube: Schedule Alarm

4.3. User Study

We conducted an exploratory study to investigate how DayCube can be used in everyday working environments. Specifically, our goals were to examine (1) how the mappings of different IoT functions with the five materials were perceived by participants, (2) how the users might feel about the tangible interaction through touch input and output from the materials, and (3) what are the positive and negative aspects of each material that users might experience.

We included a total of ten participants (aged 20–25, five males and five females, P1–P10). The number of participants was determined by referring to the previous studies that have conducted design deployment to identify how people use a particular interactive device or system.

Most researchers consider recruiting ten to twenty people to be sufficient. They also claim that six to twelve users are appropriate in observing the singular role or detailed interaction instead of the overall work process. They suggested that diversity in the participants is an essential factor (Holtzblatt & Beyer, 1997). Alternatively, the other suggested at least six participants who believed the functions in the experiment might help them (Kujala & Mäntylä, 2000).

The types of participants were mostly student researchers from a diverse field of engineering and science. The gender was proportioned, and students from various majors were recruited: 3 machine engineering, 1 design engineering, 1 human & ergonomics, 1 urban engineering, 1 computer science, 1 biotechnology, and 1 chemical engineering. During the recruitment, we excluded students who may know the intent of product development and user research. We recruited participants using social network services such as Facebook. At the same time, we asked them about their current usage patterns of digital/analog calendars. We recruited five people who use digital calendars, three who use a paper diary or calendar, and two who do not use any scheduling method. The reasoning was to understand how the informing schedules through DayCube might affect the diversified types of calendar users.

We expected to find that natural and meaningful uses of DayCube can be observed when participants used environments similar to the actual context. For experimenting in proximity to the real context, one study rented a few seats in an operating café and invited seven couples for three days after installing the product. The invited couples used the product for 20 minutes, and then participated in an interview. The interview method and time were based on an interactive prototype study upon couples (Park et al., 2015).

Following this, we rented independent office space for two days. Additionally, we placed a laptop, books, and a small flowerpot on the table and located DayCube next to the laptop. After the participants had been selected, we asked them to visit for two consecutive days. Before starting the use of DayCube, we gave instructions regarding each function and interaction.

Participants used the DayCube for 30 to 40 minutes per day for a total of two days. This was to see whether there are any differences after the first use of the device. We set the shape-changing schedule notification twice for the middle and latter parts of the user study. Furthermore, we let the participants use the weather notification as much as they wanted. After the end of the DayCube use, we interviewed participants for about 20 minutes per day. To grasp the participants' general perception after using DayCube, we conducted semi-structured interviews, which are frequently used in field studies (Kujala & Kauppinen, 2004).

Two interviewers participated in every session and inquired about further questions from users' behavior during the test. On the first day, questions focused on the most and least favorite functions and materials recognition. On the second day, we asked about the details for each function and materials one by one, and interaction improvements that participants desired. The reason for giving another day to use our prototype was to make the participants use the DayCube naturally beyond the novelty effect of the first day. The collected interview data totaled 400 minutes, and our research team transcribed all after finishing the interview. Interview contents were investigated with thematic analysis to find the results (Maguire & Delahunt, 2017). Researchers developed groups by reading interview content repeatedly. Relevant or intriguing contents were checked on the first reading of the data. Feedbacks were grouped into themes as they emerged during the analysis. Throughout the interviews, we established consistent and opposing opinions for each participant.

4.4. Findings

By analyzing interview data of the user study, we gathered feedback on the various materials and the connecting material properties' functions.

4.4.1. Intriguing New Visual–Haptic Interactions with Various Materials

We found the various materials composing the functions of DayCube intrigued users about new visual-haptic interactions. Based on the four types of experiences materials can deliver during the user interactions—sensorial, interpretative, affective, and performative

(Giaccardi & Karana, 2015)—we could identify what experiences each material provided to the users when those properties were in connection with digital data interaction.

Regarding the wood material's shape-changes for schedule notification, all participants replied that wood is a familiar material. Furthermore, using this familiar material to notify the upcoming schedules visually has brought their attention to the device. P9 mentioned, *"There was no sound, but it attracted my attention because the movement was like it wanted me to look at it."* P2 stated, *"The alarm by the movement of the wood was novel and startling."* The alarm through movement stimulated the user with newness and curiosity that is different from the alarm method used before. Previous studies have indicated that active data can be determined with form transformation (Coelho & Zigelbaum, 2011). From this, the shape-change might be utilized to deliver digital information; for instance, an alarm of a specific event to the user. In this respect, although wood is a familiar material at the affective level, by adding physical actuation to it, we identified that the sentiment of the interpretive level conveyed by the material could be changed from static to dynamic.

Apart from the interest in the material and functions, we could also see that users may not notice the movement of wood because the moving range is not wide enough. Some participants suggested a more noticeable change in the movement for straightforward recognition.

Six participants revealed their interest in the object designed from various materials. Specifically, there were many responses to the haptic aspect of the materials. P3 mentioned, *"It seems like I am inclined to touch the object continuously due to the material diversity."* Additionally, eight participants responded positively to the concrete material. This positive reaction comes from the experience that the user saw and touched the material through an electronic device that was mainly used for building construction. P1 stated, *"There are not many chances to touch concrete usually. Using it was pleasing because it is not easy to get acquainted with the material. It seems novel to know the weather by touching [concrete]."* In particular, seven participants responded that the concrete texture was smooth. Four of them described the selection of concrete as satisfactory because concrete is considered rough but it seems soft upon touching. This demonstrates that the sharp contrast between visual and tactile feedback in the sensorial experience and affective emotion triggered by their inner thoughts creates a surprising and exciting impression on the user. In the existing literature, the perception of concrete itself is that people may not want to place it in a living room. However, the author stated that it can be utilized effectively if a design with concrete material can provide a feeling of novelty to the users (Ashby, 2008). This result indicates the possibility of concrete being adopted as a material for designing interactive objects.

In the case of cork, participants had an unfavorable opinion (at the affective level), explaining that it seemed to have low solidity. After the first interaction, participants suggested negative opinions about its haptic feeling and durability. P2 mentioned, *"The haptic feeling is not so good because it is sandpapery. It seems easily torn out by scratches with the fingernail."* For cork, users initially had a negative perception due to its image. After interacting, it still afforded a negative attitude from the rough surface.

On the other hand, P9 stated, *"It seems I will use and touch it (DayCube) often with my hands if it is soft."* Related research examining users' emotions toward material features (Hurtienne et al., 2009) has suggested that soft texture is experienced as non-problematic and rough material is perceived as problematic and dangerous. In other words, a soft surface is capable of providing a favorable feeling to the user.

Also, in the case of marble, five participants described it as luxurious due to its previous image possessed by users. In other cases, for brass, six participants mentioned that it felt freezing and heavy. There was also a slight difference in the description of the interpretive level of haptic perception between marble and brass.

Regarding the interpreted emotions after a sensorial encounter with the material, users commented that marble was cold; however, there were many positive responses, while in brass, it was freezing and had several negative comments.

By taking a closer look at the reason for these different reactions, one possibility is that perception varies depending on the degree of tactile coldness (sensorial property). In the DayCube, brass and marble were adjoined to each other. When users touch two materials simultaneously, the tactile coldness of brass (metal) can be felt more potently than that of marble (stone), which can cause relatively negative emotions. In other words, the user's feelings have the potential to be changed depending on the intensity perceived by the sensory property.

From another point of view, the existing affective image, such as the haptic and visual feeling (sensorial) of the material (e.g., roughness and temperature), are closely related. Therefore, it is plausible that the existing assumption of the users that marble is high-grade influenced the evaluation of materials with sensorial properties.

From the visual perspective, a total of seven participants responded DayCube manufactured with various material combinations with a rectangular shape and monotone color would be excellent for interior accessories. P4 mentioned, *"It will coordinate well with a black-and-white monotone office."* P8 states, *"It seems appropriate to place on the office desk, from rectangular shape and materials with cool emotion."*

4.4.1.1. A Quick Encounter with Digital Data through the Material's Affordance

Furthermore, through interacting with the material to verify the information, we confirmed the participants' positive feelings on providing clear notifications of daily information through a shorter process than the conventional method (e.g., opening apps in phones or webpages in computers). Correctly, a total of seven participants responded they could verify the weather expeditiously. P9 mentioned, *"The vibration [to show the weather information] is discerned new. I liked its sound."* P1 stated, *"I like the convenience and ease of recognizing the weather when I touch it [the concrete body] instantly."* This interest was generated from utilizing the function that has never been used as an independent product before. At the same time, there was a response that the advantage of the weather function can be maximized if it is utilized in preparation for going to work. There was also an opinion that vibration is not properly distinguished because motors were attached too firmly to the three materials. This was our technical limitation in not having enough space for the motors to make the sound when it vibrates inside the material. Notably, three participants showed the need to know where the sound and vibration derive from in the device. For this, users offered a complementary function, including a more aggressive alarm, such as the material itself shaking or creating space between materials.

Previous research has addressed the benefits of improved accessibility, including shorter verification routes and time through tangible devices (Kim et al., 2018; Lee et al., 2017). In line with these studies, our findings show the possibility of designing an everyday tangible object that delivers data archived in the digital world. Notably, it is essential to consider using materials' multi-sensory features to increase accessibility to the digital information represented in a tangible device.

4.4.2. Connecting Digital Functions through Different Material Features

Through the interview data analysis, we identified the value of weather and schedule notification symbolically delivered by each different material's sensorial properties. In particular, seven participants showed positive responses to the output given by separating the weather into three different materials.

Table 4.2. Sensorial Perception for Matching the Materials with Digital Function

	Vision		Tactile	
	Color	Size	Roughness	Temperature
P1				
P2				
P3				
P4				
P5				
P6				
P7				
P8				
P9				
P10				

When looking at the differences in the material recognition schemes of users, two sensorial properties—vision, and touch—were primarily involved. All participants mentioned that color contributed mostly to distinguishing the materials. Except for the color, they used tactile features of the material [e.g., surface pattern (P1~P10), roughness (P1, P2, P3, P6, P8, P9), temperature (P3, P4, P10)], and the size of the material (P4, P7) as given in Table 4.2.

Seven participants classified materials using colors with visual–haptic characteristics (color–texture [roughness], color-temperature, and color-size), and three participants combined three characteristics (color–temperature–texture and color–temperature–size) of the material properties for classification. These classification criteria show that at least two different aspects of the material, visual and haptic, are involved in the classification of the materials.

Color: Half of the participants agreed with the mapping between the weather and materials. Three participants agreed with rainy (dyed cork) and cloudy (marble) weather. They stated brass is not appropriate for representing sunny days due to its turbid color. This implies that the color yellow is well suited for sunny weather; however, the surface of the brass is muddy. Therefore, they expressed the need for a brighter yellow material. All participants agreed with the matching of cloudiness with marble. In particular, five participants mentioned it (the matching) was effective because the marble's black stripes on the white background seem similar to floating clouds. However, marble is a natural material and has a wide variety of patterns and colors. This finding cannot apply to all other marbles. In the case of cork, eight participants stated that the dyed black color of the cork reminded them of bad weather conditions such as rain. In other words, when using materials in products, it is necessary to consider additional processing without using existing materials since they are to be made more suitable for transmitting the information.

Size: A user commented on weather mapping according to the size of the material. Previously, Hurtienne et al. (2009) proposed how emotions can be matched with weight and size properties. Therefore, when using several materials in one product, it would offer further refinement to increase the size of the material to convey digital information that users feel positive.

Roughness: Participants suggested that the rough tactile surface of cork is suitable for expressing an unfavorable weather. Conversely, the smooth surface of the brass conveyed a relatively positive feeling compared to the cork. It felt suitable to represent a positive, sunny weather. As mentioned earlier, a soft texture is considered non-problematic and rough material is perceived as problematic (Hurtienne et al., 2009).

Temperature: Concerning the temperature delivered by the material from touch, it was opined that the coldness felt with brass is not suitable for expressing favorable, sunny weather. Thus, a tactile coldness from materials can serve as a stand-in for information that expresses relatively negative emotions.

Combining the above findings, we could check the sensorial properties involved in distinguishing information linked to materials. Accordingly, the characteristics of digital information can be expressed through the color and pattern of the material. When using various materials, it is possible to express a relatively positive or negative feeling by considering each material’s size. Finally, it is possible to distinguish positive and negative information through tactile temperature and roughness of the materials.

4.5. Discussion and Implications

4.5.1. Using Sensorial Properties of Materials to Design Interactions for Daily Interactive Product

Our findings imply that in the case of material, marble—which received the most positive comments from the participants—can be used to create interior accessory objects that implement the I/O functions of interactive products through the physical and visual properties of materials. Moreover, as marble provides more natural color and positive cold feelings, it is suitable for creating interactive products that coordinate with office-like environments. Marble, however, is a material procured from nature and every piece follows a slightly different pattern and color. In consideration of this, it will be necessary to allow users to search and select a suitable type of marble for expressing specific information and function.

As observed earlier, users preferred to touch a smooth surface and expressed negative opinions on prickly feeling materials. Therefore, it is appropriate to adopt a polished surface for the materials and to use materials with a rough surface only if the interface element needs to express a negative emotion or reaction. Additionally, we found that users' perception of the materials at the sensorial level affects their interpretive and affective levels. It is necessary to take both two factors—visual and haptic—into account during the selection of the material in designing tangible user interfaces. This is because the visual factor influences critically on identifying and distinguishing the material and the tactile factor has a crucial influence on judging the goodness of the material.

4.5.2. Design by Expected and Unexpected Perception of Materials

Second, during the interviews, when the participants expressed each material perception, there were many descriptions of whether those materials were familiar or unfamiliar. Concrete is a material often used in buildings; however, it is unfamiliar because they are rarely used in home IoT appliances. Additionally, cork, brass, and marble are perceived to be uncommon for electronic devices, and wood is mentioned as a common material for digital products.

Participants answered that they had assumed that concrete feels rough. However, there were many opinions about it being pleasing to feel a soft surface upon touching concrete. In other words, it was found that unexpected feelings can be conveyed to the user through the inconsistency between the user's thoughts and feelings in actual use. In the case of brass, cork, and marble material, users were found to have similar perceptions after using them through DayCube. Brass and cork conveyed negative feelings in accordance with their preexisting knowledge. Furthermore, marble brought a positive feeling of luxury.

From these findings, it is expected that a different feeling can be transmitted to the user by reflecting the user's existing perception or reversing the background perception in designing the product (similar to the example of concrete in the DayCube). It is possible to provide a positive value that is incongruent with the user's background knowledge through processing and manufacturing material.

4.5.3. Maximizing the Symbolic Meaning of Materials with Ambiguity

Our study results showed that the abstract representation of information by matching it to materials is required along with considering visual, haptic, and auditory aspects of the material. This could furnish opportunities for the users to engage with the object further by providing room for them to interpret materials by themselves.

Through this, we may propose a concept for a future device that uses the symbolism of materials. The idea was to develop a tangible digital product with dividing smooth and rough touch feeling with the same material as participants use the touch sense to evaluate and classify materials.

Representatively, when designing devices using wood, the degree of haptic feeling can represent different degrees in the weather. Soft surfaced wood that can provide a positive haptic feeling could symbolize sunny weather and cloudy weather can be designed with a rough material surface. In another perspective, Vallgårda (2014) suggested one example of changing the temperature of copper with the user's interaction. As we mentioned above, users were affected by the material's seamless temperature from the haptic sense. Participants also highlighted the difference between their background knowledge regarding the material and actual perceptions upon use (e.g., concrete). Thus, we could also envision a new design space in transmitting information by changing the temperature of the material. For example, brass was perceived negatively by the users as per their background knowledge and due to its cold touching feeling. In this, changing the temperature of the brass material through technology may bring an intriguing perception if it becomes warm on a sunny day.

As mentioned above, one of the most used features of home IoT speakers today is reporting weather information (Brittany, 2018). The development of products in the direction of combining positive factors, including transmitting information with a low threshold via simple touch, is expected. Furthermore, the product can provide the value of ambiguous information transfer (Gaver et al., 2003; Strong & Gaver, 1996) with the material's characteristics and generate interest in interaction with the material.

4.6. Limitations and Future Work

There are a few limitations to this study regarding the technical implementation and user study. First, the study of DayCube examined the possibility of digital information transmission through vibration and sound expressed by materials. A detailed investigation should be conducted in future works to express digital information by utilizing multiple characteristics of materials such as vibration. One possible way is suggesting the vibration of materials and the oscillation sound in various directions so that the participant feels it through their sensorial faculties and maps the digital information themselves.

Second, we conducted a user survey by renting an office and inviting users. However, to reach a deeper understanding of the users' perception, it may be necessary to consider increasing the duration, the number of participants, or conducting a user study by installing the product in the user's real office.

Third, weather information conveys information of the current region and weather. However, since this information can be checked simply by inspecting the outside, there is a risk of losing the information's value. Therefore, it may be necessary to consider changing the digital information to inform the weather change in the day or weather in the other location.

The purpose of this study was to connect materials, interaction, and digital functions, and to investigate how people perceive and judge this combination. In particular, we identified the characteristics of the materials to match the external weather conditions to the three materials. These characteristics were the material's tactile and visual elements and the feasibility of manufacturing. We believe that this study and the design of DayCube may provide insights for utilizing material properties for conveying digital information.

5. Rematerializing the Calendar and Traffic Information: Traffico

A previous version of this article was presented at the DIS (Designing Interactive Systems) Conference in HongKong, 2018.

5.1. Purpose of Research

Second, it was developed a tangible timetable called Traffico, which was rematerialized with calendar and traffic information. There were studies that introduced devices displaying schedules in a physical form (Han, 2017; Lee et al., 2017), focused on suggesting ambient ways of displaying upcoming schedules. These emergent studies provoke tangible experiences through physical devices, which are often forgotten in the dematerialized world. As such, providing tangible form to dematerialized information is valuable for bringing the richness of the physical world back to the user.

Regarding the visualization of schedules with a transportation option, Dragicevic and Huot introduced displaying time notice for buses and shuttles within a virtual digital clock (Dragicevic & Huot, 2002). In another study, researchers presented “Intelligent Alarms,” a digital calendar applied to prepare reminders and location-related alarms (Tungare et al., 2008). These studies implied the possibility of displaying transportation information between schedules as a valuable option. However, they focused on proposing solutions as intangible interfaces, rarely represented in a physical form. Building upon the existing studies, the current study aimed to explore the provision of dematerialized information in daily life via a physical form and to examine implications for the user experience.

Figure 5.1. Traffico, Representing the Upcoming Schedule and the Required Time through the Walk, Bicycle, Bus, and Car

For this, we designed a desktop timetable (see Figure 5.1) positioned as a dematerialized alternative to the current trend in application design (i.e., digital calendar apps) (Tungare et al., 2008). As existing analog scheduling systems, including paper calendars, our study describes the design and implementation of a tangible device, which combines the merits of using the past paper calendar (e.g., easy accessibility) (Brush & Turner., 2005) while taking advantage of digital applications (e.g., convenient confirmation of daily information).

5.1.1. Design of Traffico

Transportation Information between Schedules: The information to be punctual to our schedule helps us in our lives (Sultana & Rashid., 2013). It especially needs to find the means and the required time of transportation in order to ensure the upcoming schedule is on time. To do this, we used additional map applications or navigation for searching the time taken by transportation options (e.g., walk, bicycle, bus or taxi) when traveling to the scheduled place. In this process, there is also the cumbersome action of re-entering place information into the map application. Also, if users are familiar with a place to go, they may find that they tend to use a specific transportation choice repeatedly, even if there are faster or more convenient traffic options. Traffico’s design started through understanding the effectiveness of preceding study and desktop calendars, along with navigation apps. Although many online calendars exist, people still use paper calendars because of their favorites, such as the opportunistic rehearsal of schedule monitoring at a glance (Tungare et al. 2008), and positional accessibility (Brush & Turner., 2005). To integrate the benefits of paper-based calendars, Traffico displays schedules on an electronic ink (e-ink) display when put on a desk, offering both positional advantages and opportunistic rehearsal. Also, we concentrated on both the notification of schedules and efficient day-to-day time administration. Because we noticed that former calendars concentrated mostly on delivering simple schedules, additional apps are required to help their simplicity (i.e., navigation to the destination). Thus, we singled out the value of presenting transportation information to a schedule through existing research (Tungare et al. 2008; Dragicevic & Huot, 2002). From this, we represented four dominant types of transportation information: walking, bicycling, public transportation (bus), and driving a car. We chose the four transportation options due to their frequent use as moving options in daily life. Considering there is no subway in the area where the product was tested, subway data was not included. Through this integrated daily information presentation, we endeavored to research alternative ways of managing events and users’ time scheduling to understand how the materialization of immaterial information influences the product experience.

Peripheral Desktop Object: We also wanted to build the device seamlessly harmonize within the house or office conditions. We designed the device as a peripheral object because users are asked to give too frequent attention when handling digital devices, especially when performing multiple tasks (Hausen., 2012). For this, we designed the device to exhibit schedule and transportation data to flow on the screen. Besides, we picked an e-ink display and Jesmonite material for the exterior form. E-ink is useful for delivering ambient sensibilities (Fernández et al., 2015) while contributing less eye strain (Potu et al., 2016), and it also helps with mimicking the paper-based calendar. We estimated Jesmonite to provide a soft tactile feeling (Heliot & Co, 2016) and a physical sense of stability (Chandler, 2017) and to afford an ambient experience by pairing the color with the e-ink display.

Figure 5.2. The Design Process of Traffico

Three design principles were used in the Traffico's design process. The external shape of the product was designed in various forms based on the three points that

1) the user can effortlessly control the time zone by a rotating interaction,

2) the user can easily notice the change of timeline,

3) being peripherally absorbed in the user's environment (Figure 5.2.a).

We developed various design concepts, including turning the product by putting a finger in the product, pushing and pulling the product on the floor, and turning the disk on the left or top of the product. Based on this, we did the modeling to check the form and color of the device (Figure 5.2.b). In the screen design, we tried various designs with the consideration of displaying correctly the means of transportation, the information related to the schedule, and transportation (Figure 5.2.c).

Figure 5.3. The Final Design of Traffico

The final design of Traffico is shown in Figure 5.3. The time plate was on the left side. We thought it would be more convenient to control it with the left hand because users usually hold the mouse or smartphone with the right hand. At the same time, we tested the prototypes during the development process and determined that it would not be too difficult to control it with the left hand because the rotating interaction is spontaneous. The plate covered a portion of the e-ink screen. Through this, we tried to connect the rotation of the plate and the change of the screen more smoothly. We expected users could check and notice the change of display and the rotation of the time plate more intuitively. The overall surface was painted gray. It was believed that an inconspicuous color helps the appropriate penetration in the user's environment and supports achieving a smooth connection with an e-ink display.

5.2. Interacting with the Tangible Timetable

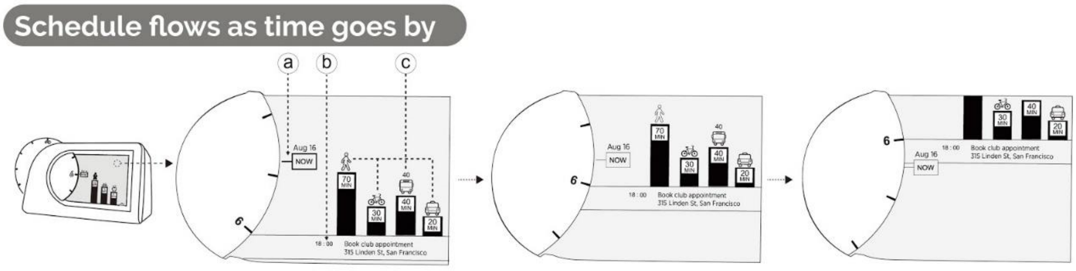

Figure 5.4. Screen Design

Traffico displays the present time (Figure 5.4.a), schedule, and transportation information (Figure 5.4.c) with clock plate rotation. The transportation report reports an expected time for each moving option and the bus number. Figure 5.4.b presents data about the start time, title, and place of scheduled appointments. As time goes by, the schedule information naturally goes up along the clock plate and disappears from the screen.

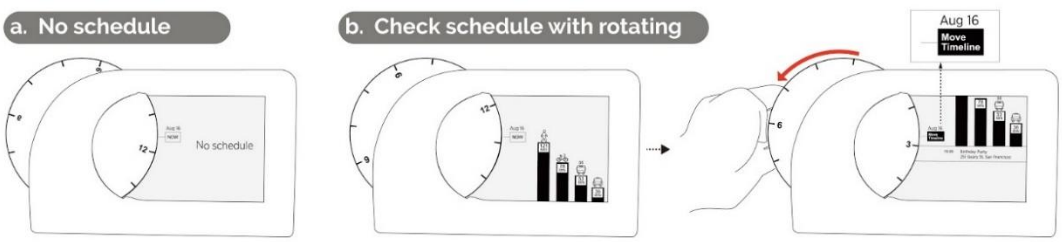

Figure 5.5. Screen Design and Interaction: a) No Schedule and b) Check the Schedule with Rotating

When the user does not have a schedule at that time, the phrase “No Schedule” appears on the screen (Figure 5.5.a). The user can spin the clock plate to a particular time to check a schedule at another time (Figure 5.5.b). It highlights this time with a notification line (Figure5.5.b). Then, Traffico shows the schedule with the transportation information at the rotated time. When the user moves the time by a rotating interaction, an icon “Move Timeline” is displayed on display to inform the user that the time has changed (Figure 5.5.b).

A rotating interaction method was chosen due to its potential to assist the user’s control of the plate through clockwise and counterclockwise turning in a natural way (Kim & Eune, 2015). This feature could thus provide the interaction needed to easily modify the time so users can confirm the day’s schedule. In this way, interaction design was driven by a desire to embed physical interaction possibilities within the design (tangible form) and to replace the app design interface with tangible control.

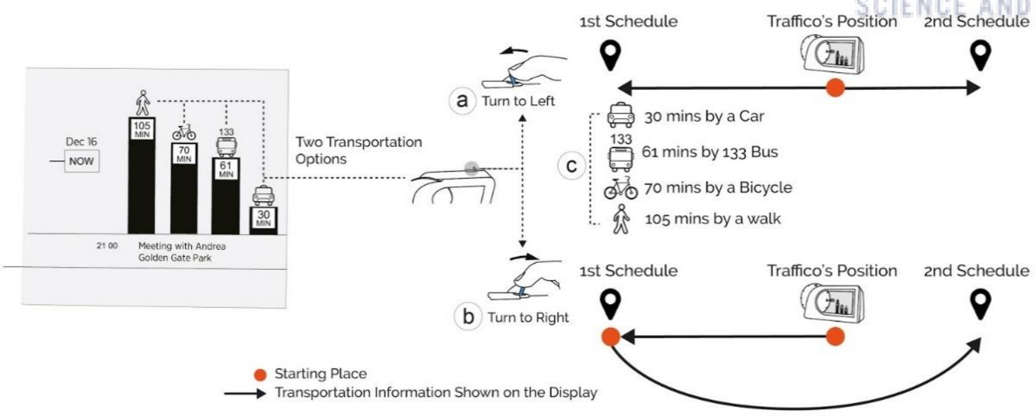

Figure 5.6. Change Mode of Transportation Information

Users can select a method for calculating the required times between schedules by using the switch in the rear body (Figure 5.8.a and b) of Traffico. First, the time needed from the current position is displayed, which Traffico has already installed in a scheduled location (Figure 5.6.a). Second, it demonstrates the needed time from the specific schedule to the following scheduled place (Figure 5.6.b). The schedule and transportation data are updated every 30 minutes; however, whenever the users want to update them in real-time, they can push the button (Figure 5.8.a) at the top.

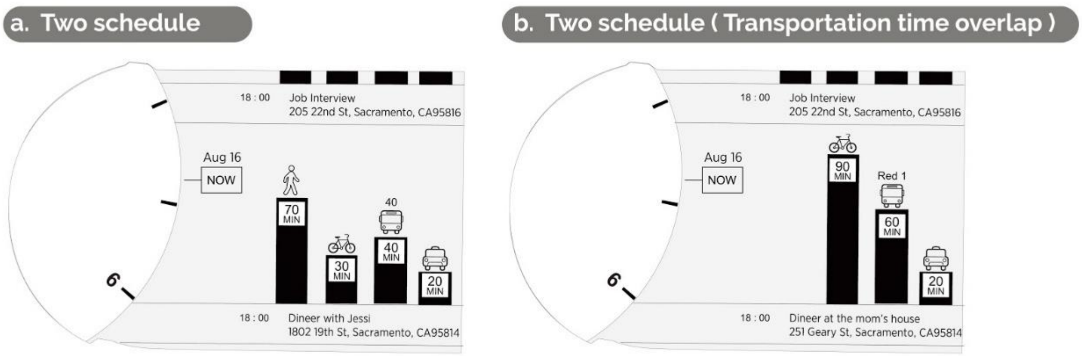

Figure 5.7. Two Schedules in Close Timeline

If there is more than one schedule in the close timeline, all schedules will be displayed on display, but not for traffic information if the needed time for transportation is longer than the remained time between the two schedules. In figure 5.7.a, all traffic information is available because the time it takes for the second schedule was less than the time between the first and second schedules. On the contrary, In Figure 5.7.b, it does not show up time information for walking because the walking time for the second schedule was longer than the free time between the first schedule and the second schedule.

5.3. Implementation

Hardware: Our hardware fabrication started with the front panel and clock plate produced with the Jesmonite (Figure 5.9.g and h). We utilized Jesmonite AC100 and a small amount of black and green pigment, Liquid Dye. Because the original color of Jesmonite is close to the dark pink, we blended 120 ml of the Jesmonite with four drops of black (approximately 0.2 gram) and two drops of green (approximately 0.1 gram).

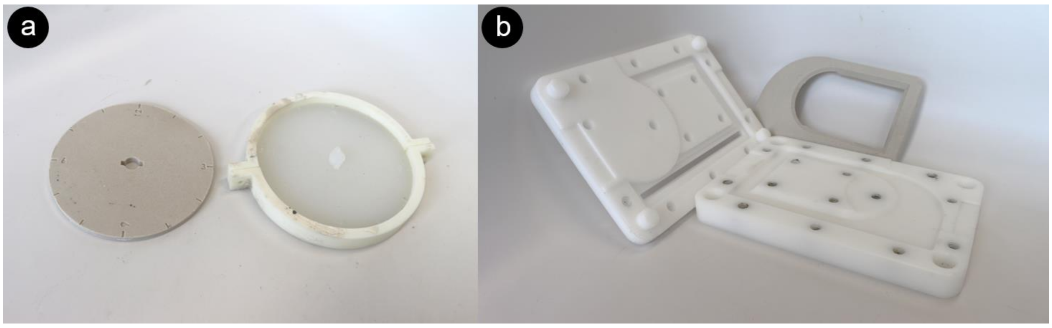

Figure 5.8. Jesmonite Molds, a) Clock Plate Mold, b) Front Plate Mold

Through this, we could match the Jesmonite cast with the gray color of the E-ink display. The mixture was poured into the Two-layer CNC-machined plastic mold (Figure 5.8.b). A lubricant was sprayed inside the mold for easy removal of the solidified Jesmonite. For the clock plate (Figure 5.8.a), the silicon mold was firstly produced by pouring silicon into an acrylic plate made of CNC. Next, it was surrounded by a circular wall made of 3D printing next to the silicon mold, and then we spilled Jesmonite liquid into it. The device includes the Jesmonite casted front and clock panels (Figure 5.9.g and h). An e-ink display (Figure 5.9.f) was attached to the back of the front side. A rotary sensor (Figure 5.9.c), connected parallel to the stepper motor, was used for measuring the rotation of the clock plate (Figure 5.9.h).

Software: Arduino Yun (Figure 5.9.d) connects to the wireless internet and gains calendar data once an hour from Google Calendar. Linux-based Arduino Yun is connected to the network and identifies its current location by embracing Google's Geolocation API. Basically, this API knows the approximate location based on the IP address, and to receive the current location with higher precision, and we utilized the built-in wireless LAN to read the information from the surrounding broadcasting AP. After that, data related to each MAC address, SSID and radio field intensity are additionally delivered to the relevant API. The advantage of this approach is that we can identify the current position of Traffico with a fairly high degree of accuracy before exploring the transportation time, even if it is in an indoor space where the signal is not constant due to obstacles. We utilized the Google Maps API for walking, bicycling, bus and bus number. The local API termed the SKT map for the real-time car traffic of our country is applied to bring the time needed by a car. The place information needs a value of the address format so that it can be represented on the map. If it is a proper noun, such as a building name like the Empire State Building, that value is enough to be searched on a map through a simple keyword entry. Also, when the destination is written in the form of a detailed road address, it can be somewhat inaccurate; therefore, Google's Geocoding API is applied to convert address to the latitude and longitude GPS coordinates. In the end, the user will employ departure and destination values to calculate the time required for each mode of transportation, including walking or using a bicycle, bus, and car.

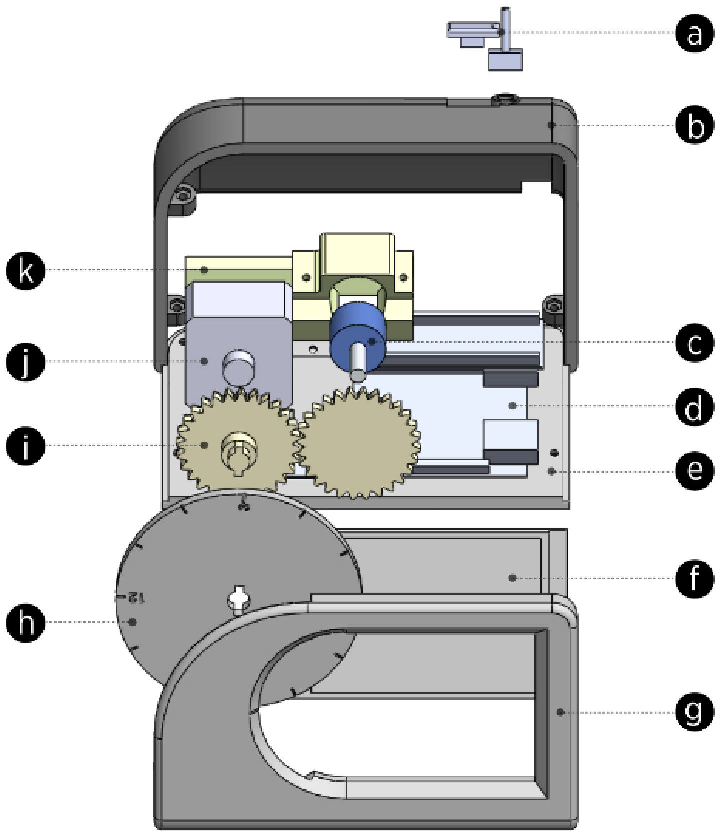

Figure 5.9. A Detailed Structure of Traffico, a) Push and Toggle Switch, b) Rear Body, c) Rotary Sensor, d) Arduino Yun, Yun Mini, e) Bottom Plate, f) E-ink Display, g) Front Plate, h) Clock Plate, i) Gear, j) Stepper Motor, and k) Parts Holder

The movement time data of transport options, except for walking and bicycling, reflect the traffic situation, and the walking time required to reach the bus stop is applied. Therefore, the calculation result may change every hour, and the new value will be updated every 30 minutes. In general, when moving on foot, it is assumed that the situation of the road will not influence the velocity of walking. Therefore, the moving time was calculated by assuming travel time at a speed of 3.6 km/h. However, it has limitations that cannot reflect the time taken to move indoors, including moving up and down. This must be improved in the future. Regarding the campus location, it could not search for the location of a detailed building name due to the limitation of Google Maps. Given the fact that most of the surveyed participants would use Traffico on the campus, we manually included the detailed road address of the university building to solve this problem. A total of two Arduinos were used (Figure 5.9.d). This was because the capacity of the RAM required for the operation of the e-ink display was high; therefore, one Arduino cannot handle both running the e-ink display and getting transportation and schedule information. One Arduino was used to load the e-ink display, and the other Arduino was to load traffic information and schedule information. The two Arduinos were connected by wires to exchange information continuously.

The rotary sensor (Figure 5.9.c) has a 0 to 1024 value, and a total of 10 laps can be rotated to the maximum. In Traffico, we map the rotary sensor values from 0 to 720; thus, if one lap is 12 hours, it can travel five days with ten laps in total. If the sensor value changes by 1, the time will be increased by 10 minutes. When Traffico is turned on, the initial setup process initiates, and the stepper motor (Figure 5.9.j) begins to spin until the rotary sensor value is equal to zero. At the same time, the 12 o'clock mark on the clock plate is positioned in parallel to the notification line on the E-ink display. Next, Arduino Yun takes the current time through the Internet, and the stepper motor turns as much as the current time. We set up 12800 steps for the stepper motor, which is one complete rotation. Therefore, if the current time is 9 o'clock, it moves 9600 steps in order to correspond to the current hour. After that, to turn the clock plate following the current time, we set it to run 8 steps every 27000 milliseconds. Then it will rotate 12800 steps, which is one round, for 12 hours. Therefore, Yun does not need to receive the current time data through the Internet, except with this initial setup process. In addition, if the user presses the reset button after rotating the clock plate to check the schedule, this initial setup process runs again to calibrate the current time.

5.4. User Study

We conducted an in-field study to explore the value of Traffico. Specifically, we wanted to know what kinds of advantages this tangible device may provide to users through the combination of dematerialized information (schedule and transportation). To explore the influence of Traffico on the user experience, we utilized the field study method (Brown et al., 2011). Ten people (aged 23–31, seven males, and three females, P1–P10) studying at the authors' research institution were chosen. Four participants conducted in the office, and six did in their home. We selected them because all participants managed their own schedules through various online (i.e., applications) or offline (paper calendars) systems.

Three identical Traffico prototypes were built. Each participant used Traffico for five days, including two days of a weekend or even a holiday, because we thought it had a high probability of going out on the weekend and holiday. We requested participants to go out at least two times as a test to familiarize themselves with the use of Traffico. Two interviews with each participant of approximately 30 minutes were conducted on the third and final day of the field test. We brought the Traffico prototype to each interview session to stimulate the participant's thought and response.

Table 5.1. Interview Questions

Interview day	**Interview contents**
1st Interview	• Expectations before participating in the user study • The perception from checking schedules through a tangible device and rotating interaction • Functional feedback from checking transportation information with the schedule • Design perception by placing Traffico in their space • The difference in the schedule checking experience while using Traffico compared to previous digital or analog devices
2nd Interview	• Change in perception related to utilizing Traffico compared with the first interview • The impact of Traffico on their personal life

Table 5.1 shows the interview question asked for two days. In the first interview, we investigated participants' attitudes toward Traffico during the initial two days, as well as their expectations before using Traffico. In the second interview aimed at distinguishing their impressions over the entire five-day period, we asked if any differences existed from the initial use of the device, and the impact of Traffico on their personal lives. Generally, all participants were asked to answer questions about the overall usability, interaction, benefits, and drawbacks of the transportation information and scheduling, and design perception from placing Traffico in their space.

The data collected included 497 minutes of interview recordings. All data were transcribed, with transcriptions. Interview data were analyzed using thematic analysis (Maguire & Delahunt, 2017). Relevant or interesting quotations were marked with memos, and researchers created groups by continuously and frequently examining interview. Throughout the interviews, we identified constant and opposing opinions from each participant with an across-case approach (Ayres et al., 2003). During categorizing, interview content was first classified under four topics following the primary function: rotate interaction, notification of schedule and transportation time, and also design aspects of Traffico. Afterward, within each feature, data were classified into specific categories according to the similarity of answers, including the following: the characteristics, advantages, and disadvantages.

5.5. Findings

5.5.1. Better Reminding by the Interaction with the Schedules Displayed in Chronological Order

We found that all participants confirmed their daily schedules instantly and continuously by displaying them in chronological order and a rotating interaction.

First, the participants responded positively to Traffico's presentation of the day's schedule. In total, nine participants reported this. P2 stated, *"It is good that the day's schedule is shown in chronological order. Therefore the schedule is drawn as a picture in sequential order in my head."*

In addition, eight participants described the usefulness and joy of navigating through the rotating interaction in the process of checking the schedules. P1 mentioned, *"I was surprised to see that the time was displayed in accordance with the physical rotation of the clock… It was amazing to display a digitized image (schedule) by analog rotation."* One study indicated that it was confusing to check upcoming schedules through the virtual rotation of the clock hands (Dragicevic & Huot, 2002). On the other hand, Traffico's physical rotating interaction can provide an enjoyable and useful experience as well as benefit the participant with a constant reminder of the schedule.

However, there was a slight disconnection between rotating interaction and e-ink display. The e-ink display takes a long time to refresh screens. Therefore, the reaction speed is slow compared with turning the plate. The e-ink display used in the Traffico had a delay of about 4 seconds following the product specs. In contrast, there was also a positive opinion that participants could quickly notice the change of the screen as the display totally disappeared and reappeared. In other words, it is necessary to consider the pros and cons of applying the e-ink display. In detail, overall, the e-ink display affords a definite and clear screen. The user's eye did not get any pressure and the merit is that it seems to be entertaining and stimulating following the screen switches. The main disadvantages mentioned were the speed of transformation and the inability to identify information in a dark environment accurately.

Lastly, six participants noted that Traffico offered the advantage of being able to remind each of the schedules, making stricter to set a time for themselves. P3 mentioned, *"I feel like working properly with seeing the schedule on the E-ink display... I think to become scrupulous to myself (by doing exactly the same following schedule on display)".* We could confirm that the way of displaying schedules through a tangible medium provides the advantage of continuous reminding (Tungare et al., 2008). Traffico's feature of showing the movement of time using the physical clock rotation controlled by the rotary input in the same plate underpins this finding, which differs from the existing cases. In line with previous studies of tangible devices representing schedules, Traffico encouraged participants to remember forgotten obligations and to perform them instantly (Lee et al., 2017). This result indicated how Traffico provided some of the properties of paper-based calendars through a physical device. On the other hand, the three users showed discomfort in presenting only the day schedule. They revealed the need to show the whole month or weekly schedule. P2 said, *"I used to grasp the week's overall schedule (in the previous online calendar). It was unfortunate that Traffico did not support this."* This finding suggests that it is necessary to consider an additional function to check the weekly or monthly schedule, as in the usual online calendar.

Moreover, related to this, three participants suggested the inconvenience of rotating to check the next schedule. This is intriguing because eight participants said that the rotating interaction was interesting, but among those eight users, three said that it is a little inconvenient. We found that if the time for interaction becomes long, participants said that interaction is cumbersome. It may change the interaction of Traffico by combining a more straightforward physical left-right button for day change, and the plate rotation used in the searching schedule only in one day.

5.5.2. Effective Time Planning through Showing Transportation Information on the Materialized Calendar

We discovered the value of Traffico by adding transportation information to a tangible device reflecting a dematerialized calendar. In particular, we confirmed that Traffico's transportation time and schedule confirmation process was valuable for understanding the moving time, planning, and use of the time of the day.

Every participant commented that the combined suggestion of a transportation time with the schedule was convenient. P8 answered by comparing his previous experience with using a smartphone: *"I was surprised that the bus number and the image (bus icon) are also* *displayed when using Traffico before going outside. Especially on a moving schedule (had to go far), it provides transportation information that fits me better than the (smartphone's) apps."*

Notably, we heard from seven participants that Traffico helped to plan the entire day's travel time. P2 stated, *"I can see how much time is needed to travel by reviewing the day. The movement time can be caught; thus, it was good to see how much time I was investing in the day's transportation at a glance."* P6 noted, *"It will be helpful to reduce wasted time to visit a new place."* He clarified that it was because if he leaves early for an appointment, the remaining time will seem like the time to be thrown away, but Traffico tells him how much time he needs to travel. Regarding the identification of the available time prior to the upcoming schedule, P4 answered, *"I usually start to prepare one hour before the transportation time; therefore, I had to arrange myself for one hour before the transportation time shown here. I think the purpose of this device is utilizing the time efficiently with transportation time (because we can check the transportation time and figure out when to leave)."* Similarly, with an existing study (Dragicevic & Huot, 2002), Traffico shows the potential as a device to understand and plan the time needed to travel in a day. Our finding revealed the efficacy of providing the required transportation time. Traffico, positioned on the desk, allows users to enjoy continuous tangible interaction; thus, it has the potential to generate convenient accessibility like a paper calendar (Brush & Turner, 2005), through its physical form.

However, to increase usability, we have found the need to provide more diverse information. This information was mainly mentioned in public transportation. It has been suggested, for example, to provide a variety of bus numbers to maximize the user's selection options and to deliver a location or name of a nearby stop or bus route.

5.5.2.1. Security Issues: Public Information Display

Six participants provided opinions about security issues. Because Traffico did not have any tools for hiding the information, others can quickly check and search the schedule.

Related to this, two proposed their way to hide the information, such as writing encrypted schedule information in a way that only they can understand. P3 said that *"I thought it might be a little annoying (other people watch the Traffico). Hence, I wrote it a little ambiguously rather than writing it in a note."* One suggested the further idea of adapting fingerprint recognition. Two users mentioned the possibilities of utilizing Traffico as a public calendar. For example, if participants are not on the desk, other coworkers come to the desk and verify the information about what they are doing and where they are now.

These findings appear to be not just findings related to the Traffico, but also findings that can be applied across physical calendars. What we noticed is that users tended to manage the information themselves or required application of additional security measures. Alternatively, we could consider changing the purpose of the product and utilizing it with a bulletin board with all colleagues. According to the previous study (Partil et al., 2005), personal information such as a calendar is free to disclose to family and coworkers during business hours. Conversely, after the working hour, people seemed reluctant to disclose personal information. This shows that using Traffico in a work environment requires a way to turn off or lock the product after working hours. On the other hand, it seems that it reduces the necessity to restrict information in a home situation.

5.5.3. Jesmonite's Soft Texture and Colors for Interactive Design

From all the participants, the benefits of the Jesmonite texture used in Traffico were identified. In addition, the color of the Jesmonite, adjusted to a gray color for matching with the E-ink display, provided the participants with a positive impression, as they perceived it to have a harmonious and modern design. First, all participants mentioned that the material's texture was soft when touching the surface and rotating the clock plate made of Jesmonite. P7 compared the Jesmonite with other materials and stated, *"I like its feeling because it does not feel like metal. Plastic is perceived to be material for infants, but I loved this because it does not feel like that. Metal has a cold and uncomfortable texture, but this has a good feeling."*

In addition, all participants expressed a positive opinion about the Jesmonite incorporated with the E-ink display. It was primarily found that the color of those two coordinates was received well. P6 mentioned, *"The color was not fancy. However, it looked neat. The display can only express black and white, Jesmonite is also gray color, and therefore it is well-matched."*

From this, we believe that Jesmonite's texture can be an engaging factor when utilized for a tangible interface. When referring to previous research, it has been demonstrated that the smooth surface is considered unproblematic and continuous (Lee et al., 2017). Also, the matching grayscale of the Jesmonite and E-ink display demonstrates its functionality that offers a sense of reliability and modesty that does not attract too much attention. It will also encourage the designers to make the desired color mixture when developing interactive devices, and, at the same time, it will help to generate positive feelings with the smooth texture of Jesmonite, which the user can actively touch for physical interaction.

5.6. Discussion and Design Implication

Traffico identified the possibilities of demonstrating dematerialized things (analog calendars and timetables) in a tangible form. We also saw possible use experiences with a combination of two separate functions, transportation, and schedule notifications for managing the day and planning time. Based on this, we propose some reference points for the development of materialized devices showing transportation and schedule information.

5.6.1. Bringing Analog Perspective to the Digital

First, as Traffico merged the benefits of analog calendars, such as opportunistic rehearsal (Tungare et al., 2008) and positional accessibility (Brush & Turner, 2005), this may generate possibilities of designing new tangible devices through analyzing the properties of existing analog products. Other advantages of paper calendars still exist, such as leaving a paper trail or writing annotations (Tungare et al., 2008). Considering these features in designing the interactions of future physical calendars may provide an effective scheduling method for previous paper calendars, which are now replacing due to the popularization of digital scheduling apps.

However, a potential obstacle with the analog characteristic of Traffico is that the individual schedules are exposed on the screen and may be seen by others. This limitation could be overcome by the use of fingerprint recognition or by adapting the function to utilize Traffico is a schedule-sharing device for business purposes, as introduced in a previous study (Sellen et al., 2006).

5.6.2. Maximizing Functionality with Two-related Digital Functions (Main function with sub-function)

Second, the consideration of providing multiple pieces of dematerialized information, related to one another, might provide additional value for an enhanced profit by coupling them through representation in a physical form. In traffico, it utilized the main function as a calendar and combined with sub-function, transportation information about that schedule information. Thus, it is required to understand and apply the advantages of the particular functions of existing digital apps beyond expressing single dematerialized information from a smart device on the tangible device. In particular, including functions such as informing about various traffic information, detailed routes and transfers to this device need be taken into account when users search coming schedules. Moreover, distinguishing these various modes could be achieved through visualizing the state of physical switches on the screen. Also, additional tangible interactions for changing to detailed traffic information or other route selection options must be considered, for instance, through the vertical input of the rotary plate. The consideration of these issues may enhance the experience of planning the time of day or week, and it will provide the efficient use of a tangible desktop timetable as well.

5.6.3. Developing Portable Traffico

It is shown that Traffico will be able to present the necessary transportation and travel time during the day. However, if there is a lot of movements due to copious schedules, the limitation is that Traffico is unable to be used at outside. Therefore, to solve this portability issue, we could improve the device to be used as a small handheld electronic object that only receives data when the calendar is updated by incorporating the energy-harvesting characteristic (Grosse-Puppendahl et al., 2016) of the E-ink display and the solar charge panel. In addition, referring to the previous study (Collins et al., 2007), applying the method of receiving a calendar notification and traffic information with a message would supplement this portability issue.

5.7. Limitation

Through the development and user study of Traffico, it was found the value of rematerializing a schedule and traffic information device. On the other hand, there were some issues related to this research.

Figure 5.9. Crack in the Jesmonite Front Side

First, the study only conducted five days of a user study. It had two semi-structured interviews to get valid data from the user. It has a limitation that these data are only limited to five days, and also it did not have any log data to identify the number of uses. Maybe, it is necessary to search for extra days to find more deep needs from the users.

Second, during the development of the prototype, a crack occurred in the Jesmonite front side due to a researcher's fault in developing the mold (Figure 5.9). As a result, users tended to consider that Jesmonite has low strength, even if it has sufficient strength (Studio Ashby, 2016). Therefore, it requires additional considerations for external completeness.

6. Rematerializing Email Data: Maili

Third research aimed to investigate the materialization of email data, how a materialized approach might affect users' engagement with email information in their everyday lives, primarily focusing upon the office environment.

6.1. Purpose of Research

We have selected "email" as the medium on which to impose physicality for several reasons. First, email as a platform for communication now plays an essential role in contemporary, everyday communication (Jovicic, 2000). Email is used as an essential tool for various purposes, from personal chatting and time administration (Mackay, 1988) to task management (Bellotti et al., 2003). Second, the number of email users and accounts is increasing. Email data now accounts for the most significant proportion of personal digital data for office workers (THE RADICATI GROUP, INC, 2015), who can now check and respond to email messages anywhere and at any time (Specht, 2018). Third, although there are significant benefits to the digitalization of communication, the increased frequency and the volume of email has resulted in issues around the management of email data (Whittaker et al., 2002). Stress-related to email management is an example (Whitaker & Sidner, 1996). These issues pose new design challenges for the HCI community.

We designed and developed an interactive device with digital email information through a rematerialization approach (Figure 6.1). The design case (Illustrated in Figure 6.1) was developed based on three guidelines from an existing dematerialized research framework (Van Campenhout et al., 2013). In using the design case, we attempted to understand the relationship between the physical product and the user from the perspective of digital function, interaction, and product form.

Figure 6.1. Design of Maili Exploring Email Data Materialization

Using the Maili design case, through a concept-driven research approach (Stolterman & Wiberg, 2010), we conducted an exploratory investigation of product use. As our design was based on the dematerialization framework theory, and we explored what value the Maili design may provide to users by deploying it in a real use situation, in particular - an office environment. We selected this context because, email usage in work environments is high (Bälter, 1998), with resulting user stress associated with email usage, management (Neustaedter et al., 2005; Whittaker & Sidner, 1996), and notifications (Pielot et al., 2014).

Maili, as an everyday tangible artifact, enables users to check and set re-confirmation times for email. We deployed Maili in the offices of five users over a month-long period to explore the impact of the Maili design case – as an example of email materialization with physical form and interaction – as means of improving the efficiency of email handling. We expected that Maili, which developed from our design process, could support the user's email confirmation and may help the process of email checking and management from its design, function, and interaction.

Our research contributions can be described as follows: a) the design of the tangible object which enables email confirmation and reconfirmation through physical interaction, b) reflections from iterative design and prototyping process toward email data materialization, and c) results of in-field study regarding how materialization of email data through an everyday object affects user experience in the work environment.

6.1.1. Tangible and Intangible Interaction with Email

Since email is used as an essential means of communication in modernity (Jovicic, 2000), earlier studies of the email were conducted to improve our understanding of email usage. For example, research was conducted to measure frequencies of email inbox use over time through a large-scale quantitative study (Alrashed et al., 2018). Other studies explored how individual businesspeople utilize email in the working context (Bälter, 1998; Quaresma et al., 2013). Building upon these works, further studies have identified challenges in email usage, such as email triage (Neustaedter et al., 2005) and email overload (Whittaker & Sidner, 1996), related to an increasing number and frequency of emails and the challenge in their management. For example, research illustrated how a smartphone's email or message alarm led to negative emotional responses (Pielot et al., 2014).

Furthermore, several methods have been proposed to deal with the above issues. For instance, one study combined mobile text messages to alert users of critical emails (Rector & Hailpern, 2014). Alternatively, another focused on the meeting schedule in users' emails, developing a system that proactively displays schedules (Zhao et al., 2018). Other studies have explored utilizing email data with physical interaction through printed emails for people who cannot access computer email properly (Cannata, 2005), or comparison of the user's response when checking email through printed text compared to the computer (Hill & Monk, 2000). Another proposed voice interfaces with a traditional telephone to assist the elderly when sending emails through voice recording (Brewer et al., 2016). One study appeared to illustrate how tangibility in email function supported improved usage through a playful interactive device. It then resulted in reducing stress (Gaunt et al., 2013).

Through this literature review, we identified the scope, importance, and challenges of contemporary email use, which were then considered in the design and development of our design case. Collectively, the strands of research have contributed to understanding how tangible forms can be designed based on dematerialized information, and how ongoing HCI research has begun to deal with the application of digital data in tangible, everyday objects.

While this research is promising, less is understood about how to physically convey email and email-related functions that utilize email data as part of a design method, and any resulting benefit of a materialized approach for email users. There is growing interest in representing digital information with tangible artifacts. Thus, we see opportunities to investigate how dematerialized email data can be designed with physical form and interaction, and what kinds of value can be delivered with an everyday object to users.

6.2. Maili Design and Implementation

Based on the concept of dematerialization (Van Campenhout et al., 2013; 2016; 2019), we first explored various ideas to show email while considering the specific target context as the work environment. During the process of exploration, we identified users’ stress associated with email management and many inbox visits (Whittaker & Sidner, 1996). For this issue, we targeted the possibility of sorting relevant emails (Neustaedter et al., 2005) and considered a design to register and inform users of important emails through a tangible product. Within the existing function of reconfirmation of emails, we noticed that users had five actions when visiting an inbox: 1) open, 2) delete, 3) reply, 4) organize, and 5) download attachment (Alrashed et al., 2018). From this, we explored features that may help users open and organize emails. As a result, we devised three ways to deliver emails to users (Figure 6.2.a): 1) print essential emails, allowing users to carry relevant emails or attach them to walls to be visible within their working environment. 2) Delivering email tokens for notification. These tokens acted as triggers to remember the information contained within relevant emails, with users able to check emails by putting the token back into the device. Lastly, 3) protruding nodes from the front or side of the device to notify the arrival of relevant emails.

Of those design ideas, we selected the protruding node type because we considered this approach would bring an exciting notification with a change of product appearance, while at the same time providing an intuitive trigger. Existing research on dematerialization suggested mode-relevant action possibilities (Van Campenhout et al., 2013) and the opportunity for inducing user interaction by changing the product appearance. While this existing research is focused on shape change following the users' input, our design (i.e., Maili) utilized this approach to notify users and induce interaction with emails. We also considered it could be a pertinent way to express digital information (e.g., essential emails) physically.

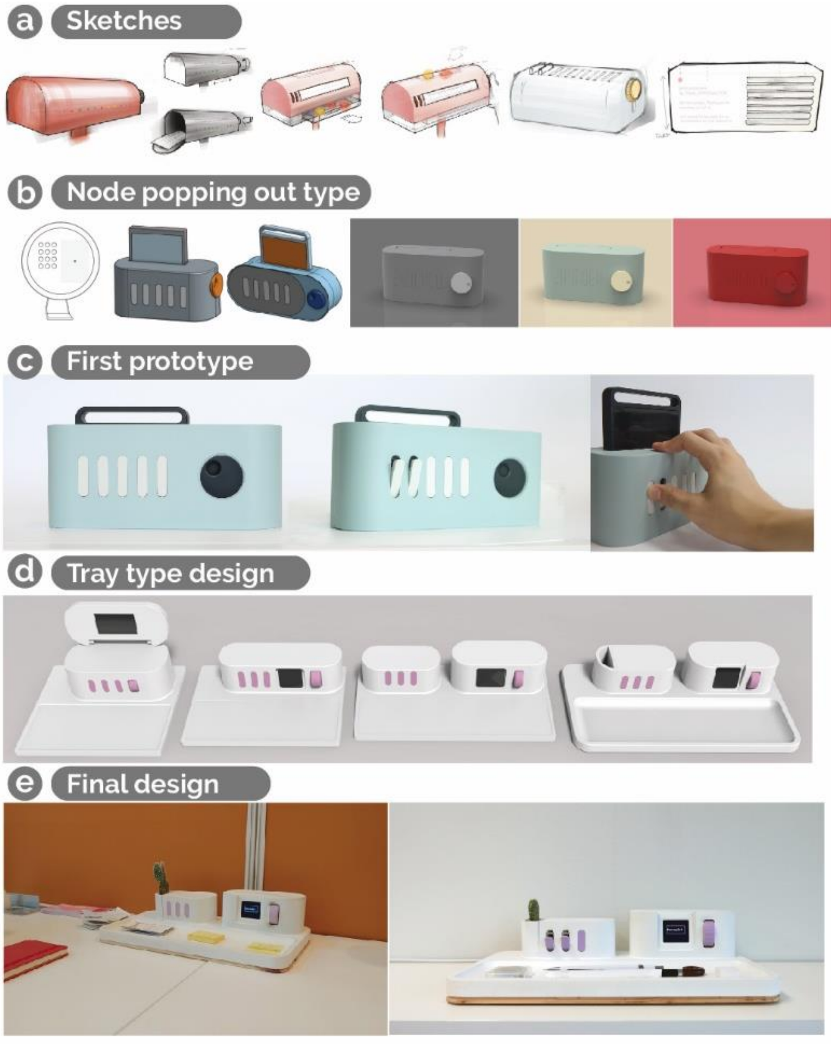

Figure 6.2. The Design Process of Maili

Based on this, the product design was progressed with the consideration of internal structure design, usability, and aesthetics for an office environment. The process started from sketching to modeling, along with diversifying colors and shapes (Figure 6.2.b). From this, we developed our first design into a working prototype (Figure 6.2.c). Detailed considerations in the design process are included in the following sections.

6.2.1. First Design Trial

We placed a dial controller at the front where it was expected to be the most comfortable placement for two interactions, rotating and pressing to set the reconfirmation time of emails that users consider to be important. The dial was designed to be slightly inward from the front side of the product, preventing the finger from slipping out when rotating. Also, we attempted to hide the display when the device is not in use, allowing users to push the top side of the display bezel to check the contents of emails. The aim was to provide an impression of not bringing an additional display in the office environment (Figure 6.3.a). The device uses a 2.8-inch LCD screen, as shown. Recently, a lot of information has being displayed on color screens, however there are cases where much concentration is required to use these products (Hausen, 2012). To prevent the user from focusing too much on the screen, this device features a black acrylic glass plate on the LCD screen to reduce the irritation caused by the brightness of the screen. Also, it helps to prevent distraction from work and harmonizes with the overall design, especially black anodized bezel. We fabricated the display bezel and dial using steel and black finishing, which provided a different feel from the body of the device. This made it easier to distinguish these two parts as interaction points. The display bezel was designed to simulate a handle form, protruding slightly upwards to allow the user to press and eject the display conveniently (Figure 6.3.a). We made the color of the nodes to be distinguished with the body of the device. It is to make users to quickly notice when the node protrudes based on the settled reconfirmation time of the emails. Finally, in the first prototype, The movement of the node is realized by using the 5V solenoid. The solenoid was applied because it can actualize push and pull functions with simple operation. However, through multiple tests, we found that the power of 5v solenoid was not enough to push the node. We searched for various actuation and chose to utilize the servo motor.

6.2.2. Lesson Learned

After the initial design and implementation, we conducted an ideation focus group with five additional researchers in design or engineering, to consider overall form, usability, function, and roles in the working environment in order to make modifications of the design. The issues were analyzed in terms of use situation and theory according to the existing literature (Stolterman & Wiberg, 2010).

Figure 6.3. Interaction in the First Prototype

6.2.2.1. Perspective from Use Situation

It was found that the vertical display angle made it difficult for users to see the email content. Besides, some researchers suggested that the way of pushing the display bezel to see email content could be cumbersome to check emails as it required additional interaction. To address this, we applied a static and smaller (1.5 inch) monochrome OLED display. We revised the angle of the display to be laid down for users to view email contents while sitting at a desk comfortably. Also, from the initial design trial, there were opinions that the dial parallel to the front side of the product is painful to rotate (Figure 6.2.c & Figure 6.3.b) and did not correctly reflect the user's ordinal routine of controlling digital information. To address this challenge, we analyzed the usage pattern in the existing time-setting application and physical rotating device. Thus, it was modified to the vertically rotatable design.

6.2.2.2. Perspective from Theory

From existing dematerialization studies (Van Campenhout et al., 2013; 2016; 2019), we identified products composed of modules, with each module designed to have a specific function. In this respect, the first design trial was not well modularized between dial and nodes components. For this, we designed a separate location for checking email and added placing nodes for the physical interaction.

6.2.3. Final Design of Maili

6.2.3.1. Design to Fit the Office Environment

After going through the initial prototype development (Figure 6.2.c), we explored how the design might better fit into an office environment. As a result, a tray-type feature (Figure 6.2.e) was incorporated into the design (Sheldon, 2017; Studio PESI, 2017), considering the tray could act as storage for stationery (Allen, 2015) along with providing a reason for the user to situate Maili on the desks. In particular, to improve the efficiency of work, the tray needed to be located within reach of the user (Allen, 2015). It was expected that the position of the device would naturally be closer to the user's hand. For this, we went through four different tray designs (Figure 6.2.d), exploring the height and width of the main body, including nodes, dials, and displays.

Through this approach to design, we attempted to increase the value of the digital product by combining non-digital with digital function to set the reconfirmation time of the important emails. Additionally, 15 different shade samples were prepared to determine the color. Throughout this design process, we attempted to improve the overall aesthetics and accessibility of Maili, believing this approach may improve usability (Frens, 2006).

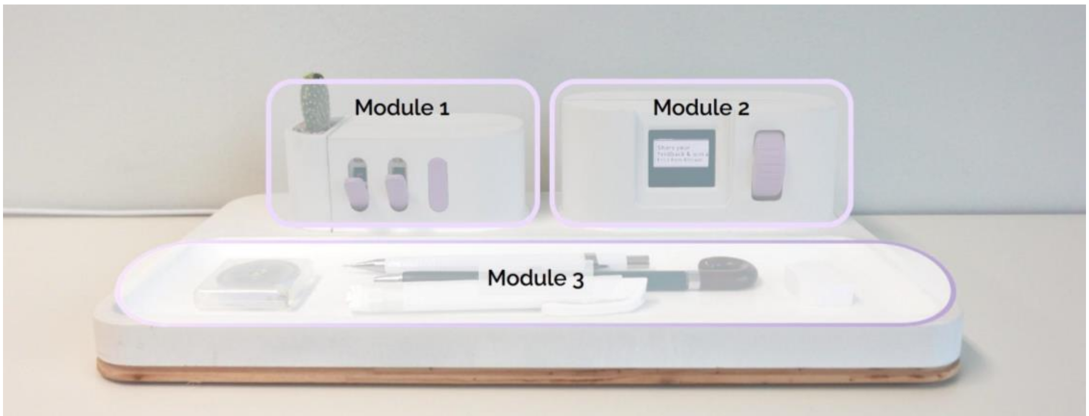

Figure 6.4. Three Divided Modules of Maili

6.2.3.2. Three Tangible Modules

The dematerialized data was assembled into tangible entities; therefore, digital information needed to be considered an essential element in the physical structure of the device (Van Campenhout et al., 2016). As such, we designed Maili with two tangible digital modules for digital function and a third module for an analog function (Figure 6.4). The first digital module was designed to interact with users through appearance changing, notifying the registered email to the user by changing of node angle (Figure 6.4, Module 1). A second digital module consisted of a display and a rotating dial for checking email content (Figure 6.4, Module 2). Providing digital functions in each visible component within Maili's design, digital information was shown as it flowed from one module to the next. Lastly, the analog function, a physical tray, was situated as a third module (Figure 6.4, Module 3).

6.2.3.3. Protruding Nodes from the Flat Surface and Rotating Interaction

Inspired by the form of a mouse wheel used when scrolling email, we implemented a rotating interaction for inbox scrolling (Figure 6.5.a). In this way, we aimed to simulate similarity existing interaction. For example, when looking at the time setting interaction in an existing smartphone alarm application, the interaction that rotates the visual dial-up and down is mainly adapted. For this reason, we decided that vertical interactions would be appropriate for physically representing the scrolling and time setting of email and naturally encouraging users to turn and press the dial (Kim & Eune, 2015). Additionally, a different pigment from the main body was adopted for the scroll wheel design.

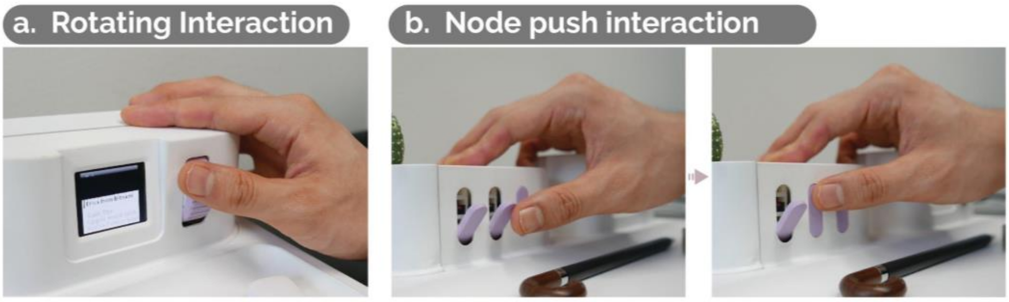

Figure 6.5. Interaction of Maili

Maili always displays information instantly. As a result of this, it was expected to shorten the process of turning on a smartphone or a computer's internet browser, making it directly recognizable. Maili presents the title of each email one-by-one to prevent the user from passing over an important email. Through a rotating interaction, users can register time to reconfirm emails deemed necessary. When the registered time is reached, the product's appearance changes through the protruding nodes from the flat surface to indicate an important email.

From the fixed exterior form, physical changes of the artifact, such as a protruding node in the Maili, serve to attract the user's attention and induce new action (Frens, 2006). We also wished to enhance usability by indicating notifications through an appearance change as nodes protrude from the flat surface, leading to the interaction, in which participants naturally push nodes back to the original position (Figure 6.5.b). The movement of the node in this study is applied as a function of actuation with 1) the characteristic of change in spatial positions of objects (Poupyrev et al., 2007) by deforming the angle of a node and 2) the characteristic of change in force applied to the user (Poupyrev et al., 2007) by holding the position of the node while the node protrudes (Figure 6.5.b). In other words, the user is required to touch the node, feel the material, and provide more force than a certain pressure on the node to return it to its original position.

These kinds of design interactions are referred to as familiarity and usability in rich interaction (Frens, 2006). This concept suggests that the general user is familiar with action-based interaction in a physical environment. Therefore, physical interaction does not have to be generalized; instead, it can be identified according to the situation. In this study, the design provides a reconfirmation of email notifications through changing a physical state by a protruding node. It is expected to provide a more familiar notification by pressing the node back to its original state. On the functional dimension, the node interaction was also expected to remind users of the multimodal sensation of touching. Additionally, the protruding node helps to reduce the additional work, such as revisiting the email inbox. This function is expected to decrease email overload (Whittaker & Sidner, 1996), miss important mail (Jovicic, 2000; Rector & Hailpern, 2014) or abandon the organization (Bentley et al., 2017) through tangible interaction.

In the previous dematerialization study, Van Campenhout et al. (2013) recommended developing a product that focuses on the main task through a combination of physical and digital aspects. For this, the primary function of Maili is to check email through physical interaction with the tangible product. Additionally, in other research based on the dematerialized information, the authors showed how the combination of sub-dematerialized function was related to the primary function, thereby improving usability (Kim et al., 2018). From this, as a sub-function, we added to register time to reconfirm important emails. We expected to increase the functional value of Maili by complementing the auxiliary function with the primary function.

6.3. Use of Maili

Figure 6.6 shows the function of checking email and registration of a reconfirmation time, and Figure 6.7 demonstrates the screen design of Maili during the whole operating process. Figure 6.8 indicates how the user can reconfirm a registered email with a pushing node.

Email Read Mode: Every half hour, a new email from Gmail is read. When a new email arrives, the phrase "New Mail" and the email's identification number is presented on display (Figure 6.7.b). If there is no new mail, "No New Mail" appears on display (Figure 6.7.b). In Figure 6.6.a, users can scroll and see the content of the title and sender in the inbox screen by rotating the dial. Detailed design of inbox with title and sender is like figure 6.7.c. Maili presents the contents of a specific email by pushing the dial (Figure 6.6.b). The body of the email is shown like figure 6.7d. The content is scrolled up automatically without the need to rotate the dial.

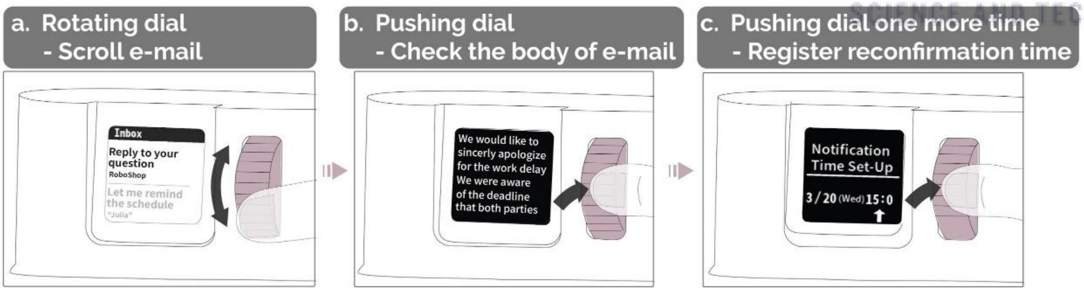

Figure 6.6. Checking the Content of the Email and Registering Reconfirmation Time for Email

Register reconfirmation time: In figure 6.6.c, for valuable emails, the user presses the dial to open the time set-up window for email reconfirmation (Figure 6.7.e). Users can set up the day and hour to reconfirm. The user can set the day first, then push the dial one more to move on to the hour setting (Figure 6.7.e). By turning the dial-up and down, it is possible to adjust the date and time. If the user appoints the reconfirmation time, the display returns to the in-box screen (Figure 6.7.c).

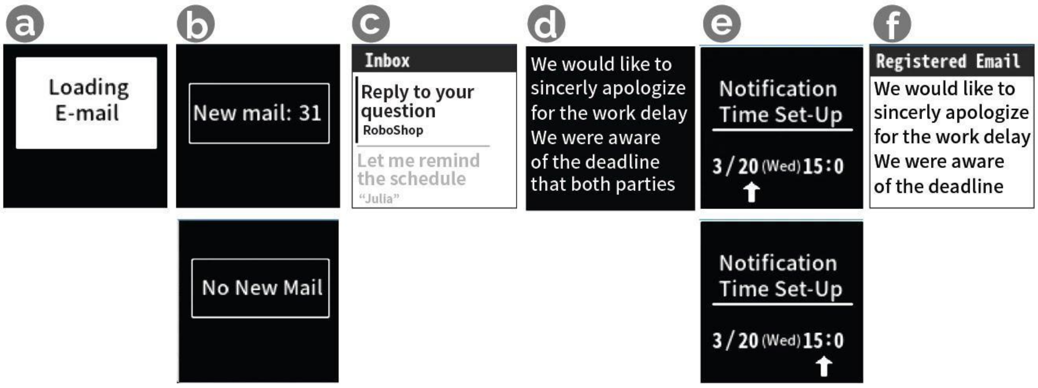

Figure 6.7. Screen Design of Maili. a) Loading email, b) New Emails or No New Email, c) Inbox with Mail Title and Sender, d) Body of the Email, e) Time Set-up for Reconfirmation and f) Showing the Title and Body of the Registered Email

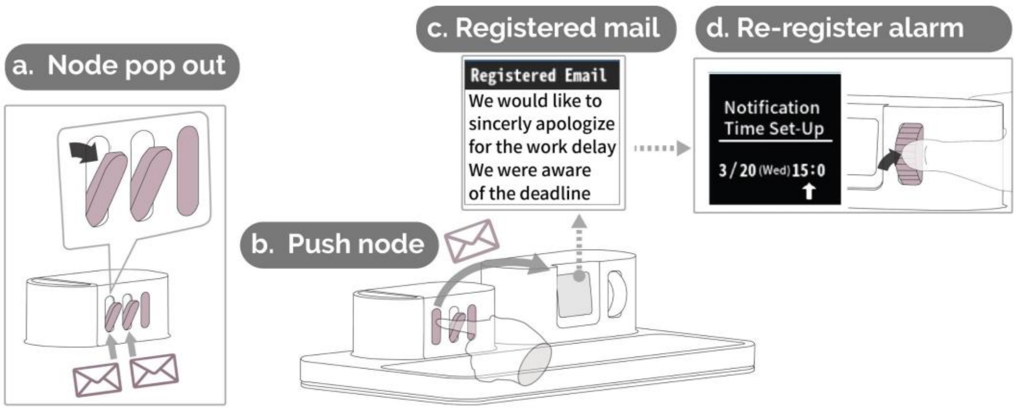

Figure 6.8. Check Registered Email Through Pushing Nodes

Registered email notification and confirmation: Maili delivers registered emails to the user by protruding nodes, and the user can check these emails by pushing the node back. If there is an email registered to reconfirm at a specific time, nodes will protrude corresponding to the number of emails received (Figure 6.8.a). The user can press the node back (Figure 6.8.b) into its original position for checking the registered email, and the contents of the registered email will be revealed on display (Figure 6.8.c). The user can re-register the email reconfirmation time or delete a registered email by pushing the dial (Figure 6.8.d).

There are three nodes in Maili. When there are more than three registered emails, the user pushes the node to check the mail, and the nodes protrude again, depending on the number of remained registered mails.

6.4. Implementation

While the external design was a consideration, the top priority was to develop the software to take the user's email data and register reconfirmation times according to the user's input.

Python code runs in the Raspberry Pi2, and physical elements, including servo motors and sensors, are operated by Arduino. These two computing elements are connected via USB and employ serial communication. In this relationship, the Raspberry Pi2 focuses only on managing emails, and the Arduino only operates the sensors and actuators, thereby reducing the functional burden. Using the Python script in the Raspberry Pi2, it retrieves 100 recent emails with the Gmail API. These email groups are converted to a CSV file format. This device is an independent device that merely retrieves emails from the user's account without affecting a user's existing Gmail account. Emails are stored every 30 minutes. When a new email arrives, the Python script sends a signal to the Arduino to indicate how many new emails have come in. The OLED display (Figure 6.9) displays that information. Because the OLED display does not support any different characters besides English, all of the email content that will be presented on display is converted into image files. When the user registers the reconfirmation time for email, the content and time information of the emails are made into a list in Python. Information about reconfirmation is stored as a text file. The reconfirmation data can be maintained even if the power is off because of a malfunction. When the reconfirmation time is reached, Maili activates the servo motors, following the number of registered reconfirmation emails. The movement of the node is realized by using the servo motor (Figure 6.9). The servo motor was applied because it can actualize push and pull functions with simple rotating.

For bringing constant torque to the node, a magnet is attached to the bottom of the node to fix the angle of the node when it protrudes forward. Infrared sensors are installed on the back of the nodes, and it can recognize when the nodes come closer. The rotary encoder is applied to perceive the user's spinning input, and the micro push button is right behind the rotating button to observe push interaction.

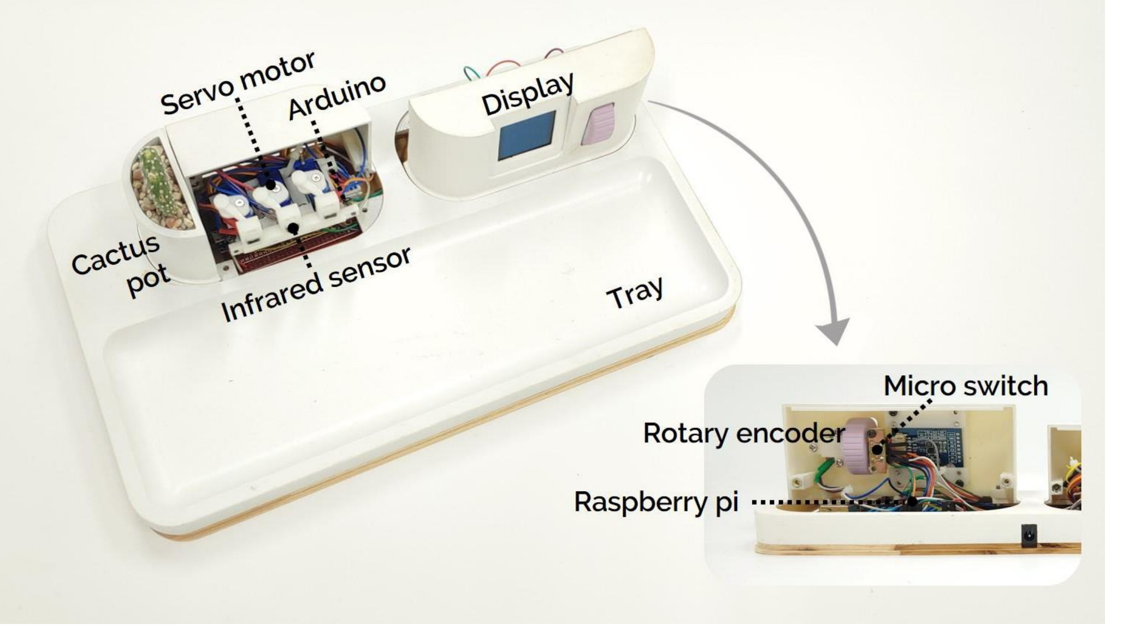

Figure 6.9. A Detailed Structure of Maili

6.5. Field Study

We conducted a series of field studies (Brown et al., 2011) with Maili to explore the experiential value of the functional and emotional meaning of the design, as well as the interaction and practical aspects obtained from the materialization of email data through a physical device. We aimed to understand 1) how the materialized email applies to an everyday tangible device and affects attitudes towards email usage and 2) how Maili influences controlling and checking email through physical interaction when utilizing this device in the office environment. We hope that the evidence above may provide some insight regarding how the Maili intervention influenced the product experience in terms of email management, and how our rematerialized approach implicated the experience of utilizing digital data.

6.5.1. Participants

A total of five subjects participated in a study using Maili for one month (thirty days). We aimed to explore how the Maili design might influence user habits from tangible email usage over one month.

Selection criteria for participants aimed to identify subjects working within an office, who regularly communicate through email with colleagues, supervisors, and other companies. Specifically, we considered the following two additional points other than the amount of their email usage. First, we checked the available space on their desk. Three participants' desks did not have much room (P2, P4, P5), and others had much free space (P1, P3). At the same time, there was a concern that the product size could be too large. However, when we looked at the usage patterns of three participants who had complex desk circumstances in the field study, we could see that they placed the email-related things (e.g., post-its and business cards) and got used to the tray part of Maili. Second, we asked how applicants managed their email and could hear that one did not use a specific technique to manage emails (P1), two placed tags on their emails (P2, P4), and two organized their emails by frequent deletion of unnecessary emails (P3, P5).

Maili used Gmail API only; therefore, we gathered participants who used Gmail primarily. If users utilized other email accounts at the same time, we asked them to forward mail from these other accounts to Gmail during the test period. Two participants (P2, P5) needed to forward emails; thus, we received permission from a person in charge of the participant's company or organization. The device was installed on the participant's desktop only. Also, employees belonging to the same company were not required to avoid influencing each other's operation and feedback. Participants were recruited through online advertisements. A total of five subjects participated in the study.

P1 (Female, mid-20s): An employee at an enterprise for product development and trading. P1 mostly contacts outside manufacturers about content related to transaction orders and the company CEO about the progress of the project through email.

P2 (Male, mid-20s): Works as a product design intern in a start-up. P2 communicates with the CEO, the supervisor in the company for delivering the product development process, and also with other organizations related to the project funding issue by email.

P3 (Male, late-20s): Is the CEO of a start-up. P3 communicates with start-up employees and start-up funding staff by email. P3 usually sends and receives emails about applicable funding projects and the situation of the current funding with funding staff and shares product development information with team members.

P4 (Male, mid-30s): Is a senior researcher in a national technology promotion agency. P4 communicates with the research team and other institutions through email.

P5 (Male, late-20s): Works as a researcher in a design lab of a national university. He communicates about the progress of project and paper writing through email with researchers in other countries.

6.5.2. Data Collection

Table 6.1. Interview Contents following the Date

Interview week	Interview contents
Week 1	● The perception from checking email through a tangible device with rotating interaction ● The perception from checking registered email with angle changing node and pushing interaction ● Functional and emotional feedback from utilizing tray combined with an email device ● Criteria for choosing email for reconfirmation through Maili ● The difference in the email checking experience while using Maili compared to other digital devices; computer or smartphone.
Week 2	● Change in perception related to utilizing Maili compared with week 1
Week 3	● Change in reaction related to email checking experience and using the reconfirmation function of Maili compared with week 2
Week 4	● The overall reaction to the design and interaction of Maili ● Overall opinions on the functional aspect of Maili, and change of interest toward the device during four weeks

In order to collect qualitative data during the user survey, 25–35-minute interviews were conducted once a week with each participant over four weeks during the user study period. A total of 553 minutes of interview data was gathered. We also gathered usage log data to see how many emails were registered to reconfirm through the dial of the Maili. More specifically, we collected the number of days and hours changed when the users were setting up the reconfirmation time. Log data was automatically saved to the Raspberry Pie when the user registered the reconfirmation time.

The interview was conducted in Korean in a semi-structured manner. The overall questions were followed, as illustrated in Table 6.1. However, queries were immediately made regarding additional questions or changes in attitudes compared to the previous week's interview. We recorded the entire interview; its contents were promptly transcribed to confirm any missing parts. Following this, we reviewed the contents and added additional questions that we wished to pose in the next week's interview.

Table 6.1 summarizes the questions that we raised during the four-weeks interview. Through these questions, we expected to derive a general user's opinion regarding the function, design, and tangible interaction provided by Maili along with the changed pattern of their weekly uses.

6.5.3. Data Analysis

Interview data were analyzed using thematic analysis to determine the results of the study (Maguire & Delahunt, 2017). Researchers created groups by continuously and repeatedly reading raw interview transcripts. Relevant or interesting quotations were marked with memos on a first review of the data. Besides the users' participation, responses were grouped into themes since they emerged consistently during the interview analysis (Maguire & Delahunt., 2017). Throughout the interviews, we identified constant, opposing opinions from each participant with an across-case approach (Ayres et al., 2003). Through this, we sought to identify the same or different users' responses following different email usage patterns.

All resulting topics were organized after identifying that three out of five participants' responses were similar or opposing on the same topic. The interview data were grouped as follows: 1) usage patterns of the existing email system, 2) overall Maili usage patterns and opinions, 3) Maili as an independent single-purpose device, 4) reconfirmation function, 5) product design factors, 6) interactions with the product (tray, dial, and nodes) and 7) the value of tray.

From this, we chose five main topics related to the research questions, as follows: 1) insights regarding the single-purpose tangible device to represent digital information; 2) interest and usability of physical interaction to control email with tangible interaction; 3) users' opinions on the overall design of Maili within the context of office environment; 4) utilization of reconfirmation function and feelings toward protruding node notification; and 5) perceptions towards the function or design during their thirty days of use.

6.6. Findings

6.6.1. Interacting with Email Desk Object with Non-digital and Digital Roles

In a previous study regarding dematerialization, separating digital functions by physical modules (Van Campenhout et al., 2016) indicated the flow of digital information according to user manipulation. In this study, by combining two types of tangible parts that include a non-digital (the tray) and a digital module (email management) into a desktop artifact named Maili, we explored opportunities to increase overall usability by providing the value of physical richness and encouraging the function of the digital module.

6.6.1.1. Maili as an Independent Device on the Desk

Maili became a reminder of the importance of email by performing as an independent artifact on user desk environments. All participants showed a similar reaction to this.

As stated by P4, *"I considered that email was one of the important means of communication. Therefore, I felt better when utilizing Maili. It is a valuable addition to the office, and it can be operated usefully. I think it is worth the space it takes on the desk."* After the fourth week, as P4 got used to Maili and learned how to utilize Maili to manage email. In the last interview, P4 remarked, *"At first, I did not do like this. However, I found I could see only emails in this device, and I did not need to open the web site. I just rotated the dial to check it. It was fresh and good for confirming email with other actions without mouse clicking."*

Primarily, this advantage came from their usage patterns while inducing natural management of their email by showing information that a new email had arrived through the display. Through this, it unconsciously encouraged email confirmation within the user's sight. P2 said, *"I think it has become standard for me to read the email by seeing new email messages on display. In the past, I used to check the inbox when I was bored during working. However, I think it made a system to check email after detecting email has come or not for certain on display."* This also helped users to focus on their work while reducing unnecessary time checking emails. All participant opinions were similar. For example, P3 pointed out, *"I feel like saving time. I'm not going to keep pressing f5 (refresh) to check the inbox. I'm focused on working because I know that new email information is coming (through Maili) at a specific time."*

6.6.1.2. Non-digital Tangible Form Affects the Digital Function

We identified the possibility of combining the non-digital tangible module part, a tray, with digital function modules. This consolidation supported increasing the usability of the device by adding simple storage with the primary digital function.

Figure 6.10. Maili in Situ. a) P1's Maili in her Office Desk, b) P2's Maili Placed on his Design work table, c) P3's Maili in his Start-up Office, d) P4's Maili on his Desk in a Large Office Shared by 30 People, and e) P5'desk Place on his Office Desk

This insight was evidenced by the possibilities to support reminders for work-related emails through items placed on the tray. P3 noted, *"In the existing tray I previously had, I just put something on it and brought it if something was needed. However, this tray (in Maili) is connected to the email function. Therefore, I kept looking at it due to checking email. I put a business card or post-it on the tray (Figure 6.10, left a). For example, I was supposed to send an email to the person who gives me the name card. However, after the meeting, I forgot to do that. I came to my desk and did something else. (In Maili) I spontaneously looked at the email on the display and tray in order and brought that business card onto the tray. It reminded me to send an email to the person."*

Participants expressed the opinion that Maili's design and function have the strength of being able to check email with the help of the non-digital tray. We could see the possibilities that the materiality of the tray provided benefit to email function by deploying the Maili design in the working context. Participants remarked that the activity of placing things into the tray also functioned as a work-related reminder (i.e., sticky notes flagging important tasks derived from email content).

6.6.2. Interaction with Node: Reminding by Intentional Unaligned Form Expression

From notifying reconfirmation emails through changing the arranged node to an unaligned status by protruding nodes from a flat surface, Maili offered the benefit of communicating information in a noticeable manner, inducing natural user interaction. Four participants positively reacted to the physical angle change notifications compared to the digital alarm.

P2 mentioned, "*If the node is protruding while I am working, it attracts my eyes. It was an interesting element in that it showed that there are reserved emails."* Previous studies have found that dynamic data can be expressed using form transformation (Coelho & Zigelbaum, 2011), showing possibilities to deliver meaning through shape changes. Similarly, the current study identified the benefit of adaptive shape change as the opportunity to express the dynamic aspect of digital data.

Regarding the pushing node interaction, all participants mentioned that the changing shape encouraged them to press the node back into place. This insight could also be divided into two types of findings related to the emotional perception towards the node shape change. P1 and P3 expressed the impression of pushing the node in order to restore Maili to its original shape. P2, P4, and P5 responded positively to completing or starting work by pressing one node. Specifically, the node for protruding and pushing interaction successfully stimulated a positive experience because it was natural to respond to and promote use.

More specifically, P4 remarked, *"It (the node) gave me a novel feeling by moving mechanically, and it is fun to push the node because it provided the perception of accomplishing something by pressing it back. The notifications in the ordinal digital system finished after time passed. This node system is good for promoting the action to push the node to the original position. It brings me a positive feeling to complete the job."* From here, pushing the node back to the original position could bring the perception of finishing a specific job clearly by making the overall shape complete again. Besides, this node interaction of Maili promoted engagement with the device by providing a different type of tangible interaction (e.g., mouse-clicking or typing), which was not common in phones. P5 mentioned, *"Touching the phone did not have a movement expression after I pressed. It was fun to see the motion from Maili that nodes were coming out, hearing the sound of node protruding, and feeling the texture while pressing. These things induced me to do new interesting actions."*

6.6.2.1. Awakening Memories and Reducing Checking Steps by Reconfirming Important Email

The email reconfirmation function was used primarily for large-scale events that the participants required to prepare. In other words, the user registered the time of their plan and utilized this function similar to a calendar application. Five participants used the time setting function through the dial for a total of eighty-six emails. Among them, fifty-one emails were delayed with days for the reconfirmation. Thirty-five emails were delayed by the only hours change without delaying the date.

Table 6.2. Number of Setting Reconfirmation Times with Changing Days (including hour change) and Changing Hour Solely (within the day) following Participants

	P1	P2	P3	P4	P5
No. of date change (incl. hour)	4	12	17	12	6
No. of hour change within the day	13	4	14	2	2

In the way of using the reconfirmation function, different patterns appeared according to user habits. P1 said that she set the alarm time of a day to finish the task in the mail (Week 3). Reflecting this, P1 showed a pattern (76%, 13 emails from a total of 17) utilizing hour change solely rather than date change compared to other users (Table 6.2). In the last week, P1 registered similar content of emails to be checked at once, regardless of reconfirmation time. Following these patterns, P2 and P4 primarily used date changes. P3 showed two different types of usage patterns. In weeks 1 and 2, P3 received notification two days before the schedule in the email. In week 3, P3 utilized the reconfirmation function to complete the work in the email by the time he registered. Following this, P3 tended to use similar rates of date and hour within the day change during the experiment.

P2, P3, and P5 checked the email contents once more before the due date when there was a task to be done. P4 appeared to register time to reconfirm whether P4 handled the business in the email properly or not.

In sum, we could categorize usage patterns of email reconfirmation function, and those were divided into four types: 1) setting up an alarm time to complete a task (P1, P3); 2) checking similar emails at once (P1); 3) receiving notification before the due date mentioned in the email (P2, P3, P5) and 4) receiving feedback (through shape change of the node) once more for checking duty in the email whether the work has been appropriately handled (P4).

Table 6.3. Number of Reconfirmation Time Set Email about How Many Days and Hours were Delayed

Changed days	**1 hour ~ 2 days 0 hour**	**3 ~ 7 days**	**Over 7 days**
No. of Mails	75	7	4

Looking at the number of days and hours users delayed in the date change (Table 6.3), most participants utilized the feature to reconfirm the email within two days (87%, 75 emails among 86). During week, 3 P5 remarked, *"It was relaxing for me to check email one more time as soon as possible because that email contains things I need to do or confirm."* As such, users showed a pattern of reconfirming the email within a short period.

In table 6.4, delayed hours only within the day, the majority of emails (83%, 29/35) were delayed in less than three hours.

Table 6.4. Number of Reconfirmation Time Set Email about How Many Hours Were Delayed Within the Day

Changed hours (within the day)	1h	2h	3h	4h ~
No. of Mails	12	12	5	6

In particular, when the hour was set within the day, as shown in Table 6.4, it was mainly used to register remained hours to finish the work described in the email at a specific time. Participants tried to finish that work before protruding the node. P3 noted, *"I made myself a promise to finish work in the email up to this hour by registering reconfirmation time."* P3 also mentioned the merits of Maili's reconfirmation function compared to the existing digital calendar function, *"When I registered an alarm in the existing calendar applications, I wrote only a piece of simple information (e.g. 'making a presentation file'). However, Maili made me think about the schedule in the email as I turned the dial to register reconfirmation time."* It was found that the process of registering email by turning the dial helps users to remember the task in the email. Three participants mentioned similar answers to this benefit of thinking about email content through dial registering.

Registering the reconfirmation time in such a short time provided the user with two advantages. 1) a reminder of essential emails, and 2) a shortening of the email reconfirmation process with no need to revisit the inbox.

In the existing literature, employees who used email in their work repeatedly accessed the inbox to obtain information about meetings (Zhao et al., 2018). Participants in our research showed similar patterns. For P2 and P4, who used tags on their essential emails, reacted positively to shortening the process so that they did not have to enter the mailbox repeatedly. P4 stated, *"The equipment gave a notification (through protruding node); therefore, I did not have to go looking again to the inbox. It saved me time in checking important emails. I used to access the inbox. Now I can check one exact email I needed."*

These features have helped to remind all the users of important events. P3 mentioned that, *"In the reconfirmation of email, it shows information I did not catch before. Even though I used to watch a smartphone or computer to check schedules, sometimes, I might have missed something. In the morning today, I forgot to prepare a presentation file that I had to make yesterday. Maili notified me in the morning (through protruding node). I was seriously shocked. Maili sent only one or two important registered emails that I could not miss. I survived thanks to Maili."* This email reconfirmation feature helped to identify the value of using it as a reminder of forgettable tasks, or a tool that sends notifications to start a specific task when the reconfirmation function was activated.

Cooperatively, Maili provided possibilities to support the user email management processes through relationships between appearance, interaction, and functionality by the reconfirmation of important email by physically protruding nodes. As P2 mentioned, *"It is satisfactory for the nodes to come out and push them back in. There are certain inputs and outputs, and not all ordinal electronics in the office react physically. Because of this, I focused on email notification once more. It was fun in that sense. I felt like working, processing, and finishing one work by pressing one node. It played a role as a reminder function. It was helpful because I did not have to go to the inbox and check multiple times."*

6.7. Discussion and Implementation

The materialization of email data, providing physical interaction to its handling, brings new possibilities as it provides improved access to information and expressive communication with users. Our findings resonate with the primary outcome of rematerializing the dematerialized (Van Campenhout et al., 2013; 2016; 2019). We offer new insights into how this design philosophy could apply to other domains, specifically email communication. We investigated opportunities for broadening this concept by applying materialized email data to an everyday tangible device to explore its effect on attitudes towards the email data, concerning its functionality and the emotional response of users'.

In the next section, we present research and design considerations for the HCI community. Notably, we suggest considerations for future research and product development in designing digital functions, interactions, and forms that leverage the re-materialization of digital data.

6.7.1. Designing Materialized Interaction

6.7.1.1. Dividing Input following Functions

Based on existing research (Van Campenhout et al., 2019), we have found from our user study that physical interaction can attract interest by providing a novel form of control. We divided the function of Maili into two: inbox control and registered mail reconfirmation. By applying the interaction considering the characteristics of the distinct digital functions, we attempted to provide physical interaction that followed digital functions. Previous research was also able to identify the possibility of controlling complex IoT functions by modularizing interactions according to increasing digital functions (Frens et al., 2018).

Rather than controlling multiple digital functions with a single physical controller, in designing physical products with digital information, our results indicate the possibility of inducing the user's interest while providing a functional advantage through the division of each disparate physical interaction. For example, in evolving Maili design, we might consider dividing digital function between inbox control, setting up a time for reconfirmation, and checking registered emails. Moreover, we could also implement physical interactions to more clearly represent each digital function.

6.7.1.2. Context and Moment of the Materialized Interaction

In previous research on applying physicality to dematerialized information (Van Campenhout et al., 2019), the correct contexts in which a device for materialized interaction can be situated were explored. For a physical money payment terminal, its proper context was suggested as a stylish and expensive shop where shopping experience matters. From this point of view, we could identify the possibility of increasing the experiential value of materialized interaction with the products by considering the place, environment, or even a specific moment in the context. This may positively highlight the tangible interaction and being in control by which the user can touch, control, and actively see the flow of information. Through our design and deployment of Maili, physical interaction, especially the node input and output interaction, brought positive, pleasurable feelings from being in control and showing the flow of information by pushing the node back to see the email contents through the display. Based on this, in designing tangible data artifacts, limiting the coverage of data to represent into the artifact only to vital (e.g., VIP emails or essential date/event notification emails) as a way to further enhance the value of its interaction. The combination of physical interactions with careful consideration of the encountering moment with users' data, might promote the user's experience to be more meaningful and engaging.

Besides, we could see the potential context of materialized interaction from participants' reactions to using Maili. Be it in a comfortable space, free of mental pressure, affording enough time to enjoy the experience of physical interaction.

In other words, the environment in which the user experiences materialized interactive products will be most valuable, for example, a music player designed on the concept of rematerialization, with a movable physical module that displays the cover of the music album and its song lyrics (Van Campenhout et al., 2013).

6.7.2. Enriching Rematerialization: Analog Function to Digital Product

Our approach to assigning a physical interaction to each aspect of the digital function and combining those with an analog part (the tray), opened a space for participants to relate analog storing function with the email handling digital functionality of Maili. Previous studies of dematerialized devices have indicated that all tangible elements should be given a digital function (Van Campenhout et al., 2013). However, these studies further mention that there is no fixed point as to where and how the combination of digital and tangible should occur; instead, it depends on the designer's skill (Van Campenhout et al., 2016). In other words, existing work has argued for the importance of the competence of designers and researchers who utilize the theory.

In Maili, an independent tangible element without digital information (the tray) was installed, which users could interact and utilize in any direction they wanted. The tray also demonstrated the value of blending the device into a working environment by incorporating digital functional modules for checking email with the tray's analog function, keeping physical items (post-its or business cards) (Figure 6.10).

Even though many objects are now digitized (Belk, 2016), some analog artifacts are still maintained in their physicality to provide functional through tangibility. For example, a paper-calendar utilized within the office for personal and public use, offering value by users not needing more than a glance to check the schedule and to annotate directly onto the calendar as required (Tungare et al.,2008). Depending on the user's pattern of use, products without digital technology that are still necessary for our lives remain on our desks. Identifying the hidden value of maintaining tangible areas and extending the functionality of the product through the combination of the digital and the non-digital is expected to increase the likelihood of designing new digital artifacts for the contemporary context and also leveraging the user's embodied experience of a material world.

6.8. Limitation

First, our design, Maili, did not provide users with the ability to customize the tray to fit better with their desk space and the specific order of positioning the stationary equipment. The study focused on how the combination of digital (email data materialization) and analog parts affects the users' experience handling email in their workspaces. Thus, we deployed a single type of design during the field study and found that participants wanted to modularize or personalize Maili to fit their office. As Maili only offered a tray with one extensive independent space section, participants expressed the need to change the size and shape of the tray in various ways. We found the need for users to customize Maili's design matched the same way they used to store things in the office environment.

Second, Maili utilizes a small OLED display, which is perceived as not giving additional display for the office. This may show a need for the trade-off between the materialization of digital data and the addition of another digital display in the work environment for email content delivery. Some participants suggested adding a way to completely hide the display when not in use or allowing the user to turn the display on and off quickly. This requirement is related to the accessibility of the Maili, which displays the number of new emails continuously. Therefore, if the display is covered, it is necessary to define the role of the display more clearly, such as showing minimal information for key tangible interactions with the device. This relates to the design of not including all the input functions into one dial, which reduces the digital feeling but separates the dial interaction into day and hour settings. Also, according to the study, most users reconfirm email within a short period. Consequently, the device may focus on providing interactions that establish short reconfirmation time quickly.

From a different point of view, Van Campenhout developed a money-payment device with rich interaction (Van Campenhout et al., 2019). He noted that a money payment was suitable for luxury retailers such as wine shops. This shows that even if the required interaction time is extended, the device can provide positive value to the user through its fruitful interaction. In this study, all participants were in an open office environment with other coworkers, and users frequently stopped to quickly check email while they were busy concentrating on their work. This suggests that if users are in a solitary environment or a position to manage their email in a more relaxed manner, the experience of a new everyday artifact providing digital data materialization can be enriching. For example, additional research in the private spaces, such as craft workrooms and independent professional offices, might be a way to look deeply into how the materialization of email data handling may affect the way of email management.

7. Findings from Design Iterations

In the above section, the design description and data of user study from three iterations are proposed. Based on this, this section will focus on the findings commonly obtained from three examples, especially the user experience that can be provided to users with the rematerialized product.

7.1. What Kind of Usability Can Rematerialization with Digital Data Support?

7.1.1 Presence of Technology Embedded Independent Tangible Device in Their Space: Dynamic in the Static (DayCube, Traffico, Maili)

According to the present dematerialization study, digital information has the characteristic of being dynamic. Contrarily, in tangible products, it has the characteristic of being continuous and static (Van Campenhout et al., 2013). In cases in this dissertation, what users usually notified in Traffico and Maili is the value of continuously delivering information from products. It implies that locating the device in a specific position statically within the user's line of sight increases its value since the product transmits continually changing information.

In particular, Maili showed users the number of new mails on display and encouraged users to check their mails. Traffico induced the continuous confirmation and attention of users through the continuous change of schedule on the screen (Figure 7.1) and rotating the clock plate. As described above, expressing the changing characteristics of digital information through changing the product shape or display could lower the threshold of information by drawing the user's attention.

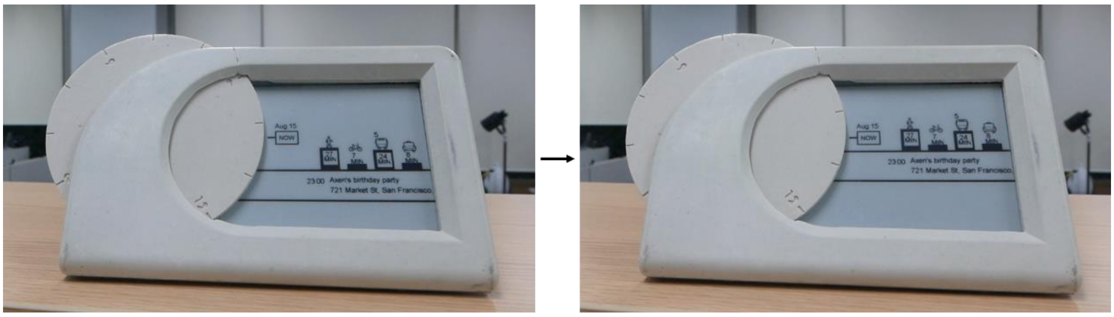

Figure 7.1. Moving Schedule following Time

7.1.1.1. Improve Access to Information: Reducing Checking Steps (DayCube, Traffico, Maili)

One functional advantage is the improved accessibility to digital information. DayCube lets users access weather information with a single touch. Traffico continuously shows the schedule and rotates the clock plate, thereby making it easy to check schedules. Similarly, Maili promptly notifies the user when a new mail arrives and offers the advantage of quickly checking the contents of the mail by merely turning the dial.

Tangible products can continuously deliver information to users and facilitate checking the information available through simple interaction. It carries the advantage of enabling faster information access than possible through opening an application or the Internet in a smartphone, which is a method regularly utilized by people.

Further Suggestions for Developing an Input of Research Prototype

Furthermore, an immediate response following input is required for the development of prototypes for research. When we use a smartphone, we observe an immediate response by pressing an option on the screen. For this reason, when users use a physical product, especially an experimental prototype, when a delay occurs in recognizing and responding to input, even if the operation does not have a problem, users might become worried about product errors or input mistakes. This feature can be a disadvantage in the in-field user research. For example, in Traffco, in a similar situation such as resetting Traffico, the text “Now loading. Please wait” is displayed. It allows users to wait patiently, even when the product’s response is slow.

7.1.1.2. Evoke Behavior Change (Traffico, Maili)

In particular, when the physical product was tested in the field, it was discovered that the presence of an independent product induces a change in user behavior. Through these cases, users recalled the importance of digital information and changed their behavior patterns. For example, Traffico displays the schedule continuously, reminding users of the importance of the schedule, and helps to more strictly follow the schedule. Moreover, it was mentioned that through continuously showing the traffic time information, the approaching transportation time made participants prepare to go out spontaneously. Maili also reminded the importance of emails and had the effect of reminding whether participants replied to the email accurately or properly handled.

It is evident that these advantages induce behavioral changes by continuously reminding digital information in terms of the existence of physical products in the user’s daily patterns.

7.1.2. Combining Related Functions to Maximize Practicality (Traffico, Maili)

In these studies, research products were designed to utilize two or more functions rather than independent functions simultaneously. DayCube conveyed the functions of weather and schedules that were not related to each other but considered essential in the indoor environment. Traffico provides traffic information associated with the schedule, thereby increasing the value to the user. Maili helps synchronic email checking and management functions.

Through this study, we found that the functional value can be increased by delivering functions related to each other (Traffico, Maili). The difference between the two studies is that Traffico brought the calendar function as the primary function and merged other digital functions that were expected to increase overall usability. Contrarily, Maili brings an additional function that was already provided in the email system: registering a re-notification time or a vital mail and associated this with an email checking system. There is a way to increase the value of digital products by distinguishing the minor functions that are expected to be most helpful in managing emails among the other functions of emails.

This finding differs from the existing research. Van Campenhout et al. (2016) claimed to design a physical interactive product to perform one function. His suggestion was based on the fact that a physical analog product originally performs only one specific function, and it is conceived that it is possible to increase the value of a product by matching interactions suitable for one function. Conversely, this study suggested that the functional value can be raised by expressing multiple related digital functions through a single product. Through this, it is possible to develop products that can increase usability value in the user’s environment. This may be a result of reflecting the characteristics of digital information and reprocessing the digital information in the intended direction. Digital information has the feature that it can perform all functions with extensibility (Van Campenhout et al., 2016). This research result showed how to increase functional product value by connecting some of the digital information characteristics. This is more than merely bringing digital information and expressing it as a physical product. It is close to reprocess information in a direction that can provide value to the user through the designer's ideation (e.g., the combination of the information of the calendar and traffic information required by the user in Traffico).

7.2. What Kind of Experiences can Rematerialization with Digital Data Provide?

7.2.1. Increasing Intrigue by Changing Shape to Deliver Information (DayCube, Traffico, Maili)

In these cases, the product's appearance change is adapted to deliver digital information (DayCube, Traffico) and simultaneously used to induce user behavior (Maili). In particular, existing studies mention that email notifications and its management are stressful. Maili use reveals that, on the contrary, it was enjoyable through exterior changes. In this regard, it supports that a physical product utilizing actuation can differentiate itself from digital notification in a smart device.

7.2.1.1. Premeditated Negativity for Inducing Positive Interaction (DayCube, Maili)

The change in appearance causes a negative feeling in the user and compels them to return it to its original shape.

With DayCube, people wish to return the movement of the tree to the original square shape from the broken shape of the square. In Maili, users exhibited the desire to return the protruding node to the original flat shape. In other words, it is identified that it is possible to bring affirmative action and interests that can induce interaction by evoking some negative emotions in the user.

Unexpected Finding: Notification through Sound (DayCube, Maili)

One unexpected finding was that in Maili, users were engaged in the protruding sound and responded positively to the sound (the servo motor's working sound) as the appearance changed. On the other hand, DayCube utilizes the movement of wood that was intentionally produced in a direction to give a soundless notification. As a result, participants sometimes did not notice the movement of wood. It gives the reasonable inference that adding a little sound (in the Traffico, the servo motor's working mechanical sound) can play a significant role in the notification of information.

7.2.1.2. Designing Interaction following the Environment (DayCube, Traffico, Maili)

In previous research on applying physicality to dematerialized information (Van Campenhout et al., 2019), the appropriate contexts in which a device for materialized interaction can be situated were explored. For a physical money payment terminal, the proper context was suggested as a stylish and expensive shop where the shopping experience is significant. The prototype of their study featured a time-consuming interaction compared to the commercial device. However, they suggested that interaction can maximize the value of the product and function following the environment.

Maili was designed for use in offices. Participants showed their preference of finishing the use as quickly as possible in the office space. This is because of physical interaction consumes time, which can distract the user's attention from work. In particular, users were uncomfortable with having to interact for a long time to set the e-mail reconfirmation time. Contrarily, it was confirmed that participants proposed a positive reaction to the interaction that can be quickly confirmed, such as protruding and pressing a node. Similarly, in Traffico, participants who experimented in the office expressed the burden of interacting for a long time. Based on this point, for products used in offices, it is recommended to minimize the steps of interaction and develop fast input to increase usability. Furthermore, according to the user survey data of Maili, users presented that interactions with long usage time can be used in a space where much time can be spent, such as at home after work.

For maximizing the user's experience with the interactive device, these findings indicate the need to consider the environment in which the product will be used during the design process. Notably, the device for the office environment, it is more efficient to design short time-consuming interactions. It may be that the usability factor is vital for the office environment.

7.2.3. Reviving the Analog with the Digital (DayCube, Traffico, Maili)

Understanding and applying the characteristics of non-digital physical elements are instrumental. Even though it is not a digital product, the analog elements that are continually being used bring positive values to people with their unique characteristics.

In detail, Maili added the value of the product by combining the non-digital tray utilized in the office environment. Traffico incorporated the advantages and characteristics of paper calendars in the digital interactive device. DayCube succeeded in delivering a positive tactile and visual sensation to users by introducing materials not frequently involved in electronic products. In these analog aspects, participants noted interest by utilizing analog materials which they did not regularly use or support in their environment. It also helped the prototype to be well-matched with the user's environment.

In each case, this research adopted that 1) the method of combining the analog product itself that can increase access and usability in the environment where the product will be used as a part of the digital product, 2) identifying and applying the advantages of the analog product that has been used before the digital product was invented, and 3) applying analog features not used frequently in the electronic product. These findings can help to increase the value of interactive products through the analysis and reflection of analog elements.

7.3. Consideration and Limitation in the Rematerialized Device (DayCube, Traffico, Maili)

7.3.1. Limited Function in the Rematerialize Device

One disadvantage of the physical interactive device is that the function of the product is limited. Digital products and information can expand infinitely, whereas physical products have limitations in information expression.

Typically, at Traffico, users hoped to check the weekly or monthly schedule beyond the daily schedule. Alternatively, among the four types of traffic information presented in the Traffico, users who only utilized buses hoped to check public transportation more deeply, including possible options for the bus. In addition, Maili's user survey showed that users wanted to send or delete mail beyond email verification.

In this aspect, the interactive product has a problem in that it may cause inconvenience to the user in that it is limited in functionality and difficult to change. In addition, this means that it is necessary to think deeply about what functions to provide through the tangible interactive device in terms of the functional usefulness.

7.2.4.2. Display in the Rematerialized Device

In three cases, a display was commonly used. DayCube and Maili used a small OLED display. Traffico utilized the E-ink display. The reason for using such a display is that many color displays already exist in society. Therefore it was expected to permeate the environment without burdening the eyes of users. Also, These displays played a role in pervading the user's environment smoothly in accordance with the product design. However, the problem of usability was also pointed out. Typically, Traffico sometimes was perceived frustrated because of the problem that the e-ink display takes time to change the screen. Besides, Maili had a small OLED screen that is different from a smartphone. Users experienced inconvenience in checking the email content. Considering that it is difficult not to utilize the display in the interactive device for delivering digital information, it is necessary to consider the aspect that there are functional advantages and disadvantages in case of using small size OLED and E-ink displays.

7.2.4.3 Security in the Rematerialized Device

The last thing is related to a security issue. Physical products have a problem that anyone can access personal information because of their excellent accessibility. According to the existing research, when users purchase the commercial IoT device, they usually do not worry about security issues. However, the worry of security increases after purchase (Emami-Naeini et al., 2019). At the same time, the Traffico and Maili utilized personal information about calendar and email. Some users mentioned security worries. In the previous paper, there was a finding that concerns about the security of personal information that might be shared were low to the family and teammates during business hours. Conversely, users had a high concern that personal data might be shared with colleagues outside of business hours (Patil et al., 2005). When referring to this, the interactive product used in the work environment or the shared place such as the dormitory will need additional locking functions after users leave that place.

8. Discussion

In this section, based on three design iterations and findings, it is elaborated on the references and suggestions for researchers, developers, and designers who wish to develop interactive products for conveying digital information.

8.1. Suggestion for Future Rematerializing Devices

8.1.1. Creative Unintended Uses of the Product

When a user survey is conducted for a month, a part frequently mentioned as an advantage of the tangible device is that users are genuinely involved in using the product. Primarily, participants perceive an interest in placing tangible goods, which did not exist before, in their space. However, the charm of novelty gradually decreases when used for a long time. On the premise that devices are used in the user's environment for a long time, it is reasonable to assume that it is essential to consider the product's usefulness and attractiveness related to the functional aspects.

In particular, a long-term study of Maili indicated that users curated the product—allowing email management and storage space—as per their needs. One participant even hung an umbrella on a tray. The other participant put a smartphone or a cup on top of the product (Figure 8.1). Besides, in the re-confirmation function of the emails, the design intention originally was to make participants recheck the email content by registering a reminding time. However, one participant set a deadline by registering a re-confirmation time. She tried to complete the task in the email before the node protruded. This user behavior was an unintended part of product development. This user's performance shows that users utilize the product by adapting its function in the desired manner with prolonged use.

Figure 8.1. Use of Maili in the Field

Previous research provided detailed information about why people do these kinds of unintended actions with products. Their data revealed that imaginative use is based on knowledge about product attributes and individual preferences. The need for cognition and pleasure triggers these activities. They proposed that such users' unintended performance supports in increasing device value and engagement with the product (Wongkitrungrueng, 2018). In this regard, the user's action is not predicted. Designers need to find or consider these users' actions by developing a room that the user can join and develop their usage pattern. This study showed some possibilities related to the email reconfirmation function and tray. However, more such responses are expected.

In this study, it is assumed that the analog products that are relatively familiar to the user are nearby to occur unintended use. According to a previous study, the knowledge of product attributes possessed by users affects unintended creative use (Wongkitrungrueng, 2018). Through this, one suggestion is to use a user-friendly component (e.g., tray in the Maili) as a part of product design. Because interactive digital devices itself may be unfamiliar to the user, elements of the product that the user already knows can help the user to feel familiar with the product. In this study, the user's unintended action was come out from the usual section, such as a tray in the Maili.

8.1.2. Analyzing the Usage of Digital Information

Digital information is being utilized through various means such as smartphones and computers. Therefore, the tangible device needs to analyze how users previously used that function. The interview data from three user studies suggest that users have minimum requirements and expectations from the product. These technical thresholds that users consider vital are essential for judging functional usefulness and accessibility.

At the same time, several studies reviewed in the literature survey consider digital function. However, it was inadequate for an analysis of the digital function itself and of how and why the digital function is currently being used. For example, in this research, Traffico displays a daily schedule. However, there was a need for users to view monthly schedules. Besides, Maili was uncomfortable for use initially because it was different from the email applications generally used. Typically, participants expressed discomfort in checking emails on a smaller screen than a smartphone and computer.

When considering this limitation, users generally perceived discomfort when there is no function that they usually perform, and this may cause a decrease in usability. Accordingly, it can be seen that functional expression is necessarily based on the analysis of the existing digital method.

8.1.2.1. Direct Engagement with the Data through a Tangible Interactive Device

One suggestion in this study is to enable users to control digital information directly through physical products. In existing research, which applied digital data such as music

(Odom et al., 2018), calendars (Lee et al., 2017), and news (Gaver et al., 2010) into tangible devices, deleting or adding elements from the materialized artifact did not affect the digital archives. From the perspective of communication direction, if it is considered that the direction of input and output of people's existing digital information about technology, emails, and calendars have two-way communication. Conversely, traffic information and weather can be obtained by simple input from existing apps. As a result, the functions required by users have diversified in case there is a two way of communication between function and user. For example, based on the user’s existing use pattern in engaging with emails, it was found that there are several actions involved in deleting an email (Alrashed et al., 2018). People usually delete old or spam email to prevent email overload (Murillo et al., 2018). In other words, email deletion itself helps to manage emails. The participants of our user study also revealed patterns of removal for organizing email. However, they had to remove emails in the computer or smartphone application during the user study because Maili did not support a delete function. This introduces the possibility of considering direct manipulation of email data itself, including deletion through a physical device, beyond bringing the existing email data to the tangible device. It could be a solution to enhance the usability of an independent email device. For example, in this study, if a pushing node interaction that returns a shape-changed form to the original is matched with deleting an email. It will be able to induce natural usage of checking and deleting email and also convey a definite feeling of finishing email work. A broader perspective may suggest a potential design space that actively involves information manipulation through a tangible device and physical interaction.

8.1.3. Improving Interaction

Based on the findings of this study, this section considers improvements in the interaction.

8.1.3.1. Tangible Input: Always Controversial

In this study, various corporeal inputs, including palm touch, plate rotation, vertical rotation, and push interaction, were applied. When digital interaction is compared with physical interaction, it is difficult for physical interactions to provide more convenience than digital inputs. This is because, as mentioned in the existing literature (Van Campenhout et al., 2016), digital input provides standardized interaction and makes it easy for users to use. However, it is noticed that participants express emotions of joy and novelty for physical interactions with using their hands. Most of these findings emerge from resorting to actions that were not handled in existing situations or smart devices and getting tactile feelings.

Explicitly, in DayCube, participants expressed fun in touching a material they are have not encountered before. In Traffico and Maili, users found physical interaction that is different from interacting with existing smartphones pleasant. Furthermore, some participants suggested more interactive and fun interactions to increasing the enjoyment factor.

However, user surveys of Traffico and Maili point to usability issues. As mentioned earlier, physical interaction itself could not be easier to use compared to digital interaction. However, the consideration usability of physical interaction is important because we found that participants said the negative perception of product usage when interaction was uncomfortable. Participants commented on the hassle of prolonged physical interaction times. Thus, when the specific usage time is exceeded in the interaction, the overall satisfaction of the device decreases. Nevertheless, in this study, it was not possible to gauge the time period that creates a pleasant interaction. According to the user's interview data, it is reasonable to assume that the specific point when the decline in the user's satisfaction occurs reflects a combination of the user's perception related to the importance of the functions and the use environment. It implies that when the function of the product is considered as necessary to the user, and the usage environment is comfortable, the time allowed for interaction increases. Contrarily, if the importance of functions is low and the place for interaction is time-critical such as work, the time allowed for interaction decreases. The specific possible time for interaction can be considered as an area requiring further study.

8.1.3.2. Connecting One Physical Interaction to One Input and One Digital Thing

DayCube and Traffico mapped one function according to one interaction. In DayCube, the user touches the product with their palms to gather weather information. Traffico shows schedules following the clock plate rotated. In the interaction between these two products, users talked about the advantage of being intuitive and easy to use. Traffico has two digital functions (calendar and traffic information), but the information controlled by the rotating interaction by the user was only one calendar information. Traffic information could not be controlled by rotating interaction.

Conversely, in Maili, the rotating dial plays two roles: viewing the mailbox and setting the reconfirmation time. In addition to the rotating interaction, pressing a button is also combined. As a result of the user survey, some participants mentioned inconvenience in using one button for two functions and two interactions, press and rotate.

Frens et al. (2018) developed an interactive input box with a modular design. It can control one digital information with one input box. In this device, people can put more inputs since the IoT function is increasing. Their purpose was to assume that the IoT function is and will be increasing. They make an interface respond to the dynamism of IoT by bringing appreciative qualities through physical design. Similar to this, this study's suggestion is to design one interaction to control only one specific digital function with one input. From this, it is possible to interest the user with physical interaction while increasing usability by making the user control the device intuitively. For example, in Maili, it is possible to design an interaction suitable for each digital function by dividing it into a scrolling inbox and an adjusting time.

However, the existing IoT sandbox research suggested a method of mapping one input to one digital function to increase richness in interaction. There was no specific standard for interaction except using physical interaction. On the contrary, the proposed method of this study focuses on increasing usability as much as possible in the physical interaction of digital information. It found why users felt uncomfortable and gave suggestions to control digital information within the product.

8.1.4. Improving Design

8.1.4.1. Over the Adapting, Modulizing with Digitality and Tangibility

In this study, users showed that they applied the product's function in the way that suits them. Furthermore, as the usage period increased, participants revealed a need to change and apply the form and interaction beyond the product's intended use.

In this regard, a physical product has a limitation in the form, interaction, and function because it is hard to change it according to the user's needs. Therefore, a physical product has the limitation that it cannot solve the needs or problems that emerge while using the product.

For this, this study proposes a modular design method for reflecting the needs of these users and figuring out digital information. This modular method has been studied in various ways in the existing tangibility studies (Rekimoto et al., 2001; Ullmer et al., 2008). These researchers suggest developing diversity by making a modular form. One study proposed a modular design as one possible direction for home IoT devices (Frens, 2017). Frens mentioned that a modular approach could be the way to match tangible form to growing IoT systems. Previously, in the software design area, the concept of appropriation was suggested. This means that users understand the technology in their way and adapt the system to the competent usages they developed (Tchounikine, 2017). Furthermore, in commercial electronic products, the modular type is applied to increase the value by assembling what they want by themselves (see Figure 8.2) (Samsung Newsroom, 2019).

Figure 8.2. Samsung BESPOKE (Samsung Newsroom, 2019)

However, as for the existing modular design, they mainly adjusted the means of the input and changed the digital function by assembling. The approach recommended in this study pertains to connecting the digital and analog functions without distinction so that users in the workspace and at home can utilize the functions as they want. This is because it is assumed that combining analog parts and digital appliances can allow easy permeation in the home or office environment. For example, if Maili is divided into specific modules, it can be arranged into the tray, email confirmation, and re-confirmation sections. One concept suggested by a user was that the tray and mail confirmation options could be merged into a two-tiered form. Through this, the size of the product can be reduced and usability can be increased by assembling the functions they want.

However, at the same time, it should be considered that not all users are designers in designing a modular design. Nielson mentions the problem that users cannot understand what they want because they have different understandings (NNgroup, 2016). To solve this, a guideline is required in the modular design. Especially in the appropriation design, Dix mentioned the importance that designers express intent behind the system (Dix, 2007). Reflecting this, in the modular design, it is necessary to consider the direction of giving a particular guideline that users get helps to follow rather than the way the user decides everything.

8.1.4.2. Still Living in the Tangible World _Connecting the Analog with the Digital

When looking at the value of the rematerialized product obtained through this study, numerous findings are frequently raised with advantages that emerge from the characteristics of past products beyond the digital functions. For example, the existence of a tray in the digital device helps to maximize the usability of the device. Thus, I suggest three factors in adapting the analog perspective to the digital product in this research. These findings go back to the literature review and, as Ishii mentioned, we live in a tangible world. Therefore, the physical way is a reasonable option for controlling something (Ishii & Ullmer, 1997). Apart from the direction suggested in this study, analog products' value can be combined as a part of digital products in numerous ways. For example, one of the characteristics of analog products is that users can write or record data by writing by hand (Tungare et al., 2008). In HCI research, a study is being conducted to analyze the handwriting pattern of a user (Haines et al., 2016) or to utilize handwritings as input for smart glasses (Yu et al., 2016). However, there is no research adapting the user's handwriting directly as the digital input. This could be potentially a digital product.

As the digital device's value has increased by reflecting the analog perspective to the digital in this study, it seems that there is a need to identify and apply analog fields that have not yet been researched.

8.1.4.3. Undiscovered Area _ Portable Way of Physicality

Searching for research on existing tangible devices revealed that an area that has not been studied in depth is the portable utilization method of digital devices. In the existing studies (Gaver et al., 2013; Lin et al., 2019), products are available that can be moved in limited environments such as at home. On the other hand, there are not many studies about products that can be carried freely outside (Gaver et al., 2016). However, participants in the user study suggested the need to use the research products while carrying them.

Thus, after developing Traffico, the idea of attributing a portable feature to it emerged from participants' expectations. The following concerns, however, accompany developing portable devices. 1) Battery issue. There are limitations to battery use in portable products because increasing the battery capacity increases the weight of the product, causing usability problems. 2) Internet connection issues. Interactive products usually require an Internet connection. However, continued Internet supply cannot be guaranteed when moving. 3) Size issues. Using a microprocessor, including Arduino and Raspberry Pi, with various sensors and input may reduce the usability of the portable product because of the increase in size. In this research product development, it was challenging to implement a portable product due to the above limitations. However, future studies can pursue this since users' needs for mobile products have not been explored in previous studies.

Conversely, looking at Traffico and other rematerialized research findings, portable rematerialized devices are expected to deliver the following value. 1) It is possible to provide necessary information with high accessibility to users. Physical products can provide a functional value that reduces the need for additional interaction because the user can immediately check the information. 2) The pleasure of physical interaction can be provided portable. Physical interaction has the strength to arouse the interest of the user. It can be expected to be a direction that can be enjoyed not only in the internal environment but also outside.

9. Conclusion

This study proposes three physical directions for rematerializing with four digital information. While developing this product, it was continuously considered physical interactions and forms that can efficiently express digital information. It is believed that these three interactive products propose attractive options in a way that users can effectively and efficiently utilize each digital information in their home and office environments.

9.1. How has the Dissertation Achieved its Proposed Goals?

In this study, three products were developed with a total of four digital information. For the development of these products, the possibility of digital functions currently required by users was identified through a literature review. Besides, four elements of actuation were combined as aspects of design. Also, a connection between input and output and a user environment was considered. The design direction of each of the three cases was as follows.

First, we developed the DayCube that combined materials and IoT functionality to explore the experience of assigning material properties for tangible interaction with daily digital data. It delivered weather information through vibration sound from the material and calendar information through the movement of wood. Second, we introduced Traffico, a tangible timetable created from dematerializing a digital schedule and transportation information. It is designed for the office and home environments. Traffico provides user’s schedule information and transportation time required to reach the appointment area by bus, car, bicycle, and on foot. In exterior design, Jesmonite and e-ink display are used for ensuring the device is well-matched with the user’s environment. Lastly, Maili is to investigate how dematerialized email data can be applied to a tangible object. Maili’s design focused on blending into the office environment through a tangible tray-type design by offering physical interaction with rotation and nodes protruding from the flat surface to naturally induce users’ manipulation and an additional reconfirmation function to provide easy email management. Each case attempted to grasp the emotional experience and usability that the user felt through a pre-setup or field study.

9.1.1. Rematerialization: Usability and Experience (Aesthetic & Emotional) Offered to Users

This study investigated participants’ views on the products’ usability and their experience from the physicalization of digital information through three case developments and user surveys.

First, the physical equipment offers the advantage of conveniently noticing changes in information (new mail, upcoming schedule) by continuously transmitting information within the user's space. Exceptionally, physical equipment has the advantage of improving the accessibility of users' information by allowing the user to acquire the desired information through short interactions. These advantages were found in all three products. Moreover, the tangible device showed that the advantage of continuously sending information provoked a change in user behavior and gave new interpretations regarding digital data. It was particularly noticeable in the experiment installing the product in the user's space.

Second, this study found an advantage in adapting actuation for transmitting information or inducing user actions. In particular, it provides a definite feeling that a tangible-active alarm can provide a fresh perception to the user different from the existing digital alarm. It was observed that changing the fixed appearance of the product to cause discomfort in the user helps induce positive interactions. At the same time, participants mentioned that engaging in physical interaction is fun and intriguing compared to the touchpads used in smartphones. Furthermore, this research pointed out the necessity of considering the time required for interaction according to the environment. In the office environment, developing short interactions is significant.

Third, this research found two things that increase the reason why the product is required to be placed in the user's space. It is to discover positive values from the existing analog elements and reflect them on digital products. In a detailed direction, it is affirmed that users find high value in combining analog products that were used previously as part of digital products. At the same time, it is recommended that it can provide positive value by increasing functional strength by finding and merging sub-functions linked to the primary function.

9.2. Designing for Rematerialization

9.2.1. Definition of Rematerialization

It brings digital information or function to the tangible form and interaction. These overall product design, interaction, and function intend to be designed to bring functional usefulness and emotional value to the user in the user's placement. Optimal user experiences can be obtained if the design for the rematerialization integrates useful digital functionality for the indoor environment, activating with actuation, the interrelation between output and input, and design to be permeated and valuable in their daily life. For this rematerializing the digital information, It is proposed the following factors for increasing the value of future rematerializing devices, with the findings obtained through the experiments of this study. In the previous research of Frens (2006), he suggested the three factors for designing interactive devices, form, interaction, and function. Based on his suggestion, it is suggested the following additions for design reference:

First, it is necessary to consider the functional value of the product. Primarily, considering that the interaction of the product can be mundane depending on the period of use, it was determined that functional value is essential to increase the value of the product and to appeal to users continuously. For this, specifically, it is proposed the need to analyze how users utilize digital information and the possibility to enhance usability by direct digital information control such as deleting digital data through the operation of the physical devices. At the same time, as a way to increase the functional advantages of the product, the findings of this study recommended creating value through combination with analog elements and sub-digital or analog functions.

Second, it is suggested for increasing usability by matching one interaction with one digital function to increase the functionality of the interaction. Moreover, the possible time for interaction primarily depends on the user’s perception related to the importance of functional and environment of use. The environment in which the product will be used requires the device to be mainly composed of short-term interactions in environments where time is essential, such as the office. More mentally demanding interactions can be adapted for products where the location can afford plenty of time, such as in the house.

Third, in terms of design, the physical shape of the product is fixed; therefore, it has the disadvantage of not accurately reflecting the user’s needs. Apart from this, it was discovered that combining analog parts with digital products may provide a reason to keep the products in the user’s space and may offer a way to increase functionality. Therefore, as a possibility of design, I propose a way to develop a modular design in which the user can assemble digital and analog modules as they want. Additionally, it made two suggestions related to further possibilities in designing by analyzing the perspective of the analog device further and adapting them to the digital device and considering it to develop a portable tangible device that has not been researched extensively.

9.3. Expected Contribution

The following contributions are expected from this study.

First, in this study, four types of digital data were conveyed through the developed physical products and user research was conducted. Thus, this research discovered new ways to utilize digital data and interview data on what kinds of emotions and usability were expressed when real users utilized devices.

Second, I used five of the outputs to represent digital information to grasp the value of these outputs in providing information. In particular, it was found that the value to the user, the reference to the designing product, and future design suggestions when the appearance of a product changes was utilized for communicating information. In particular, it has been found that by delivering the information through the appearance change, it can induce user interest and input. The reason users felt this is because shape change can provide positive anxiety that users want to return to their original position. Such a change in appearance may be used for a function capable of informing a user or inducing an interaction.

Moreover, three physical inputs are proposed to control digital information. It is suggested that it is necessary to change the way to interact following the environment to be utilized for increasing the positive value while reducing the negative emotions. In particular, it is proposed the possibility of improving the usability of information control through a method of adapting one digital information to one interaction and input for the improvement of interaction. Also, it is mentioned that the time available for interaction may vary depending on the environment in which users use the product and the degree of importance of the function perceived by the user. In designing, these two factors are proper guidelines to be considered to design the interaction.

Lastly, these three interactive devices suggested the value of combining multiple digital or analog functions. Through this, it was grasped how the functional combination affects the user. In particular, it is suggested the possibility of combining user-friendly analog elements as part of the product. These elements can help the product to permeate the user's environment. At the same time, users showed a creative usage of these familiar elements in the way they wanted.

Comprehensively, it is expected to be a reference for product development that can better penetrate the users’ environment. Regarding previous research to develop physical products by importing digital information, this study proposed a new method to physicalize digital data and, at the same time, grasped the functional advantages and emotional values felt by users. Additionally, through discussion, it is suggested further points for consideration to design a rematerialized device that allows function, design, and interaction.

9.4. Limitation

9.4.1 User Study

In this paper, three studies used the field study method. The limitations of field studies are that users might rate the system or product high due to the novelty, and it cannot investigate the effects of long-term adjustment and knowledge (Shaer & Hornecker, 2010). To this end, it is conducted a user survey from two days to one month and attempted to provide an opportunity to organize participant's thoughts while expressing their opinions through more than two interviews. At the same time, more than five participants were recruited based on previous research (Kujala and Mäntylä, 2000). Also, interview data of all three research pieces were analyzed with the same methodology, thematic analysis (Maguire & Delahunt, 2017). Relevant or interesting quotations were marked, and researchers generated collections by continuously and continually checking the transcript. Throughout the interviews, consistent and contradicting views from each participant were classified with an across-case approach (Ayres et al., 2003).

Like this, user studies were conducted based on the basic guidelines. However, the user research method of this study has the following disadvantages.

9.4.1.1. Characteristics of Participant

With reference to existing studies, at least five people were secured. However, each user study was conducted with a different number of participants. Problems may arise in generalizing data. Besides, a limited target group was selected for each research. Mostly, users in the 20s and 30s participated. These users had a high level of understanding of technology. However, there might be limitations to cover all users. Additionally, users of many age groups will need to participate.

9.4.1.2. Novelty Effect

Since field studies are difficult to make users use for a long time, there is a concern that the evaluation of products may be increased due to the novelty effect (Shaer & Hornecker, 2010). Especially in DayCube and Traffico, which conducted short-term experiments, there is a possibility that the novelty effect influenced by the result of a user study. In addition, the three studies conducted in this dissertation have a problem that each has a different study period and scope. In particular, user surveys of DayCube and Traffico were conducted in a shorter period of time than Maili, and no quantitative data was collected. To supplement this, it is expected that additional in-lab studies or long-term user surveys over several months will be required.

When referring to the existing study (Gaver et al., 2016), which conducted an in-field study for about nine months, it was noted that users had less interest in the product after one or two months of start. At the same time, participants said that the product had penetrated the user's environment and became part of the home. They said that they do not want to give prototypes back to the researcher. Based on this, a field study of at least one month will be required to study to check whether the research prototype can permeate the user's environment or not.

9.4.2 Consideration of Information Overload

This study showed the value of rematerializing digital information. However, the limitation of making an independent product is that not all information can be made into an independent device. In particular, it is impossible to physically express all information in a situation in which digital information utilized by users is increasing. To this end, beyond the development of each case, it will be necessary to grasp the possible or necessary scope to display data in the user's environment physically.

9.4.3. Lack of the Specific Finding related to the Rematerialized Device Only

In this study, the possibility of rematerialized devices was identified through product development with digital information. However, in some of the study's findings, it is not confined to rematerialized devices, but the value that physical interactive products can provide (e.g., 7.1.1.1.Improved Access to Information: Reducing Checking Steps and 7.1.1.2. Evoke Behavior Change). This will require additional research into the value that only rematerialized devices can provide.

9.5. Future Study

9.5.1. Developing Guideline for the Future Design

In the finding of this dissertation, it suggested the perception from the rematerialized device, and it was also provided suggestions to design a better-rematerialized device for the future. In section 9.2, based on the factors for interactive devices suggested by Frens (2006), this research brought additional consideration for the rematerialized device. Furthermore, each three case, It has a specific way to design. However, this research is a lack of specific guideline which other researchers can follow. Unfortunately, this dissertation ended with suggestions and value of the rematerialization that other researchers could refer to. Further research will be needed to provide detailed guideline proposals.

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