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Edited by Miguel Bruns Alonso and Elif Özcan

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Edited by **Miguel Bruns Alonso**
and **Elif Özcan**

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Meet the editors

Dr. ir. Miguel Bruns Alonso is part of the Designing Quality in Interaction Group at TU Eindhoven. He studied industrial design engineering focusing on tangible interaction design and obtained his master and doctorate degree from the Department of Industrial Design Engineering, TU Delft. He was a visiting researcher at the Center for Design Research of Stanford University, USA and at the Design Research and Ubiquitous Computing Group of Aarhus University, Denmark. Miguel investigates the aesthetics and emotional expressivity of interactive products with programmable material qualities (interactive materiality), particularly haptic and shape-changing interfaces.

Dr. Elif Özcan conducts sound-driven design and research activities at the Faculty of Industrial Design Engineering of TU Delft and leads the Silent ICU project at the Department of Intensive Care of Erasmus Medical Centre. She is the director of Critical Alarms Lab at TU Delft where she mainly investigates sound-driven wellbeing of users and professionals in critical contexts (e.g., patients and clinicians). Elif was a Guest Editor for the Journal of Sonic Studies, for the special issue on sound design. She has been involved in several European projects funded by Marie Curie Initiative, DocArtes programme, European Space Agency and Toyota Motors Europe. She is currently developing ISO standard sounds as part of the international alarm coalition funded by the Association for the Advancement of Medical Instrumentation (AAMI), USA and is rethinking the role of alarms in critical care. Elif is a mother of three daughters and an advocate for women in science as part of the DEWIS sounding board at TU Delft.

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Chapter 1

DeSForM 2017: Sense and Sensitivity

Elif Özcan and Miguel Bruns Alonso

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1. Introduction

This year we celebrate the 10th edition of the DeSForM conference series. In 2005, DeSForM was born in (Eindhoven) the Netherlands with the premise of creating meaning through objects, interactions and people. Over the years, the DeSForM community has explored and designed objects through a multi-sensorial approach always aiming at enriching users' experiences with them. Throughout previous editions, we have seen the development from digital and mechanical objects that had enriched sensorial presence to adaptive and intelligent objects that feel almost analogous to reality given their increased information processing power and sensory resolution. These are thanks to the recent developments in the material sciences, robotics, information and sensor technology, and improved production techniques. Consider, for example, developments in wearables and embedded or computational materials. Consequently, the arena that belongs to design researchers and practitioners has gotten more sophisticated by being more technical, but also raises new questions regarding the effect and the impact of the new technologically rich designs. In 2017, DeSForM is returning to its place of birth opening up to a broader audience with deeper insights to debate about the future of dynamic 'form' giving and its effects on people and their environment.

Three major themes were devised for the conference. Our ambition was to explore how we adapt to novel interactive technologies, for which we received submissions exploring the home context and situations of (health)care. Furthermore, we wanted to devise what happened in the interaction of different modalities through the perceptual and experiential gap. Authors contributed through research on auditory experiences and how the different senses can be engaged or transformed into others. Also, we intended to look into the development of sensitivity, addressing the co-creation of experiences and design explorations into dynamic esthetics. Not only did we want to explore this through the contributions of many design researchers, but also we aspired to look at it from alternative perspectives. Therefore, we invited three keynote speakers from diverse backgrounds offering their distinctive view on the state-of-the-art of dynamic form. A physicist—investigating and creating materials with surprising dynamic properties, an artist—composing the sounds for an intensive care room and a design engineer—working in one of the major navigation companies giving form to route finding through the use of data.

2. Adaptation to interactive technologies

Not only interactive technologies such as actuators, sensors, chips, lights, smart materials but also social robots and virtual reality, offer a specific challenge that humanity has not faced before. The design of interactive, responsive and self-evolving artifacts and environments challenges the physical understanding of people's surroundings and their skills to adapt to it. More than ever before, technologies create a gap between the human senses and the understanding of what is (being) sensed. Therefore, the senses are not to be trusted as much as one was used to. Novel products, interactions and experiences naturally emerge and question the way users make sense of novelty and interpret its effect on them. Authors contributing to the 10th edition confirm that soon enough more and more novel objects with interactive features will be part of our daily lives encouraging us to adapt to technological advancement in the comfort of our domestic environments. This time technology is employed in a sensitive and sensible manner in order to care and support us.

2.1. Sensible care

Technological advancement has always been in favor of addressing the imminent needs of human beings. While, in the past, technological innovations have covered many of our psychological and safety needs, today people feel the need to be 'the best one can be'. Being the best as possible (i.e., self-actualization) refers to both physical and mental performance in environments that are sensitive to rendering people's actual capacity and what they can achieve. **Feijs and Delbressine** offer a calm technology for monitoring the vitals of people and providing them with biofeedback, which is a timely solution in the age of information fatigue. **She et al.** study prolonged grief disorder (PGD) and how early signs can be detected through an internet-based screening. **Xu et al.** extend their interest in monitoring individuals and their vitals to monitoring societies and their stress levels. The authors seek answer in the field of interaction design and in the form of a clock that visualizes how people collectively experience stress. With an interactive demo, **Boess et al.** investigate ways to calm (overstressed) children with autism through technology that is respectful and that can relate to social tensions sensitive children can experience. While all authors in this session address stress and mental well-being, **Ramirez** and colleagues explore ways to introduce healthcare technology in people's homes for physical rehabilitation purposes. **Ramirez, Duncan, Brebner, and Chan** aim to make stroke rehabilitation exercises more playful, and with an interactive demo, **Ramirez, Lemke, Mccarthy, and Andreae** demonstrate women's preferences for interactions with healthcare products when the product is meant for private use as in the case of pelvic floor exercises. All these papers reflect designers' sensitivity to embed technology in domestic and social contexts with care and sensibility.

In a workshop, **Sen and Sen** show participants how listening to the world with the sensitivity of a musician can transform the way they experience the world. The workshop organizers further guide the participants to hear the future soundscape of hospitals and craft speculative narratives for 2027.

2.2. Domestic digitization

In domestic digitization projects, the developments of connected products in the home and their potential impact on our lives were investigated. Critical reflections are taken on the increasing number of such products. For example, **Frens** discusses critical design issues for upcoming Internet of Things systems and investigates how to design for embodied and rich interaction with systems in which functionality can grow to match user's preference through four design cases [FRENS]. Furthermore, **Pillan et al.** present a critical and ethical reflection on the self, privacy, personal identity and the design choices that need to be made when creating smart products for the connected world [PILLAN]. Other researchers explored how interactive products could support more sustainable practices. **Wessman et al.** present a design probe 'peacetime', which is a physical manifestation that encourages pleasant activities without the use of electricity during peak hours and compared it to a website. Their results can inspire future designs for energy saving by using more emotional approaches to engage users [WESSMAN]. Furthermore, **Bergamashi et al.** explore more sustainable behavior by means of two prototypes with which they investigated how sensory languages, that is, without explicit information exchange, can support users in decreasing their water consumption. Finally, **Liu et al.** investigate expressiveness in human-system communication using point-lights, their results show that light behaviors can convey specific state information to support intuitive communication [LIU].

In a workshop, **Hur et al.** imagine a better relationship with technologies, artifacts and design in the future. The workshop organizers intend to address and explore the pervasiveness of technology by breaking down the design of now obsolete technological artifacts and reconstructing/redesigning them in terms of current design contexts. The aim is to raise awareness to our sensual/perceptual abilities by using bodily movements in order to recall the nature of relationship users have with forgotten and future artifacts, data and networks.

Novel technologies are changing our environment and the way we interact with it. The data that is generated can help to improve our quality of life, but can also have its negative effects, for example, in terms of privacy. Designers will have to deal with these technologies and use them as new materials for creating the future. Our keynote, **Maarten Gribnau** illustrates how data about traffic is used as a material to improve the way in which we can navigate through the world.

3. The perceptual and experiential gap

The perceptual and experiential gap opens up new avenues for designers and researchers in the traditional domain of experience design. First, by exploring the new definition of satisfaction in the realm of novelty. Next, and maybe more exciting, by exploring how the gap can be used to generate new ways of interacting with, interpreting and creating an intriguing new world rather than a mundane one. As a creative community, we have reached a crunch point where we are able to shape the future of product, interaction and experience design in an exciting way. Thus, it has become possible to envision a world where people are intrigued by design, have dialog with designed artifacts, or artifacts that have discussions with other objects. These encounters will move people in surprising ways. The natural design habitat enriches people's sensory repertoire and deepens the meanings attached to artifacts allowing for, for example, poetry, reciprocity and seduction in relation to designed objects.

3.1. Transcending acoustics

In our daily interactions in domestic and professional environments, we are often habituated to the norms offered by certain senses. In this session, the contributing authors investigate future design interventions that challenge the existing role of auditory experiences in sensitive and critical contexts. With HAPTIC, a wearable haptic device designed for ICUs and ORs, **Gay-Betton et al.** reassign information that usually triggers audible alarms to haptic display and investigate the position on body (e.g., wrist or ankle) that is the most appropriate in critical care contexts. Similarly, in the form of an interactive demo, **Reynolds et al.** present SLAAP as a sound attenuating device that can help overcome not only alarm fatigue in clinicians but also delirium and PTSD experienced in ICU patients. Thus, often lack of certain frequencies or even sound itself can be a desirable design feature. **Misdariis and Cera** address the issue of lack of conventional sound in electric vehicles and how such technological outcome helps rethink the politics of designing sounds for commercial entities and discuss its practice from the perspectives of arts and science. **McKenzie and Lennox** investigate the physiology of spatial hearing through a bone-and-tissue conductor apparatus and how the sensation of hearing is in its essence similar to tactile stimulation. The authors report that an tactilely induced spatial hearing may substitute a real auditory experience as this new technology is described by users as enjoyable, informative and spatial but also strange.

3.2. Sensory engagement

In sensory engagement, several designs are presented that extensively involve the senses to create more pleasant or rewarding experiences. To stimulate more active behavior, **Afonso** has developed urban art installations that afford playful, action-oriented and sensorimotor encounters. By analyzing these installations in context, they argue that active modalities are more effective at placemaking [AFONSO]. Another approach to behavior change was taken by **Andreae et al.** who explored how interactive tableware could manipulate sensory perception to control portion size, thereby preventing obesity [ANDREAE]. **Lim** developed an esthetically appealing felted textile that is inspired by a hilly green landscape. With its embedded soft electronics, this interactive textile creates a sensorial experience that combines the tactile and aural senses into an esthetic experience [LIM]. Finally, **Taverna et al.** presents their design of a set of products that aim to lead children toward autonomy in their personal hygiene practices [TAVERNA]. Igeni are three colorful monsters that support children in the bathroom and remind them to flush the toilet, brush their teeth and wash their hands.

In a workshop, **Frankel et al.** aim to increase multi-sensory and multi-modal design awareness of design practitioners. The workshop organizers offer participants activities with which they identify, share and play in order for them to learn novel ways for exploring multi-sensory and multi-modal qualities for physical and virtual interaction design.

Having technology embedded in our lives also comes at a cost. The more products that are there to support us the more they contribute to the noise pollution in our domestic as well as professional environments. Such negative consequence of sound is clearly prominent in hospitals in general and in critical care contexts in particular. Currently, this issue needs urgent attention as unwanted sound threatens not only patient safety but also their well-being. Our keynote speaker, **Yoko K. Sen**, with an artistic approach, rethinks the impact of hospital-specific sounds on the healing process of patients. Sen further imagines the future of hospital sound in which sound is a display of care, love and respect and that patient can recover in tranquility.

4. Developing sensitivity

Sensitivity is no longer about 'knowing the world' but about 'being in the world' and exploring it. This means that people need to continuously adapt to a changing world and give meaning to it in a creative way. The sensitivity of the mind is grounded in the sensitivity of the senses. The question becomes: how do people develop this new sensitivity and how do we design for it? Understanding the process of adaptation sheds light on the working of human body and mind. We are able to tackle sensory and cognitive capacity of users using the knowledge, tools and methods we have been acquiring and building over the years. Designing for sensitivity using these new approaches should result in the creation of unprecedented experiences as well as the envisioning and demonstration of interactive futures.

4.1. Co-creating experiences

In this session, authors consider all stakeholders in the design processes when technological solutions are prominent in interaction design targeted at individuals as well as societies. **Jaasma et al.** reflect on individual sensemaking of public technological applications and propose that collective experience of public technological applications could be based on scaffolding the individual interpretations of the system content in face-to-face interactions. **Wetzels et al.** propose a change in the roles of researchers and system developers in the design methodology that is applied for designing healthcare monitoring products. The authors argue that software developers need to have a deeper understanding of health-related data which can only be obtained through research. They demonstrate the benefits of this new methodology with the results of an app design that has been evaluated by users. **Peeters et al.** include a multi-disciplinary design team that consists of interaction designers, professional dancers, software developers, artists and 3D modeling experts in order to unravel, and design for, an embodied esthetic experience. Their study also sheds light into understanding the complexity of tacit experiences. Finally, **Karahanoglu and Bakirlioglu** reverse the design process to understand how designers can better understand the user and incorporate the product usage early in the design processes.

In a workshop, **Ventura and Shvo** reconsider the role of designer for societal and political impact and reframe designers as interpreters of socially and culturally complex issues rather than adopters of technology for resolving complex problems. The workshop organizers aim to depict a futuristic picture for healthcare design in which designers are powerful and influential in sensitive and emotional episodes in people's lives.

4.2. Dynamic esthetics

Biology can be of great inspiration for the design of dynamic movement, animals and plants that have developed these subtle movements over time and designers should use this knowledge to their benefit. Therefore, **Fayazi et al.** propose a three step biology-to-design approach to adapt biological movements into the design, observing and identifying natural movements, classifying the types of movements based on direction, volume and path and sketching and iterative prototyping [FAYAZI]. Other natural phenomena have inspired the work of **Petersen and Kristensen**, who have looked into the possibility of integrating of natural and artificial lighting to enable dynamic lighting design [PETERSEN]. Their observational instrument enhances the subtle integration of naturally reflected and artificially emitted light, to support experimentation with its nuances. Artificial behavior can lead to surprising effects, and this is explored in the context of light by **Ramirez et al.** The authors present a set of experimental light objects that support surprising experience through their visual-tactile incongruity [RAMIREZ]. A new craft for dynamic esthetics is to be developed, and why should this not be inspired in traditional crafts? **Lim et al.** explore how to embed interactivity in traditional materials through artisanal processes thereby creating interactive and reactive hybrid materials, that is, combinations of electronics, smart and traditional materials [LIM2]. These more dynamic materials, which in human-computer interaction are referred to as shape-changing interfaces, can be used to communicate system information. **Gallegos et al.** demonstrate how such dynamic forms can help people in understanding that the system is aware of their presence [GALLEGOS].

The possibility for the use of dynamic materials in design opens up new ways of material applications. Potential directions for interaction design, embedding new materials and the esthetics of dynamic form is addressed in the keynote of **Corentin Coulais.** Coulais presents machine materials, that is, materials that combine internal architecture and active processes to interact with their environment in a programmable fashion, for us to reconsider the distance between natural sciences and interaction design.

5. Speculating futures: student interactive demo (SID)

This year we had a chance to involve interaction design students who were rethinking the future of pervasive technology and privacy issues regarding data collection and use in the course of Interactive Technology Design (TU Delft) under the supervision of Aadjan van der Helm, Roy Bendor, Tomas Jaskiewicz and Wouter van der Hoog. Students' interactive demos are used as narratives to speculate the effects of technology on us. With **AI Mayor**, we step into a future where urban planning decisions are made by Artificial Intelligence. **The Republic of Tirania** demonstrates what one would be willing to do for safe refuge. **Interstellar emotion trainer** supposes that space travel is lonely and one better needs to be prepared! **The Datactor** questions what consumers can trust in an age of fake product data. **Data Graveyard** shows what happens to your data after you die. These interactive demos make the future concrete before our eyes and help us reconsider our options now with the pros and cons of data privacy and data usage.

6. Future of DeSForm

The 10th edition of DeSForm brings together not only interaction designers but also an array of technologists, artists, scientists, software developers, futurists, politicians, clinicians and makers and builders who are passionate about establishing a fertile and creative base for interactive experience design and the individual and social benefits it brings to people's daily lives. The multi-disciplinary scientific debate at DeSForm 2017 is exemplary and has to be openly shared by this widening interaction and experience design community. Therefore, for the first time in its history, DeSForM conference takes part in open access and indexed publication with InTechOpen to allow all contributors celebrate their work with their peers with open mind and sensitivity for scientific integrity. Our action is in line with the current movement in the academia toward Open Science Open Minds philosophy and we support delivery of science to society free of charge and accessible online. By doing this, we aim to propagate creation and application of new ideas in the field of interactive experience design as well as have impact in the corresponding fields such as material sciences, robotics, (bio)medical engineering, politics, social sciences and many more. The future of DeSForM is about co-creating this community with scientific and technological advancement and sharing unprecedented scientific experiences.

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Section 2

Adaptation to Interactive Technologies - Sensible Care

Calm Technology for Biofeedback: Why and How?

Loe Feijs and Frank Delbressine

Additional information is available at the end of the chapter

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Abstract

We discuss several possibilities and fundamental difficulties when designing biofeedback systems based on calm technology. As a carrier for the discussion, we develop a novel biofeedback installation based on heart rate variability (HRV). The system is built-in to an elegant table and gives visual feedforward or feedback for relaxation based on breathing. When in feedforward mode, the system will show a sine wave of about 7 cycles per second, close to the well-known resonant breathing frequency. Alternatively, the amplitude of the movement can give feedback on the heart rate variability level, which is known to be directly associated with a reduced level of mental stress. The demonstrator has a pulse-plethysmography sensor which measures the beat-to-beat intervals of successive heart beats. The mechanical design of the actuator is designed to operate completely noiseless. Both the adaptive algorithm and the actuator are new to the best of our knowledge. Still new fundamental questions arise.

Keywords: biofeedback, breathing, active surface, data visualization, real-time, calm technology

1. Introduction

There are many relaxation techniques and meditation techniques in which breathing plays an important role. Burn-out and depression are contemporary conditions with high prevalence [1, 2] and there is an increasing evidence that certain types of breathing-based biofeedback are helpful to support therapies [3, 4]. Key notions in these feedback approaches are breathing and heart rate variability (HRV).

The term "calm technology" has been proposed by Weiser and Brown in their first essay in 1995 [5] and it has been very influential in the sense that ambitious research programs have been based on it such as the Ambient Intelligence program described by Aarts and Marzano [6]. As Weiser and Brown argue, "Information technology is more often the enemy of calm. Pagers, cellphones, newservices, the World-Wide-Web, email, TV, and radio bombard us frenetically". Despite the original enthusiasm for calm technology, we are still bombarded frenetically, by these media, and at the same time by a growing variety of new social media, geographic information systems and large public displays. One would expect that the application domain of biofeedback for relaxation would embrace calm technology but, with a few exceptions, that is not what happened. Instead, different developments can be observed: gamification of biofeedback and the rise of mindfulness as an alternative approach for coping with stress. But the topic of calm biofeedback technology is still studied in Stanford University's Calming Technology Lab [7] and at TU/e. Also, there exist several design proposals where the biofeedback is rendered more ambient, not in a handheld device or a smart phone. Examples are the ExoPranayama system by Moran and others [8] and the Living Surface by Yu in cooperation with Alissa and Nienke [9].

Traditional breathing techniques fall into two categories: (1) breathing in a prescribed rhythm and (2) observing one's own breath mindfully, without any restrictions. Pranayama yoga belongs to the first category, Anapanasati (mindfulness of breathing) to the second. Modern technology-based techniques can be categorized into two somewhat related categories: feed-forward systems and feedback systems. Paced breathing software such as EZ-air belongs to the first category, Stress-eraser and Cardio Sense Trainer to the second category. But there are differences between the modern technology-based techniques and the traditional-breathing techniques, based on a new understanding of our internal mechanisms connecting breathing, heart rate (HR) and stress. We mention the following insights [10].

- Heart rate variability (HRV) tends to go up under conditions of relaxation and it goes down under stress. The HRV signal is rich and complicated and can be analyzed in many ways, for example, distinguishing low- and high-frequency components. Visualizing HRV allows performing biofeedback training to reduce stress levels and supports reducing anxiety, burnout and depression.
- Breathing in, heart rate goes up, if we breathe out, heart rate goes down. The phenomenon is called respiratory sinus arrhythmia (RSA), and it allows to artificially increase heart rate variability. The effect is most strong at a particular frequency near 0.1 Hz which is called resonant breathing.

In this article we present and demonstrate a novel biofeedback installation based on heart rate variability. We discuss the design choices, some of the alternatives and some of the fundamental challenges we encountered. Both the information display and the model-based biofeedback software are new to the best of our knowledge. Whereas today's trend is to use the smart phone as the main platform for displaying information, we believe there is a need for a real calm technology, which keeps a distance from the overloaded screen, the multi-functionality and the busy social-media life that are associated with smart phones. Therefore we decided to try turning the biofeedback system into a minimalist modernist furniture element with a novel shape-changing interface as information display. To be in contact again with one's heart and indirectly with one's unconscious emotion regulation system is an important activity which deserves a special place and attention to the biofeedback training ritual. The biofeedback system is designed to support that. We aim at an information display which is a subtly shape-changing interface, which is completely flat at rest, having certain esthetic qualities of its own.

The idea of calmness is also essential to the design of the software implementing the translation from the sensor to the actuator. Existing feedback systems fall into various overlapping categories:

1. The system calculates a variety of plots such as frequency distributions, tachograms, numeric representations of heart rate and heart rate variability (which has many different ways of being quantified).
2. The system calculates a performance indicator related to heart rate variability (HRV) and uses that in an abstract or playful setting to motivate the user and try to raise HRV levels and do that during a longer period of time or more sessions.
3. The system presents a direct visualization of the beat-to-beat intervals, which is close to the raw data of the sensor, for example, a tachogram (a plot of successive beat-to-beat intervals).
4. The system highlights the differences between successive beat-to-beat intervals so the user has immediate and fast feedback.

The first category is a rich cocktail of 2–4. But it is certainly not adopted here because it is not calm. On the contrary, it adds to the information overload which is perhaps one of the causes of stress in the first place. The second category (labeled I, for integrating in our 2010 paper [11]) has great potential for being calm or playful, but the integrative nature of the calculation has the effect that the improvements are only apparent after a significant number of heart beats or even after several breaths. The delay between cause and effect is likely to hamper learning. The third and fourth interventions, called proportional (P) and differential (D) in [11], are more immediate, but they are another source of unrest themselves: as each heart beat appears, the pumping irregular rhythm of the heart is visible in a dominant way. Yu tested auditory variations of the fourth category [12] and found that they were difficult to understand and not optimal for relaxation. Of course it is possible to filter the tachogram, smoothing the plot so the individual beats do longer appear. Regretfully, the classical filter techniques unavoidably cause delays of at least several seconds (several beats). This is a fundamental difficulty which we set out to resolve in Section 4. We developed a novel filter which combines smoothing with predictive filtering. Sections 2 (usage scenario) and 3 (shape-changing information display) provide a context for the more technical work in Sections 4 and 5.

2. Usage scenario

The installation will be in the living room or private library of the user. Next to the dedicated table, which includes the shape-changing information display and the embedded software, there is a comfortable chair. When the user decides to do a relaxation session, she sits in the comfortable chair, attaches the sensor to one finger and relaxes. She watches the shape-changing information display, which is the top of the table, and observes the regular rhythm of the subtly moving surface. Alternatively she can put a hand on the top of the table and feel the moving surface. She breathes in the very same rhythm indicated by the moving surface. During the first 5 min, that is what she does. It is a relaxing experience. Then the system gradually and automatically moves into feedback mode. The user has to train in a goal-oriented fashion now. The goal is to maximize the amplitude of the movement of the surface. Larger amplitude means higher heart rate variability, which means higher level of relaxation. The system does not provide instructions explicitly, the goal to maximize amplitude is told to the user beforehand when she obtains or buys the system. After a total of 10 or 15 min, the session can be stopped, as the user wishes. The user feels more relaxed and is ready for other daily tasks. The user can do one or two relaxation sessions per day, according to personal preferences or needs.

3. Design of a shape-changing information display

The side table was designed by Sander Lucas and produced in studio LUCAS&LUCAS in Eindhoven. We had asked Lucas to re-use the design language of furniture for the Mind the Step exhibition, which was also designed by Lucas. *Mind the Step* is an annual design and technology exhibit which is part of the Dutch Design Week (DDW). We appreciate the modernist and minimalist form of this furniture. The table is made of wood, painted white, very compatible with the calm design aim. On top is the shape-changing interface: a surface which moves up and down, in accordance with the breath feedforward or feedback. The surface is made of polyoxymethylene (POM), which has high stiffness and low friction. We experimented with polymethylacrylate (PMA) too, but it is too brittle. The plate material is turned into a flexure by laser-cutting. The cut is a double-threaded spiral with a particular pattern with angles of (close to) 90° forming an interlocking tessellation. The basic tiles are connected by thin strips, which give rise to an extremely flexible surface. One sees not only the laser-cut spiral, but also, as a Gestalt, emerging spiral lines like in a pine cone or a pineapple (phyllotaxis). When the surface is flat, the latter spirals are apparent, the cut spiral is harder to see. When the surface deforms from flat to non-flat, the vertical cuts appear very clearly with a subtle and beautiful effect (**Figure 1**).

There is significant freedom in the design of the flexure. The spiral was considered a good solution for the shape-changing surface because it is a kind of labyrinth, the archetype of the journey to one's self. For the tessellation, we adopted a specific fashionable and intriguing pattern, mathematically explored by the first author in earlier studies published in Bridges. The spiral generator is written in Processing, and uses Oogway, a turtle-graphics library designed by Hu in 2013 [13]. Each spiral is written, starting at the inner loop, with the turtle spiraling outward. The outer demarcation line of one basic tile consist of 20 commands forward(s) in turtle graphics, 8 commands left (90) and 9 right ($90 + d\alpha$). So each right-turning angle has a slight deviation $d\alpha$ and the accumulated effect is that after T tiles there is a total deviation of $T \times 9 \times d\alpha$, which must be 360°. We arbitrarily chose $T = 21$, solving $d\alpha = 1.90476190°$. After each tile, the basic step-size s is increased by a factor 1.0148. So after each full turn, the tessellated tiles are a factor $(1.0148)^{21} = 1.3614$ larger than before. After nine full turns, the outermost tile is $(1.3614)^9 = 16$ times larger than the innermost tile (**Figure 2**).

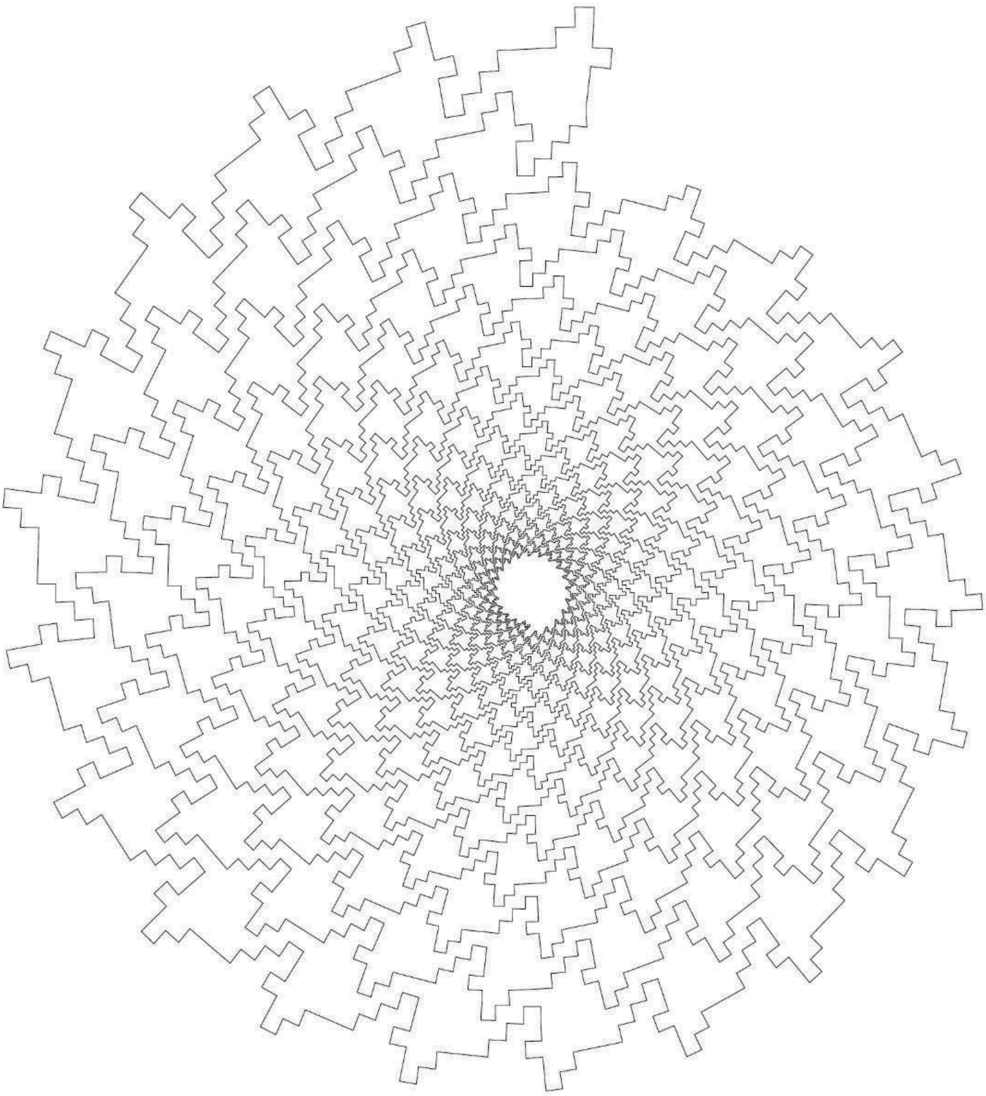

Figure 1. The double-threaded tessellated spiral used for laser-cutting.

We were surprised by the extreme flexibility of the spiral, first cut in a wooden version. Just holding it in our hands, we got the serendipity moment to see that such spiral would be a good solution for the design challenge of a shape-changing interface to be combined with the biofeedback algorithms already under development. We then optimized the design by choosing size, material and more technical elements such as a voice coil to obtain the visible effects for the biofeedback installation. We considered servo-motors but they are noisy and they wear out, so we rejected them and began exploring voice coils. The voice coil is precisely the same as the voice coils used in loudspeakers and a current of 0.5 A is enough to move 5 mm (free) or 3 mm (loaded with the spiral). Although it is very difficult to produce very low

Figure 2. The furniture of the biofeedback installation.

frequency soundwaves with voice coils, it is not hard to produce mechanical movement (the difficulty would be in transferring the movement to the free air). To drive the voice coil we developed a simple direct current (DC) amplifier with a LM324 op-amp and an MJE3055 transistor in emitter-follower configuration (traditional audio amplifiers will not work). During further explorations we found that the actuator does not serve well as a haptic actuator, yet the visible effect is precisely what we need. The connection between the voice coil and the spiral went through many rounds of exploration and testing. In the end we found the best solution to be that the spiral is supported by flat surface underneath and is pushed up by the voice coil at one or a few off-center points only. The effect is that the spiral lies completely flat when not in use but works as an information display during feedforward and feedback sessions. In the terminology of Skakoon [14] the surface is flat by force closure where the weight of the spirals acts as the nesting force (in the flat state). We found that the actuator works completely silently (no noticeable voice-coil sounds, no noticeable mechanical friction sounds).

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4. Design of the smoothing predictive filter

The main characteristic of the heart signal is that it consists of discrete events appearing at intervals which are slightly irregular. The heart beat events can be detected using a variety of techniques. The most reliable method is by peak detection in the electrocardiogram (ECG), which requires a fairly obtrusive sensor (something with electrodes). Each peak is called an R event (referring to the QRS complex discovered by Einthoven). We used a pulse-plethysmography (PPG) sensor, which works with a small clip on the finger or the ear. PPG is a reasonable compromise between ease of use and reliability. The sensor, amplifier, detection circuit and Arduino interrupt routine are described by Langereis [15]. Note that most smart watches and face color-based camera detector systems can deliver heart rate (HR), but are not yet able to detect each individual beat and hence cannot (yet) reliably calculate beat-to-beat intervals, which is essential for heart rate variability (HRV).

Now we describe why we aim at a novel filter which combines smoothing with predictive filtering. To clarify the fundamental challenge we refer to **Figure 3**. Consider a sequence of heart beats arising at times t(i − 5), t(i − 4), …, t(i − 1), t(i), where i is the index of the last beat detected (a). In a tachogram, the beat-to-beat intervals RR(k) = t(k) − t(k − 1) are plotted vertically against a horizontal time axis, which is a typical way to visualize heart rate variability on a screen (as in stress-eraser). For a shape-changing interface, we could translate them directly into a Voltage V(t) proportional to RR(i) and use that to drive the voice coil during the time interval t(i) < t < t(i + 1). But the heart beats appear as staircases in the tachogram and as jumps in V(t) and hence as jumps by the shape-changing interface (b). It is technically possible to get rid of the staircases by analog or digital filter techniques such as resistor-capacitor filters or finite impulse response (digital) filters, but the filters always introduce a delay. So an increase in RR interval appears in the filtered tachogram or on the voice-coil's Voltage only several beats after the increase happened (c). Even if we would interpolate the vertical plots linearly (d, first four lines), we would still not know what to plot or what Voltage to provide during the interval *after* the last beat, t(i) < t < t(i + 1)? But if we would have a prediction RR*(t + 1) for RR(t + 1),

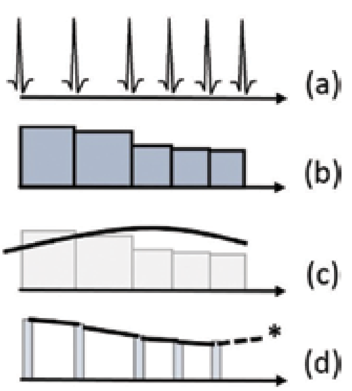

Figure 3. Heart beats appearing at irregular intervals (a), tachogram with intervals plotted vertically (b), RC-filtered signal (c) and continuous smooth interpolation with predication for last segment (d).

"looking into the future", we could plot a continuous line (d, including dashed line). Next we could explore all kinds of spline techniques or smoothing techniques to eliminate the staircases and triangular forms. Therefore we decided to develop an experimental predictive filter.

Predictive filters are used in areas such as motion detection of cameras or path prediction of airplanes (for military purposes, regretfully). The most used technique is Kalman filtering, which deploys a given dynamic model of the object's behavior (typically based on Newtonian or Lagrangian equations of motion). The time constants and Eigen-frequencies of the dynamic behavior are built-in to the model. In our case, we do not know the breathing frequency beforehand so we need a special model, not precisely Kalman. We work in a transformed RR space where we can estimate the momentary breathing rate, denoted as E(BR). The algorithm is remotely related to the minima and maxima-counting method of Schaefer and Kratky [16], who claim that it allows not only determining average values over the investigated time interval, but also to define an instantaneous respiratory rate. A Fourier transform is not very helpful because that would find a spectrum after many breaths only and cannot adapt quickly (and is not accurate either, as shown by McMullen et al. [17]). Further details of the special model are outside the scope of the present paper. We take the previous RR intervals RR(i), RR(i − 1), RR(i − 2), etc. as inputs, but using exponential weighing (so the very old values do not matter anymore). From RR(i) and RR*(i + 1) we can find plot values or Voltages for at least one (estimated) interval duration after the last detected beat. We explored Catmull Rom splines, based on the polynomial $V(\tau) = ½(-\tau + 2\tau^2 - \tau^3)RR(i-1) + ½(2 - 5\tau^2 + 3\tau^3)RR(i) + ½(\tau + 4\tau^2 - 3\tau^3) RR^*(i+1) + ½(-\tau^2 + \tau^3)RR^*(i+2)$ with $\tau = t - t(i)$ for $t > t(i)$, which has the advantage that the lines are continuous and their slopes are continuous too. Schaefer and Kratky [16] work with splines as well, yet not for $t > t(i)$. After multiple trial versions we decided for linear interpolation with jump smoothing of slope discontinuities, which we found to be more robust against outliers and poor predictions as shown in **Figure 4**. The filter is realized in software, first developed in Processing (for easy testing) and then ported to Arduino as an embedded system within the installation. The system has no buttons, remote control or data collection options, in accordance with the design goal to create calm technology. Plugged into the mains, it works.

There are several alternative options for extracting meaningful data from the sensor data. We could work with mixed linear models (good in case of missing data) or machine learning

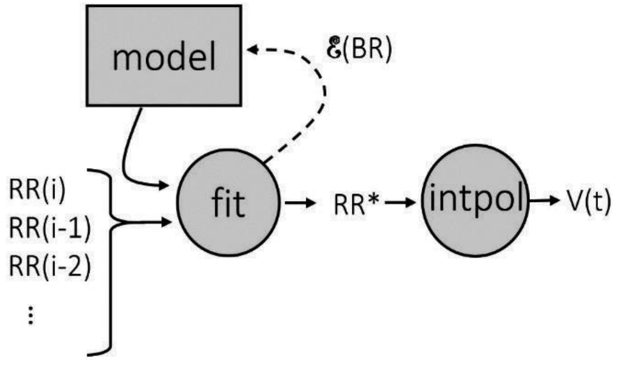

Figure 4. Overview of predictive and smoothing system.

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(taking advantage of large data sets). We should also mention that we see new technologies at the horizon for getting the heart beat or respiratory data even better, that is, less intrusively. Ballistocardiographic or face image-based methods (vascular mapping, blood perfusion modeling) could allow us to get rid of the PPG sensor.

5. Mechanical design of the actuator

The mechanical design of the actuator is designed to operate completely noiseless. Although specific users might like the sound of servo-motors [8], the requirement of calm design suggests that it is much better to keep the mechanism silent. A voice coil meets this requirement very well. Although this is the very same mechanism used in loudspeakers to generate high volume sound, a voice coil can operate silently at very low frequencies—as in this design. The basic idea of the mechanism is described in **Figure 5**. At present there are two driving pins, but it could be any other number. The force of gravity makes sure that the spiral flexure lays completely flat, except at certain positions where a driving pin pushes it upward. The force of gravity works as a nesting force [14], yet when the driving pin is low, the spiral flexure cannot sink into the (circular) holes.

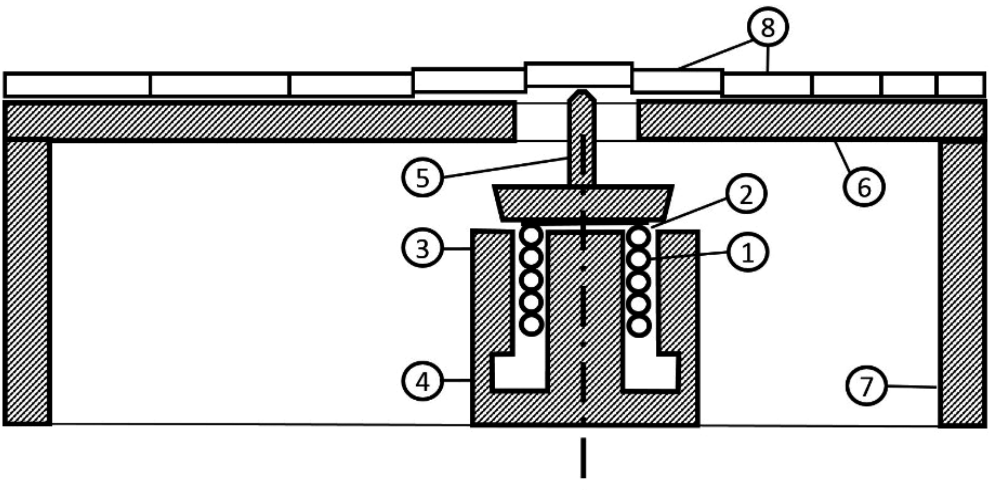

Figure 5. Mechanical design of the actuator (1: moving voice coil, 2: air gap, 3: magnet, 4: steel flux return, 5: driving pin, 6: horizontal support plate with holes, 7: support structure, 8: spiral flexure).

6. Conclusions and outlook

The system can work both in feedforward mode and in feedback mode. When in feedforward mode, the system will show a sine wave of about 7 cycles per second, close to the well-known resonant breathing frequency [10]. This is an easy way for the user to get started. Then after

5 min, the system gradually goes into feedback mode. When the deep and regular breathing continues, the system will respond with movements which are of the same frequency and approximate phase as the user's breathing. In this state, the distinction between feedback and feedforward has disappeared (with respect to frequency). User and system are synchronized. The amplitude of the actuator's movement still provides feedback on HRV amplitude.

As a limitation we mention that the present set-up is not yet comfortable enough for sessions longer than 10 or 20 min. However, for relaxation that should be enough (typical audio tapes of progressive muscle relaxation are also not longer than 10 min).

The design goal of creating calm technology has been met in several ways. We found that for the form-giving, and the display the aim of "calm" can be implemented satisfactorily: the chosen hounds-tooth labyrinth is just one of many possibilities for the flexure pattern; the voice coil works silently. The PPG sensor is not very comfortable, but we leave it for now (in a few years, camera-based pulse detection technology could be available). The interaction by breathing works well in feedforward mode and also in feedback mode when breathing is regular indeed. Still there is a lot of work to be done as we found that irregular breathing breaks the synchronization, and we are still exploring options to provide useful feedback in such conditions. We also found an open question regarding HRV: how to interpret the HRV components which are *not* caused by RSA? If breathing is shallow and other, non-breath HRV components dominate, the combined smoothing and predictive filtering algorithm does not work well. In a different setting McMullen et al. [17] discuss how RSA peak frequency and breathing frequency do not coincide. We do not know what precisely causes the non-breathing-related HRV component? Does it allow one-beat ahead prediction? How does it correlate to thoughts or absence thereof? There is literature on the various sources of vagal cardiac control, but so far we got lost in literature, which is either on vagal control brain nuclei studied in rats, or on statistical long-term HRV parameters—which are not helpful for short-term prediction. We leave the matter as an (extremely interesting) option for future research.

Finally let us mention how to conduct experiments for fine-tuning the feedforward and feedback subsystems. The formal evaluation of the feedforward could be done along the lines of Yu's research who has been testing soundscapes and their effect on subjective and objective relaxation [18]: for subjective relaxation there exist instruments such as the Relaxation Rating Scale (RSS). An alternative is the State-Trait Anxiety Inventory (STAI). These can be combined with open interviews. Objective relaxation can be assessed using HRV. For testing the feedback subsystem it would make sense to benchmark the breathing extraction algorithm against other ways of deriving the respiratory influences on the HRV, for example, using so-called Orthogonal Subspace Projection (OSP) [19]. We leave these as options for future research.

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Toward the Development of a Monitoring and Feedback System for Predicting Poor Adjustment to Grief

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Additional information is available at the end of the chapter

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Abstract

Losing a loved one is a fundamental and ubiquitous life experience that is often characterized by a certain period of grief and emotional distress. Although the majority of the bereaved can cope with grief resiliently, around 1 of 10 individuals could experience an unusually protracted and intense response referred to as prolonged grief disorder (PGD) following death of a loved one. PGD is associated with work and social impairment and heightened risk of severe medical and psychological conditions. Current means of diagnosis requires a minimum of 6 months to confirm and identify PGD and is discrepant with the fact that the bereaved may need psychotherapeutic intervention in a more timely manner. Contemporary studies have outlined prospective risk factors that could cause poor bereavement outcome, which can potentially contribute to early identification and prevention of problematic response to grief. Self-monitoring applications have been developed and broadly implemented in a vast spectrum of mental and health-related interventions and self-managing processes. This study presents the conceptualization and development of an Internet-based screening method designed by the researchers and psychotherapists that aims to provide meaningful and quantitative feedback in the early phase of the grief and to support decision making in the bereavement process through monitoring the susceptibility to problematic grief outcome.

Keywords: bereavement, prolonged grief disorder, self-monitoring system, Internet-based bereavement support

1. Introduction

Self-management is often considered one of the critical factors that contribute to promoting a better medical or mental health care outcome [1–8]. Applications specifically designed for this purpose are widely implemented in a spectrum of medical and psychological conditions ranging from self-exam of blood pressure and heart rate through screening methods to identify depressive symptoms or assess the level of posttraumatic stress. Users of self-managing applications are not only more informed about their health-related conditions but also more empowered to act as an active role in the health care processes [9, 10]. In 2015, the Wall Street Journal pointed out the frequent implementation and the explicit benefits of self-managing applications in certain medical practices such as cardiovascular rehabilitation program and cancer pain management [11]. The advantage of utilizing self-managing applications in the medical and psychological care procedures is that these applications are more accessible and integrated to users' everyday life experiences. They are often characterized by low cost, connectivity, anonymity, nonstop availability, and opportunities for a self-paced health care approach. For health care service providers, the versatile data gathered or reported from the applications facilitate better monitoring of the users' health-related behaviors and are informative to further studies of the health conditions when compared and analyzed with data from a large group of users.

In the context of bereavement, studies as early as in 2004 have demonstrated that more than half of the bereaved used online bereavement support, and such resources yield potential in preventing and protecting the bereaved from further mental disorders [12–14]. However, as Krysinska and Andriessen warned in one of their papers, most of the websites created by professional bereavement organizations are not immediately available or credited from the search, rendering the quality of online bereavement support and the authenticity of information under question [15].

Accordingly, this article takes a focus on designing a self-management application in bereavement-related contexts and presents the conceptualization and development procedures of it. We start by introducing the context of usage, followed by the process of conceptualizing two approaches to attend the needs in bereavement context. These two approaches were further prototyped into two applications, and one of which was selected for further development and evaluation. In the end, this paper reports a preliminary evaluation of the selected application and elaborates its potential to serve as both a data collection instrument in the future studies and a self-monitoring system for the bereavement process.

2. Context of usage-bereavement

Bereavement refers to an individual's adaptive process following the loss of a loved one through death. The process is characterized by a variety of emotional responses (e.g., grief and distress) and cognitive crisis (e.g., meaning reconstruction), as well as heightened risk of syndromal medical conditioning and social and occupational impairment. It is also a fundamental and life-changing event that almost everyone will encounter in his or her lifetime. The prevalence and ubiquity of loss and grief are reflected in studies showing that most individuals will have experienced at least one loss by early adulthood (e.g., 60% have lost a friend; 81% have lost an extended family member; Herberman et al., 2013). Losing a loved one through death is frequently reported as one of the most stressful life events and was formally rated as the most stressful event in the Holmes and Rahe Stress Scale.

Looking from the other side of bereavement, it is a natural mechanism that helps individuals to gradually come to terms with the potentially overwhelming loss and to continue living a productive life in which the deceased is recognized in a different form of existence. The majority of bereaved coped with grief resiliently, and some of them even adopted so well that they further experienced enhanced meaning and spirituality post loss. However, a noteworthy percentage of bereaved, around 1 of 10 bereaved individuals, could experience a protracted and intense response to their grief referred to as prolonged grief disorder (PGD) [16].

Individuals who suffer from PGD often feel "stuck" in the process of bereavement and find it hard to accommodate to a different lifestyle or the world without the deceased. PGD can severely hamper an individual's psychological well-being, as well as the social functioning and physical health. In the extreme situation, individuals could experience strong suicidal tendency. For the individuals who suffer from PGD, psychotherapeutic intervention is mostly needed to support their adaptation and acceptance of the loss. On the other hand, performing grief counseling and therapy to normal grievers could yield deleterious effect and even disturb the natural bereavement procedure.

Since offering grief counseling to normal grievers is unwarranted, a screening method that helps to determine who will benefit from the psychotherapeutic intervention is of the primary importance. Psychologists have outlined the importance and pressing need of a trustworthy screening method, whereas the current PGD diagnosis instruments require a minimum 6 months to identify the PGD symptoms. The amount of time required to issue a PGD diagnosis and to allow psychotherapists' active involvement is discrepant with the fact that individuals who suffer from intense grief or suicidality may need psychotherapeutic intervention in a more timely manner.

The inability to identify potential PGD grievers in an earlier phase could also posit a negative implication on the development of preventive intervention and enhance the difficulty of attending the disorder after 6 months have elapsed. It could potentially explain why studies related to preventing PGD remained scarce and the effect far from warranted.

3. Two approaches to predict PGD symptoms in early phase

Assessing symptomatology and attending to the needs of grievers with severe emotional distress as quickly as possible is imperative. Various approaches were explored by previous bereavement-related studies to identify problematic self-evaluations and potentially traumatic characteristics that contribute to predicting poor adjustment outcomes to bereavement. These approaches can be briefly categorized into two groups.

The first group stems from the problematic narratives and coping strategies can potentially be detected through linguistic cues or behaviors post loss [17–20]. Examples of the first approach include negative self-evaluation such as thinking that the self is less worthy without the deceased and problematic coping strategies such as repetitive rumination of the deceased. The second group evaluates the traumatic loss circumstances and psychological states that can make the bereaved vulnerable to poor adaptation, all of which are often static at the time of loss and are harder to change [21–29]. Examples of the second approach range from traumatic death, lacking social support to the strong dependency on the deceased and an insecure attachment style.

Both approaches are informative for follow-up development of screening methods that could support grievers and psychotherapists to monitor the bereaved's susceptibility to PGD and to target the appropriate interventions in a more timely manner. A primary concern is that these methods remain in a highly theoretical and explorative phase and are in demand of empirical validation. In this regard, the applications developed should also serve as a means of evaluating and validating the proposed screening approaches. With this concept in mind, we propose two Internet-based applications that seek to empower the bereaved by providing meaningful feedback to the aspects related to their grief experiences and, on the other hand, collect useful data that contribute to further validation of the screening methods.

4. Method

4.1. The design and conceptualization of two prototypes of PGD screening methods

Two prototypes were developed using different approaches. The first prototype, My Grief Journal, was a technology-driven concept based on the available technological solutions and studying the related bereavement literature. The second prototype, Grief Inquiry Following Trauma, was developed with field experts and psychotherapists. The overall aim of both applications is to empower the users to gain knowledge and control of their bereavement-related decisions. To achieve this goal, the research team defined the following concepts that should be achieved by both prototypes:

- Target users: individuals who have experienced death of a loved one and would be interested in searching for support on the Internet, especially individuals who have experienced the loss very recently or less than 6 months ago.
- Deliverables: an Internet-based Product Service System (PSS) that provides meaningful, objective, trustworthy, and quantitative feedback of the various bereavement-related aspects.
- Portal: the application should be affordable, easy-to-use, and widely accessible through the computer and mobile devices.
- The system must collect only bereavement-related data from the users and generate personalized feedback based on the data collected.
- The feedback provided to the users must contain both positive and negative aspects of their grief situation and must come from the authentic sources.

- The prototypes should attempt to integrate and utilize the existing and validated measures as a starting point but should remain flexible for developing and validating new measures.

4.2. External experts from the psychological field

Although the purpose of this project was not to develop an intervention of PCBD, due to the sensitive nature of loss and grief study, the team included one researcher specified on bereavement and post-loss meaning reconstruction and one psychotherapist specified on grief counseling. The external experts brought contribution to the design and phrasing of questions that were used in assessing the grievers' grief experiences and provided further opinions from psychological field on the ethics and design of the study. The author, as a lead investigator of this study, first proposed two prototype concepts based on previous literature review for evaluation within the team, and the final decision was made based on the practicality of the concept and the available technology that could facilitate the prototyping of the app.

Based on the suggestion of the IRB, to pilot test the app and gain users feedback from the concept, the team had recruited a certified thanatologist and grief counselor to facilitate the session. It was meant to avoid bias in interviewing the users and to maintain anonymity of the study. An interview protocol was drafted by the researcher and the psychotherapist to ensure the questions would not provoke excessive/harmful emotional responses. The interview was conducted in English, and all of the users were native English speakers.

4.3. My Grief Journal

The concept of My Grief Journal was inspired by studies concerning the self-narratives in the bereavement process and the meaning reconstruction theory. Narrative variables can be effective predictors of psychological health during bereavement and even of the outcome of coping with bereavement. Counting the relevant words in the written text was considered an effective approach to measuring the cognitive changes and emotional expression in the bereavement context. Many suggested endorsed that verbal materials carry more additional information about psychological phenomena and symptoms, which are often less detectable from self-report [19, 30]. For instance, consider the following two examples, "it's so hard to say good bye" and "I am lucky to have somebody that makes saying goodbye so hard." Both sentences included a negative statement but were framed in a different manner and hence reflected different appraisal to an event.

The researchers tested various available types of software and APIs to perform the keywords extraction and analysis and determine the positive emotions and negative emotions in the narratives. We used a narrative that described feelings in an indirect manner. For instance, "I am feeling terribly good today," or "…determined to enjoy her luxury of grief uncomforted." It was easy for human to understand but hard for programs to determine whether the sentence really described a positive perception or a negative one. The most precise software appeared to be Linguistic Inquiry and Word Count (LIWC). However, it was not available in command line interface (CLI) and the EULA prevented users from implementing it in a customized application. Other alternatives tested were NLTK in python, Afinn, and AlchemyAPI. In the end, IBM Alchemy API was implemented to extract meta-data such as concepts, entities, keywords, categories, sentiment, emotion, relations, and semantic roles. Unfortunately, there was no corpus specifically trained for bereavement-related sentences or articles. Therefore, it could not be as precise as the corpus for movie reviews, tweets, or advertisement.

My Grief Journal was developed to store users' short articles (e.g., diaries) and analyze the sentiment of the article. The analysis will yield two types of results, providing a visualized feedback of the frequency of the emotional keywords detected in the article and determining the positive or negative valence of the keyword and its relationship to five types of emotions (anger, disgust, fear, joy and sadness). **Figures 1** and **2** showed the sample page and report of My Grief Journal. Unfortunately so far, there was no available corpus specifically trained for bereavement-related sentences or articles. Therefore, it could not be as precise as the corpus for movie reviews, tweets, or advertisement, which was an obvious drawback that obstructs the researchers from testing it with grievers. Only the developers and the research team members tested it. Developing My Grief Journal should include training the corpus with plenty of bereavement-related articles or sentences in order to determine how to precisely analyze the sentiment in the users' writing.

4.4. Grief Inquiry Following Trauma (GIFT)

The concept of GIFT stemmed from psychological studies related to prospective risk factors that could render grievers more vulnerable to PGD, such as low social support, low income, or traumatic death circumstances. A framework of risk factors was created based on literature review (see **Table 1**).

Figure 1. The entry page of My Grief Journal.

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Figure 2. The demo visualization of keywords and the valence of the keywords.

All of the risk factors were reviewed by the researcher and the external experts [21, 24]. Two measurement tools were designed together by the researcher and the external experts in order to measure the risk factors. The team has further included another to-be-validated scale for identifying risk factors related to bereavement and loss circumstances. These three questionnaires were grouped into the major section, Basic Information. Basic Information consisted of questionnaires related to the participant's demographic characteristics and proposed predictors of bereavement distress (**Table 1**; scales #1–3). Six validated questionnaires were selected to provide feedback on bereavement-related perspectives. They measured respectively grief degree (PG-13), depression (CESD-R), post-traumatic stress disorder (PCL), resilience (CD-RISC-10), meaning making (ISLES-SF), post-traumatic growth (PTGI). These six questionnaires belonged to the secondary section named Monitor My Grief. **Table 2** displayed a list of scales included in the application. The validated scales administered were, if not openly available, all requested or purchased from the respective researchers and consent acquired to use in the app.

The feedback that addressed the participants' result after taking the questionnaire was drafted for the six validated questionnaires in the Monitor My Grief section. Users who successfully completed the questionnaire will be presented a personalized feedback according to the score of each validated questionnaire. It was meant to adhere to the purpose of design of GIFT and to lessen participants' stress after taking the emotionally disruptive questionnaires.

Risk factors	Primary or potential risk factor	Details
Social support level	Primary	Lacking social support is a salient risk factor that is highly related to problematic grief
Discovering the body	Primary	Discovering the body or viewing the death scene (especially with traumatic nature) is a salient risk factor for PGD
Satisfaction with the death notification	Primary	Dissatisfaction with death notification
Pre-death dependency	Primary	High levels of pre-death marital dependency
Attachment style	Primary	Avoidant/anxious/insecure attachment style
Close kinship	Primary	Being a spouse or a parent of the deceased
Gender	Potential	Female grievers are more susceptible to PGD than male grievers
Ethnicity	Potential	Being non-Caucasian is regarded as a risk factor for PGD
Educational level	Potential	Low education is connected to having more severe grief
Income level	Potential	Insufficient income
Type of loss	Potential	Losing a child of any age to a violent sudden death
Anticipation of grief	Potential	Death is unexpected
Prior losses	Potential	Prior losses

Table 1. Risk factors suggested in the review papers.

Scale set	Scale name	To assess
Basic information (including loss-related characteristics)	1. Background information	Demographic data, such as age, gender, ethnicity, religious affiliation
	2. Complicated grief risk factors checklist (CGRF)	Proposed predictors of bereavement distress
	3. Bereavement Risk Inventory and Screening Questionnaire (for the bereaved; BRISQ-B)	Risk factors of Prolonged Grief
Monitor My Grief	4. PG-13	Grief severity
	5. PCL	Posttraumatic stress
	6. CESD-R	Depression
	7. CD-RISC-10	Resilience
	8. ISLES-SF	Meaning made of loss
	9. PTGI	Posttraumatic growth

Scales #1–3 assess bereavement-related risk factors. Scales #4–9 have been empirically validated and are widely used in bereavement research.

Table 2. Assessment instruments.

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Personalize the questionnaire with the name of the deceased. An important feature for GIFT was that all of the questions were personalized with the name and gender of the deceased (replace "the deceased" or "the person I lost" into the name of the deceased) to engage the users.

Slider selection for Likert scale questions. Most of the Likert scale options were displayed in a horizontal slider to enhance the linear relationship of the options (see **Figure 6** for an example). The handle will change color after an answer has been indicated (see **Figure 7** for an example). When users access GIFT on a mobile, we choose to keep the two items in the left and right of a Likert scale question but allow users to review the default value after hovering or clicking on the pip on the slider (see **Figure 8**).

Add the option "not applicable" to the risk factor questionnaires. For scale #2 and scale #3, users were provided "not applicable" on the right of all of the questions. This was to allow them to better express themselves when the presented risk circumstances appeared not applicable to them and the options failed to help them to convey it (see **Figure 9**).

According to the IRB suggestion, the website was certified by SSL protocol protection, and all of the data collected in GIFT were coded and encrypted in order to ensure the security of the data.

4.4.1. Preliminary evaluation of GIFT

The research team evaluated both applications regarding the opportunities to yield trustworthy and quantifiable predictions in the earliest phase of bereavement. In comparison to My Grief Journal, which required a period of contemplation and was less precise in determining the positive and negative thinking style, GIFT exhibited better potential to offer users meaningful and objective feedback based on evaluating the factors that are relatively static and foreseeable even before the loss (**Figures 3** and **4**).

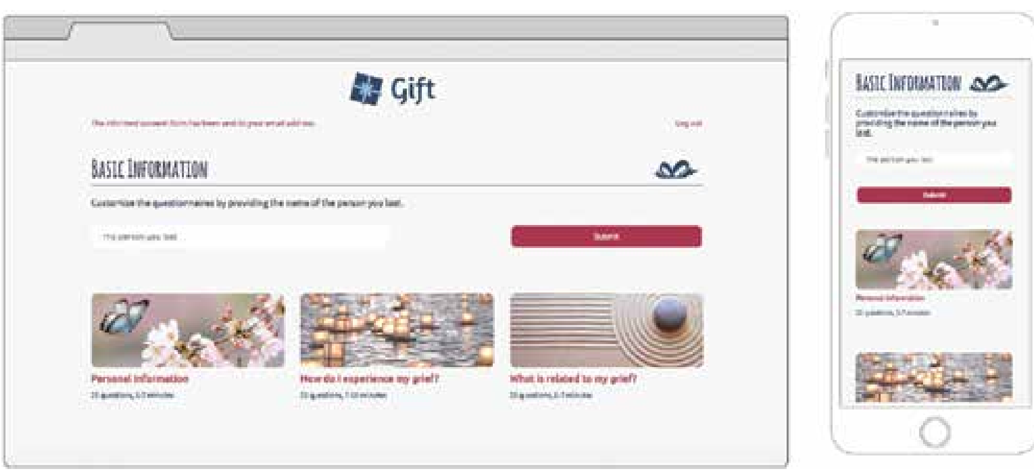

Figure 3. GIFT entry page.

Figure 4. GIFT slider scale.

Figure 5. Gift personalized report.

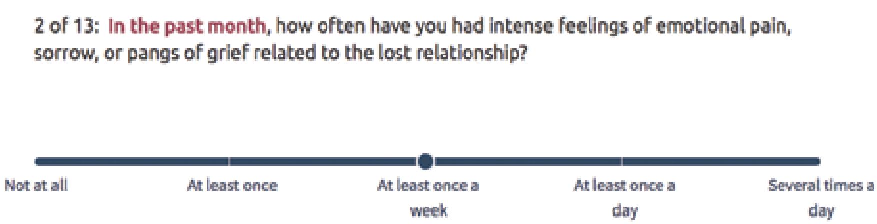

Figure 6. A slider for Likert scale answer.

In the end, GIFT was selected for further development and implementation to validate the proposed risk factors with a larger base of participants. To gauge the applicability of the app in the real life situation and optimize the user experiences of using it, five sessions of protocol analysis were conducted in the United States with the patients of one of the collaborative psychotherapists. The approval to conduct the study with the bereaved patients and to deploy the application through the Internet was sought in the respective Institutional Review Boards from both United States and the Netherlands, in which the former is where the study will be conducted and the latter is where the app was conceptualized and developed (**Figures 5–9**).

In the protocol analysis session, participants were prompted to "think out loud" on an individual basis as they completed the questionnaires by a certified thanatologist, who is also a graduating counseling student. After completion of the scales, participants were interviewed with questions regarding their general experiences of using GIFT, the wordings of the application as well as of the personalized feedback they received after completing the scales from the second section (Monitor My Grief). The protocol analysis sessions were all audio recorded and completely transcribed. Each session was approximately 1.5 hour long, generating approximately 7.5 hours of recording from the interview and the notes from the interviewer.

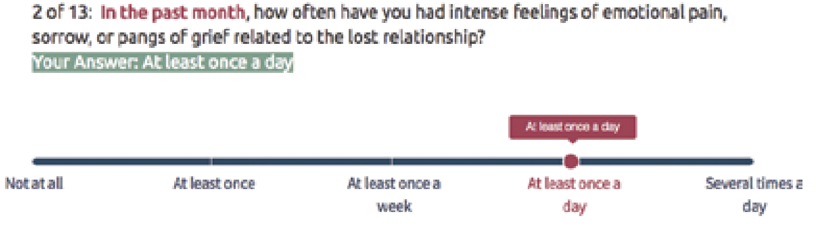

Figure 7. Slider response after an answer is indicated.

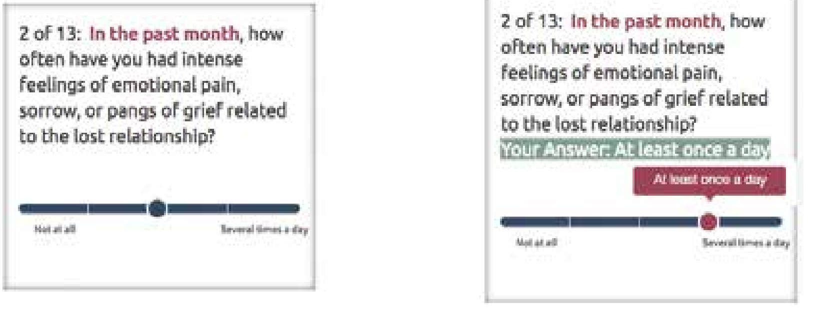

Figure 8. The responsive slider on a mobile device.

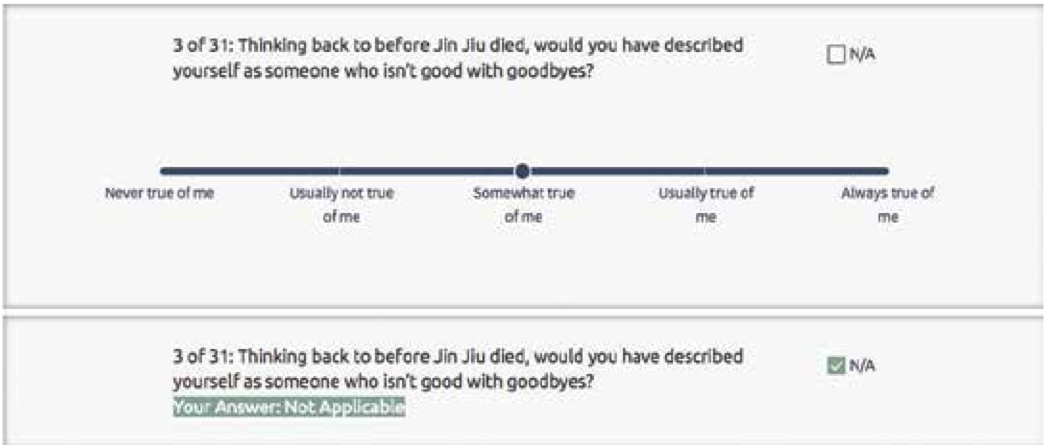

Figure 9. When user selects "N/A," it means that the statement could not apply to his/her situation.

5. Result

The protocol analysis sessions for GIFT pilot testing were all audio recorded and completely transcribed. Each session was approximately 1.5 hour long, generating approximately 7.5 hours of recording from the interview and the notes from the interviewer. All of the participants were from the United States. There were total five participants, including one male and four female grievers. Their socio-demographic data are displayed in **Table 3**. Almost all of the participants bereaved about the loss of a family member. Of the total, 80% have received formal education for more than 13 years and had their religion. Participants who considered religion important practiced religious activity more frequently. Except PA3, who experienced death of a loved one around 6 months ago, the other participants generally experienced death of a loved one for more than 6 months to receive psychotherapeutic support. Two of our participants experienced unnatural death of a loved one such as suicide or fatal accident, and 60% of our participants were in contact with the deceased almost daily before the death happened.

Participant	**PA1**	**PA2**	**PA3**	**PA4**	**PA5**
Gender of the participant	Female	Female	Female	Male	Female
Gender of the deceased	Male	Male	Male	Male	Female
Age of the participant	70	39	32	61	31
Age of the deceased	70	26	40	87	95
Relation to the deceased	Spouse	Sister	Partner/ fiancé	Son	Granddaughter
Marital status	Widowed	Married or living together in a committed relationship	Single	Married or living together in a committed relationship	Single

Participant	PA1	PA2	PA3	PA4	PA5
Years of formal education	17–20 years	0–8 years	13–14 years	17–20 years	15–16 years
Faith tradition (religious belief)	Christianity	Christianity	Atheism	Christianity	Buddhism
Regularity of religious activities	Daily	At least once per week	Never	At least twice per week	At least twice per year
Importance of faith	Extremely important	Extremely important	Not very important	Very important	Somewhat important
Prior experiences of death of loved ones in the past 3 years	3	0	0	1	2
Time since the loved one died	1 year and 4 months	1 year and 9 months	6 months	1 year and 4 months	11 months
Type of death	Natural anticipated death	Fatal accident	Suicide	Natural sudden death	Natural sudden death
For how long did the participant know the deceased	46 years	26 years	3 years	60 years	31 years
The frequency of contact before death	2–7 times per week	2–7 times per week	2–7 times per week	Every other week	Less often than once per month

Table 3. The socio-demographic data of the protocol analysis participants.

6. Discussion

The preliminary test of GIFT yielded fruitful data for future optimization. Since the three questionnaires from the background information were still under development, and the details of wordings and content refinement would not be of interest to the readers of this article, this discussion concentrated on the general experiences of using the app and participants' feedback on the applicability of this app in their bereavement process.

6.1. Participants' experiences of searching for support on the Internet

All of the participants were under bereavement intervention by professional therapist and trusted that they need professional counseling. We were particularly interested in participants' support seeking on the Internet, since this app was developed as an Internet-based app. Three out of five participants reported having searched for information related to bereavement or grief support on the Internet. One participant did not answer, and one indicated that she had never thought of searching for support on the Internet. The information on the Internet helped them to gauge their grief level or target the therapies that were available/ appropriate for them. One participant specifically stated that reading other people's stories about surviving traumatic loss was helpful. Another participant indicated that grief is too personal and looking for support on the Internet did not feel safe.

In general, Internet sites, blogs, and forums were resources that participants could turn to when they needed immediate answer to their questions or information related to grief counseling or coping strategies. However, it was still obvious that participants were mostly prone to find a therapists or "somebody" who knows grief to support them, implying that bereavement-related services or information on the Internet, disregarding the quality of it, could face the difficulty to gain trust from the users. It could also be because most of our participants knew that they needed psychotherapeutic support at the first hand and only used the Internet to help them gain access to the services.

6.2. Participants' general experiences of using GIFT

Most of the participants were satisfied with GIFT and found the feedback relevant, authentic, and reflective to their real situation and trustworthy. Some positive feedback pieces were as follows:

- GIFT was a tool for thinking and widens awareness of the bereavement-related aspects.
- GIFT was a tool that enhance self-referring from grievers who obviously need grief counseling
- Personalizing the questionnaires with the name of the deceased was really immersive, love it.
- The process of using GIFT was therapeutic.
- The feedback was trustworthy and reassuring.
- The questionnaire results were similar to what the participant thought about herself, but it was more validating.

Some negative feedback pieces and suggestions were also reported:

- The session took too long to complete, and the data should be saved step by step.
- The feedback only presented shallow and "canned" responses to the questionnaires result.
- It should connect to useful resources in the end of the feedback (e.g., books, grief counselors).
- The fifth participant encountered enormous technical difficulties because of older version of hardware.
- Participants should be "guided" through the process instead of choosing what questionnaires they should do next. The navigation had to be more clear and straightforward.
- The application should allow participants to share the results with others (e.g., sending the report to their family or friends).

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- The slider scale required some time to get used to, but participants grew accustomed to it after several questions.
- The instructions of the questionnaires needed to be highlighted and emphasized so participants would not oversee them.

6.3. The evaluation of the performance of the app

Based on the participants' feedback, there were several points to take into consideration for next stage app refinement.

The problem of various usage platform: GIFT was a Web application, and we tested it with different devices such as computer, tablet, and mobile phone. One participant was using an iPhone 5S, and the questions and answers were completely overlapped. The problem could be caused by the older version of browser that did not support libraries such as jQuery. Designers usually need to take into consideration of how much the application was backward compatible and make a clear suggestion to the users.

The difference between mobile navigation and large screen navigation: on the larger screen, the questionnaire were separated into two groups and placed horizontally within each group. This design generated confusion for the participants who used tablet or laptop. One the mobile devices, the blocks were naturally sorted from top to bottom and participants who used mobile devices did not have problems related to navigation.

The app should add a function to share the report with other people.

Format of date: In the U.S., it would make more sense if the date was formatted as "month/day/year." In this question, we provided a date picker powered by jQuery. However, it should be noted that the date format had to accustom to the familiar format of the participants.

There should be a save button where participants can review the in-progress questionnaires. This feature was added later on.

The environment of using this app should be suggested in the welcoming message. One participant mentioned that she would not be able to complete the questionnaires at home with her kids, suggesting that participant would appreciate a certain period of engagement in the app.

The app will welcome the users with a note of how long they could expect to complete the app in one session. In the introduction of each questionnaire, we should also indicate a time range of how long users usually take to complete the questionnaire.

Keywords such as "in the past month" in some questionnaires should be enlarged/bold and highlighted with visible colors. Some of the questionnaires such as PTSD or CESD-R were designed specifically to inquire the participants' experiences in the past months or past weeks. These keywords should be stressed since without emphasizing these conditions, the whole questionnaire could not precisely measure the participants' experiences.

The sliders in the questionnaires were nice, but there should be instructions of how to operate the sliders and the default option needed to be considered with caution. Some of the questionnaires were designed with Likert scale responses. Since the items in a Likert scale usually had a linear relationship between each other, it was a conscious choice of the research team to use a horizontal slider that allowed users to slide between each "pip" on the bar. However, researchers need to be very cautious in choosing where to place the default option or not to place it. In the study, the default option was placed in the 3rd Likert scale item. For instance from "Strongly disagree" to "Strongly agree," the default option was placed in the middle "Neither agree nor disagree." However, when the participants had the same answer with the default value, they simply skipped this question and realized that they needed to click or slide on the slider when trying to submit the questionnaire. It is important to provide certain instruction at the beginning that informs users how to interact with the slider

It should be explicit that the question has been answered, and the participants should be able to review their answers.

7. Conclusion

Disregarding the obvious need to enhance the navigation and user experiences of the application, from the preliminary test, we could conclude that GIFT exhibits a good potential to be implemented in the early phase of bereavement and could empower the bereaved to be more attentive and autonomous to their grief response. Alone with the design of the application, a study was also planned to test GIFT with a larger base of participants and collect data that could be informative to validate the risk factors of PGD empirically. Modern technologies are more and more interwoven into our everyday life experiences. Grief was, and maybe still is, a highly private experience, but contemporary researchers have notified a growing phenomenon of bereaved individuals seeking social support and sharing their grief experiences or emotions on the Internet. Furthermore, the Internet likely also serves as a medium of communicating and connecting with the deceased. Examples are frequent addressing the deceased in a post on social media or talking to the deceased in a public forum. The effect of these phenomena remains unknown in both an intra- and interpersonal level but is by far worth heeding. More studies are being planned and will be presented elsewhere. We hope more results from the future studies can contribute to informing the field and professional practitioners how to better support the bereaved and facilitate positive health outcomes following the coping process of the bereavement.

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The Design Process and Usability Assessment of an Exergame System to Facilitate Strength for Task Training for Lower Limb Stroke Rehabilitation

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Additional information is available at the end of the chapter

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Abstract

Successful stroke rehabilitation relies on early, long-term, repetitive and intensive treatment, which is rarely adhered to by patients. Exergames can increase patients' engagement with their therapy. Marketed exergaming systems for lower limb rehabilitation are hard to find and, none yet, facilitate Strength for Task Training (STT), a novel physiotherapeutic method for stroke rehabilitation. STT involves performing brief but intensive strength training (priming) prior to task-specific training to promote neural plasticity and maximize the gains in locomotor ability. This research investigates how the design of an exergame system (game and game controller) for lower limb stroke rehabilitation can facilitate unsupervised STT and therefore allow stroke patients to care for their own health. The findings suggest that specific elements of STT can be incorporated in an exergame system. Barriers to use can be reduced through considering the diverse physiological and cognitive abilities of patients and aesthetic consideration can help create a meaningful system than promotes its use in the home. The semantics of form and movement play an essential role for stroke patients to be able to carry out their exercises.

Keywords: engagement, rehabilitation, stroke, exergame, game controller, serious games, strength for task training

1. Background

With over 15 million cases worldwide every year [1], strokes are a leading cause of serious long-term disability [2, 3]. Up to 75% of people affected by stroke have lower limb mobility limitations [3, 4], including hemiplegia (muscle paralysis) or hemiparesis (muscle weakness) down one side of the body [5]. The World Health Organization (WHO) has highlighted the need for home health care that calls for rehabilitative devices, self-monitoring tools and self-management skills [6].

Success for stroke rehabilitation relies on early, intensive, long term repetitive treatment to regain motor control [5, 7] by learning to use existing redundant neural pathways [8]. However, although abundantly prescribed by clinicians, as little as 31% of patients perform these exercises correctly and consistently, often due to their monotonous nature [9].

Recent studies show that systems of rehabilitative devices with incorporated digital games for exercising (exergames) improve patient engagement with their home-based therapies. This has promoted beneficial patient outcomes for different long-term conditions, including upper limb stroke rehabilitation [5, 10, 11], and more effective recovery [12]. While there exist systems designed for upper-limb stroke rehabilitation [5, 13, 14] and for improving gait and balance [15–17], only one was found targeted specifically towards lower limb stroke rehabilitation [18].

1.1. Strength for task training

Strength for task training (STT) is a novel and promising approach to lower limb stroke rehabilitation [19]. STT combines priming the brain for learning through strength-based exercises, with task-specific movements promoting neural plasticity. Neural plasticity finds new pathways or rebuilds obsolete ones in the brain. These pathways establish the connection between the brain and subsequent muscle movement. Relearning these movements helps the patient attain better locomotion [19]. Priming involves the strengthening of the muscles using a weight or a resistance band while getting the patient to exert themselves as much as possible. This exertion creates corticomotor excitability. This primes the neural pathways in the brain so when followed promptly with task-specific training the brain is better equipped to promote neural plasticity [19].

While there are many systems of exergames for stroke rehabilitation, there currently exists an opportunity for the development of an exergame system that facilitates unsupervised STT for home-based lower limb rehabilitation. As an adjunct to clinical rehabilitation, this system could help promote therapy, optimizing recovery of lower limb function and reduce the load on the public health system.

2. Methodology

This project reports on the design and usability testing of a system that involves an exergame and game controllers for facilitating home-based STT for stroke rehabilitation. We used a research-through-design approach based on design criteria through a user centered and iterative design (UCD) methodology to involve the clinicians and stroke patients in the designing of the system [5, 14, 20]. Shirzad et al. [14] proposed that UCD for rehabilitative exergames consists of three stages:

1. Understanding the contextual and functional needs
2. Generating feasible concepts and prototypes
3. Development of solutions and clinical assessment

Initial design criteria were developed through literature and design reviews [21, 22], expert reviews, workshops and interviews with stroke clinicians [23]. The design reviews included hundreds of sketches, paper models and quick prototypes. The interviews and workshops involved a PhD and practitioner in physiotherapy, a PhD and neurophysiologist expert in stroke rehabilitation, a PhD and Associate Professor psychologist and a PhD and Senior Lecturer in a Graduate School of Nursing, Midwifery and Health. Initially, we interviewed clinicians through semi-structured interviews and asked them how they facilitate STT. We developed hundreds of sketches and showed them to clinicians in a design workshop that lasted 3 hours to discuss the different ways in which STT could be deployed. The most promising concepts were prototyped and showed to clinicians in an expert review workshop that lasted 3 hours.

The design criteria are listed in **Table 1**. The list of criteria was used to design and build prototypes, test them with participants and clinicians, iterate several times and then to assess the final designs. The list of criteria was also useful to explicitly communicate the design knowledge produced through this research-through-design process. There is much embedded tacit design knowledge within the designed products in this type of research-through-design processes that it is necessary to make it explicit to clarify the findings of the research.

Function
The design should provide sufficient load for intensive hip abduction and extension during the priming component
The design should enable the user to perform part and whole tasks to maintain intensity during the task training component
Ergonomics and usability
The shoe should be able to be put on and taken off using one hand
The design should allow for load to be removed quickly and easily to facilitate priming
The design should allow for load to be added/removed handsfree
The shoe and weighted sole should be able to be put on and taken off without written instruction
The design should be easy to setup and use, reducing the number of steps required for interaction
The design should use materials that consider the movement of the stroke patient
The design should be comfortable
The design should be usable for patients at different stages of recovery
The design should allow for increasing complexity and challenge to facilitate the state of flow and increase engagement
The design should involve competition as an option to increase engagement
The design should include positive feedback along its many interactions and avoid negative feedback to increase engagement
The design should involve social interaction to increase engagement

Aesthetics
Areas of high contrast should help distinguish between the shoe's inner and outer
Areas of high contrast should help distinguish Key points of interaction
The designs aesthetic should reflect contemporary footwear appropriate for the audience
The user should not feel embarrassed wearing and using the design
The games should look like a game familiar to the audience

Table 1. List of design criteria that the design should fulfill based on literature review, review of existing systems, expert reviews, interviews with clinicians and stroke patients.

Initial concepts were produced and assessed using a decision matrix model [24]. This model involved using several potential designs assessed next to prioritized criteria. The criteria were developed and revisited based on literature research, interviews with clinicians and finally user testing. Concepts were evaluated accordingly until a final design concept was formed for subsequent prototyping. Prototypes were reviewed by clinicians then iterated. Subsequent prototypes were submitted to user testing with stroke patients.

3. Iterative design process

3.1. Selection of technology

Based on feedback from interviewed clinicians and from a review of the literature and existing devices, the following criteria were decided upon for the technology to be used (**Table 2**). From the clinician's perspective, the technology should allow STT movements to act as inputs for playing the exergame, including priming and task exercises. The literature includes similar exergaming systems that rely on stationary cameras (for instance Kinect), balance boards (Wii balance board), remote controls (Wii remote) or movement sensors. We compared those systems with the initial criteria for the selection of technology in **Table 2**.

3.2. Defining the therapeutic intervention

In discussion with neuro-physiotherapist experts in STT, two STT exercises were chosen based on their feasibility of being emulated in an unsupervised environment as inputs for the game: Hip abduction and hamstrings (**Table 3**).

3.3. Design process

3.3.1. The physical game controller

The prototypes tested of the physical controller were made up of two components: a pair of shoes and a weighted sole. The weighted sole can facilitate up to 2500 g of weight for use in intense strength priming.

	Microsoft Kinect	Wii Balance Board	Wii Remote	Wireless IMU sensors and iPad
A	✓	×	✓	✓
B	✓	×	×	✓
C	×	✓	✓	✓
D	✓	✓	✓	×
E	✓	✓	✓	✓
F	×	×	×	✓
G	✓	✓	✓	✓

A: The design should allow STT movements to act as inputs for playing an exergame; B: The design should allow the user to perform priming and task exercise uninhibited by the game controller; C: The design should be reliably accurate; D: The design should be of a similar price to commercial gaming system; E: The design should be easy to setup and use, reducing the number of steps required for interaction; F: The design should be able to be played anywhere in the home; G: The design should have easy to use controls.

Table 2. Criteria for selection of technology.

After many iterations, the final concept builds on the idea of a slipper with a modular sole system. A sleeve around the ankle was added for resistance band attachment and the upper folds across the foot for ease of access. Shoe lasts, which are used to create the pattern for a shoe's upper, were digitally modeled and then 3D printed and iterated. This process allowed the experimentation with different last shapes that represent the dynamic foot types of stroke patients due to spasticity.

Load is applied differently to the foot according to the STT exercise. The priming component for hip abduction requires load to be applied to the foot using a resistance band. The priming component for hamstrings requires weight to be attached to the foot using a Westminster pulley. Modular soles of different weights were proposed to facilitate similar load to what is applied using the Westminster pulley.

3.3.2. The game

Based on feedback from clinicians, the final game is a set of dominoes, with the intention that our target audiences would be familiar with the game's mechanics. Initially, the player performs

Exercise	Hip abduction and sideways walking	Hamstrings and backwards walking
Priming component	Moving a straightened leg away from the midline with a resistance band attached to the ankle.	Sideways stepping with progression to elevated stepping onto a foam mat or stepping board.
Task training component	Attach weight to foot, bend at the Knee and move foot backwards.	Walking backwards with progression to backwards stepping and backwards walking + pivot.

Table 3. Definition of exercises selected to design the games: hip abduction and hamstrings.

strength-based priming exercises while wearing the weighted sole. This movement in turn shuffles a bag of dominoes in the game. Players progress through the game by performing sets of task exercises to push their dominoes into the desired position on the board. For instance, performing sideways walking task exercises moves the chosen piece of dominoes sideways to the desired location on the board. Mapping these rehabilitative processes to their in-game equivalents intends to help maintain immersion.

4. User testing

4.1. Users

Testing of the exergame system involved the smart shoe, weighted sole and gaming media. We completed three sessions of tests of the system at stroke clubs at 2-week interval with the findings influencing iterations to the design between each session. Inclusion criteria: aged >18; had experienced a disabling stroke; has or has experienced hemiplegia or hemiparesis following their stroke and can walk without standby assistance. Exclusion criteria: significant cognitive deficit; unable to follow a one step verbal command; unable to give informed consent; medically unsuitable in the opinion of the screening physiotherapist, G.P. or medical specialist; experiences excessive joint pain and suffering other conditions that could impact results (e.g. substance abuse, significant mental illness such as major depression).

Recruited participants (N: 3) included: one with left hemiplegia with little to no use of his left arm due to contractures and no fine motor control over his left leg; one can walk unassisted but has minor weakness on the right side of her body and one has right hemiparesis with minor issues with her balance.

4.2. Testing protocol

With consent from participants, testing took place in their homes. User testing took 25–30 min and involved usability testing followed by a short semi-structured interview and filling of a Geneva Emotion Wheel [25]. User testing involved the user putting on the smart shoe and playing one round of the Dominoes game 12–12 on the iPad. The game then prompted them to put on, use and remove the weighted sole for the priming component, followed by repetitions of STT's task component. Hip abduction and sideways walking were observed. The think aloud protocol was used to assist our observation to fill usability heuristics. Usability heuristics were created based on the relevant criteria that informed the ergonomic and usability requirements of the design.

4.3. User testing sessions

Three user testing sessions took place and design iterations addressed issues found in each testing sessions. **Table 4** and **Figures 1–4** show some of the main findings from the user testing sessions and how the redesign addressed them.

	How the re-design addressed the feedback
Feedback from user testing session 1	
It was assumed that the participant would place the shoe on the ground, then slide their foot into shoe, so an internal closing mechanism using this interaction was incorporated. This was accurate in one case, however two participants brought their affected foot up towards their midline to put the shoe on.	The internal self-closing mechanism was removed and the ankle straps were lengthened for a more adaptable fit. A heel tab was added to the heel to help with picking up the shoe and to help stop the heel collapsing when put on.
The length of the ankle straps proved to be an issue with how the fit of the shoe adapted from person to person. Although each shoe was designed to the shoe size of each participant, the shoe size of each participant ,the length of the ankle straps did not account for different ankle sizes. This resulted in fit issues as the velcro did not adhere properly.	The toe and heel clips were redesigned to sit on spring loaded rails. This would allow the user to either slide or clip their heels and toes into the weighted sole.
Participants found it very difficult to navigate the different elements of the game.	An overhaul of the user interface was necessary after the interactive elements were found to be too subtle. Objects such as buttons were given idle animations to draw attention and supporting text was made more explicit.
No pain or major discomfort was report from any of the users during the first session	
Issues with participants' balance became apparent during the priming phase. When lifting the leg with load attached all participants became unstable.	Load and mechanism to load weight were adjusted.
Early feedback on the look of the device provided some insight into form was received: " it's fashionable. Nowadays everyone wants to wear boots and I have one on".	
Feedback from user testing session 2	
Putting on the weighted sole proved to be significantly easier than the previous session.	
Confusion as to how to do up the shoe's straps.	The hierarchy of the straps was changed so the user would fold the top strap over their foot then wrap and adhere the ankle strap. The colour of different parts was changed to offer hierarchy and semantics of use.
Discomfort around the toes of the affected foot due to contractures.	The sole of the shoes was altered to consider abnormal foot shapes due to spasticity.
Removal of the weighted soles still provided some difficulty.	A fabric tab was added to the back of the weighted sole for removal and weight increments were recalibrated.
Shoe felt too cold.	The material of the shoe was changed to a felted wool outer and ultra-fine merino wool inner.
Regarding the game, more animated elements were needed, particularly for prompting players which exercise they needed to perform when.	Animations were implemented.
More encouraging feedback was also needed for possible mistake players might make during interaction.	Feedback elements were added.
Multiple testers become unsure of what to do when they made a mistake but the times they received assistive text they could reorient themselves without our assistance.	More feedback was implemented.

Feedback from user testing session 3	How the re-design addressed the feedback
The following issues were resolved: participants found the revised order of strapping a lot more intuitive and easy to use. All participants reported the shoes were a lot more comfortable and secure than the previous design. All participants could quickly remove the weighted sole after priming. Issues observed: one participant had trouble with getting the vamp over the top of his affected foot. One participant required assistance in engaging the weighted sole. No participant reported feelings of embarrassment towards wearing the shoes. Two participants commented that they would be proud to wear the shoes in their homes. One of them expanded on this saying he enjoyed that he was wearing something that "useful (to his rehabilitation) and fashionable". Two participants related their feelings of enjoyment and relief towards the hardware as it symbolized their steps towards making progress towards regaining their independence.	

Table 4. Feedback from the user testing sessions and how the design iterations addressed them.

Figure 1. Helping a participant put on the shoes in the first user testing session.

Figure 2. The design of the shoe is intended to be used with one hand, which participants could do well.

Figure 3. A participant using the game on a tablet.

Figure 4. The physical game controller system: shoe, weighted sole, recharging dock, iMu sensors and cables.

5. Final design

Final changes to the design addressed small aesthetic and usability concerns brought up in the final user test. The vamp was given slightly more stretch to help with the upper stretching over the foot to reduce time taken to put the shoe on. Red stitching was used on the toe clips to highlight what foot the user should be using the weighted sole. A small magnet was added to both the back of the heel clip and the fabric loop to minimize risks of tripping. The form of the weighted sole was changed to minimize the look of complexity and bulkiness reported by participants. All mechanisms were internalized concealing any complexity. The form was also streamlined to take away any protruding componentry. The size of steel plates added to increase load was also changed. Small uniform profiles allow the weight to be changed at smaller increments and distributed evenly across the weighted sole. **Figures 5–8** show the final design of the shoe-game controller.

Figure 5. Putting on the weighted sole one-handed.

Figure 6. The iMu sensor clips into place on the back of the shoe.

Figure 7. The shoes clipped onto the weighted sole.

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Figure 8. Detail of the clipping mechanism for the weighted sole.

The final version of 12–12 has a reduced user interface and options menu to minimize the chance of overwhelming new players. Enough options were kept allowing for variation in the game's complexity with a failsafe to ensure the game remained playable regardless of what player changed. 12–12's tutorial feature was enabled by default, taking users through a predetermined game that allowed them to experience the different mechanics. The tutorial requires 15 priming exercises and 30 standard repetitions to complete. **Figures 9–13** show elements of the design of the game.

Figure 9. Progression of tasks to motivate users engage in their exercises. Left: "If I can do forty leg raises now…"; centre: "…I could be walking by the end of the month"; right: "…I can see my friends at the café down the road whenever I want".

Figure 10. Home menu of the game.

Figure 11. Initially, and to shuffle the box of dominoes, the user performs strength-based hip abduction exercises, which primes their brain for learning.

Figure 12. Tabletop of the game.

Figure 13. To move the piece of dominoes, the user needs to perform their task exercises. In this case, sideways walking makes the piece of domino roll to the player's chosen location.

6. Discussion

The findings from user testing of the system suggest that the hardware can facilitate aspects of STT in an unsupervised environment. Currently, STT is only conducted in a clinical environment. Facilitating STT through the medium of an exergame could provide an engaging way to motivate the user to perform this lower limb therapy intensively and consistently in their home. This not only can reduce the load on the public health system but also can help maximize patients' locomotive gains and retain their mobility and subsequently their independence.

The design requirements of the system proved to be complex due to the diversity in our target audience. The functional criteria of the hardware were primarily defined by the requirements of STT. Ergonomic and usability requirements aimed to minimize barriers to using the exergame in an unsupervised environment. Addressing the diverse cognitive and physiological abilities of stroke survivors was paramount to overcoming these obstacles. The aesthetics of the system were designed to address the stigma of medical intervention products within the hardware and make the exergame's interface as cohesive as possible for an audience unfamiliar with digital technology.

6.1. Evaluation through design criteria

The final designs were evaluated according to the design criteria developed throughout the process (**Table 5**).

6.1.1. Functional requirements

Priming and task training components of STT can be used as a means of interaction with gaming media. A gaming controller in the form of a smart shoe could be used to track movement of the lower limb noninvasively.

Initial user tests indicate that intensive hip abduction priming can be facilitated by securely and comfortably fixing load in the form of external weight to the smart shoe. Load must also be specific to the user's capabilities through adapting the weight of the sole. Avoiding resistance bands during unsupervised rehabilitation also circumvents fall risks and their observed erroneous use outside of a clinical context. By mitigating the use of resistance bands unsupervised this ensures the priming component is intensive yet safe and manageable, keeping the user motivated to continue using the exergaming system. Clinician review of the weighted sole also indicated that beyond STT, any unsupervised rehabilitative strength training could benefit from the design's ability to mitigate the use of resistance bands.

Maintaining intensity during the task training component requires increasing the complexity of the task. Complexity is increased across nine components, part and whole task being one element where the patient must complete more dynamic movements as they progress. Testing indicates that creating footwear that provides a comfortable and stable base of support can allow the user to perform movements of increased complexity this progression demands.

Initial design criteria	Assessment based on design criteria	Explicit design knowledge applicable to this system based on criteria
Function		
The design should provide sufficient load for intensive hip abduction and extension during the priming component.	Clinicians reported that the load was sufficient for the patients tested. However, load needs to be adjustable.	The added shoe can add load for STT. However, this adds height and imbalance. Depending on user, exercises should be done either sitting or with good support.
The design should enable the user to perform part and whole tasks to maintain intensity during the task training component.	The users could perform part and whole tasks and maintained intensity.	Exergames can separate between part and whole tasks.
Ergonomics and usability		
The shoe should be able to be put on and taken off using one hand.	All participants were able to put the shoes on using one hand.	Large openings for inserting the feet into the shoe and large straps facilitate one-handed use of shoes.
The design should allow for load to be removed quickly and easily to facilitate priming.	All participants could remove the load immediately when needed.	A pullable tab can facilitate quick release of extra sole.
The design should allow for load to be added/removed handsfree.	All participants could add and remove the load handsfree.	A click step-on system can facilitate adding an extra sole to shoes.
The shoe and weighted sole should be able to be put on and taken off without written instruction.	All participants needed instruction on how to put on the load the first time. They could do it independently subsequently.	Initial instruction of how to put on a new sole system in shoes is needed.
The design should be easy to setup and use, reducing the number of steps required for interaction	There are many steps in the full interaction including shoes, load and game. All were reduced to a minimum during the different interactions were easier with less steps.	Reducing steps in the interaction can help with its usability.
The design should use materials that consider the movement of the stroke patient.	All participants could move and perform the exercises.	Soft felt and flexible 3D printing filament (TPU) can produce shoes that allow movement of stroke patients.
The design should be comfortable.	All participants reported the shoes were comfortable. However, all needed to have the tablet on a table to be able the games.	Soft felt and flexible 3D printing filament (TPU) can produce shoes that users report as comfortable.
The design should be usable for patients at different stages of recovery.	All three participants were at different stages of recovery and all found the games usable. However, the designs have not been tested within participants as they progress in their recovery.	Games with different stages of difficulty can cater and be usable for different stages of recovery in stroke patients.
The design should allow for increasing complexity and challenge to facilitate the state of flow and increase engagement.	All participants reported that the different levels increased complexity. However the results are unclear at this stage whether the participants entered a state of flow. Further research needed in this area.	Different levels of complexity in the design of games can induce different levels of challenge.

Initial design criteria	**Assessment based on design criteria**	**Explicit design knowledge applicable to this system based on criteria**
The design should involve competition as on option to increase engagement.	All participants were keen to participate in competition through the game.	Competition based on known games (in this case dominoes) resulted in a natural understanding and willingness to engage in competition in rehabilitative games.
The design should include positive feedback along its many interactions and avoid negative feedback to increase engagement.	All participants reported feeling encouraged by the feedback in the game.	Feedback based on pop up messages as individual tasks are completed (for instance shuffling the dominoes pieces or moving individual pieces within the game) can be encourage for participants.
The design should involve social interaction to increase engagement.	All participants were keen to play with other participants through the game.	A social interaction based on an already known game (dominoes) was easy to adapt to an acceptable social interaction in game for rehabilitation.
Aesthetics		
Areas of high contrast should help distinguish between the shoe's inner and outer.	There was no report on this from participants. When prompted, they agreed that it was easy to distinguish.	High contrast can help distinguish between shoe's inner and outer when this is important for the interaction.
Areas of high contrast should help distinguish key points of interaction.	Participants were able to find key points of interaction.	Areas of high contrast can help users distinguish key points of interaction.
The design aesthetic should reflect contemporary footwear appropriate for the audience.	All participants expressed that the shoes and designs had high aesthetic appeal.	The design of the aesthetics of shoes for rehabilitation is both discernable for users and important for their willingness to use them.
The user should not feel embarrassed wearing and using the design.	The participants initially expressed their desire to own the system and did not express embarrassment.	The aesthetic of rehabilitative system can influence the desire of users to own the system and avoid embarrassment.
The games should look like a game familiar to the audience.	All participants understood the game as a dominoes game immediately.	Using a game familiar to the audience can help with its intuitive use.

Table 5. Assessment of final designs according to the design criteria.

The flexibility of game options allowed for 12-12 to be playable by a range of people with different physical capabilities. User tests made it apparent that there was a cognitive threshold to the game that meant survivors of stroke who had suffered severe cognitive deficits would not be able to play. A version of the game with reduced functionality, therefore reduced expectations of the player, would be necessary for making 12-12 accessible to this subgroup of our target demographic.

6.1.2. Contextual requirements

Ergonomics and usability. The dynamic range of abilities that survivors of stroke possess must be addressed to ensure that the patient can use lower limb exergame hardware independently and intuitively. To consider the physiological effects of hemiparesis, one-handed interaction was necessary to complete all tasks. Observation of tests indicated that, apart from Ned needing assistance to put on the weighted sole, participants could put on and take off the shoe and weighted sole independently. It is critical that hardware promotes its use across all ability levels.

Reducing time between strength and task training components was crucial to facilitate priming. User observation illustrated that the design of the weighted sole enabled the user to remove load and promptly begin task training. This suggests that the hardware can maximize corticomotor excitability during strength training to subsequently enhance neural plasticity during the task component. Effective priming maximizes the patient's gains in locomotive ability helping them regain independence.

An unanticipated but important outcome was the feeling of pride participants felt after figuring out how to complete certain interactions with the exergame system. We speculate that reducing cognitive/physical challenges rather than removing them completely could create a more beneficial experience for the user. In addition to this, it is apparent that more consistent feedback from the system to the user will help maintain their confidence in its use. Our user testers enjoyed the 'you can do it' mentality of the game and wished to see more feedback throughout their experience that let them know if they were progressing or not.

Aesthetics. Feedback suggests that aesthetic consideration of exergame hardware can remove any medical semantics and address the stigma towards using medical devices. By designing a game controller that was considered a "fashionable" piece of footwear, the user avoided the feeling of embarrassment while wearing and using the smart shoes. Counter to the praise of the footwear's aesthetic, the weighted sole receives critique on its perceived complexity.

Beyond "fashionable" semantics, the aesthetic seemed to resonate on a deep emotional level with participants. The design elicited emotions that relate to positive progress that the patient was making in their recovery. Moreover, participants seemed to find that wearing shoes does not just make rehabilitation novel and motivating but also can act as a tool to help them regain their independence. Furthermore, just knowing that there was something designed specifically for them made the user feel valued as a person. Based on these results we speculate that the aesthetics of an exergame controller could transcend the stigma towards medical devices and help create a meaningful object that represents the survivor of stroke's journey back to independence.

Lastly, the aesthetic of the game yielded no complaints from participants. They reported it to be vibrant and the text was easy to read. This aligned with the works of [26], Gerling et al. [27], Ijsselsteijn et al. [28], Kopacz [29] and Martin et al. [30], which informed most of the design decisions regarding the game's interface.

7. Conclusion

Stroke is a leading cause of disability in developing nations leading to impairments affecting patients' locomotion and limiting their independence. Research into exergames for rehabilitation is an emerging field; however, the benefits they present make further exploration a necessity. STT is a novel intervention for lower limb stroke rehabilitation, which aims to promote gains in locomotion, however currently only practiced in a clinical environment. This research has contributed to the greater field of exergame rehabilitation tools by investigating how the design of an exergame controller could facilitate unsupervised STT for lower limb stroke rehabilitation.

The functional and contextual requirements of an exergame and its controller were explored through background research and interviews with stroke clinicians. These initial requirements informed the design and prototyping of exergame and its controlling hardware as part of an exergaming system for unsupervised STT.

Smart footwear that interacts with an adaptable strength training weighted sole to control an exergame was prototyped and tested. Functional requirements of the system promoted a way to strength training safely and comfortably by applying load to the lower limb. The weighted sole that provides load was removed to promptly begin task training to facilitate the merits of priming. The interactions with the system needed to be intuitive and facilitate a one-handed interaction. Aesthetic consideration of the hardware and exergame indicated that the system could disrupt the stigma of using medical devices in the home and become a meaningful HCI system in the user's life.

Reviews with clinicians and feedback from user testing with stroke patients helped to substantiate and build on the functional and contextual requirements and to better understand how exergaming systems can facilitate clinical interventions like STT. The growing population of stroke patients represent a diverse and complex demographic target group. The final design could benefit from further testing with a wider user base of patients over longer periods of time.

There is a growing amount of research examples in the field of exergaming media design; however, little research furthering the design of purpose built game controllers has been done. There is undiscovered potential through a designerly approach to exergaming HCI. More case studies into these processes could help foster an abundance of novel and innovative design discoveries and broaden the abilities of home-based rehabilitation systems.

We have presented a complete exergaming system with meaningful HCI that is user friendly and provides a safe way to participate in home based stroke rehabilitation. This research has proposed a way to enhance the lives of survivors of stroke and potentially the wider population of people living with muscular disabilities, such as multiple sclerosis and cerebral palsy. Further research into similar systems can benefit the ageing population and assist those seeking to reclaim their independence, and it should involve a full assessment on the effectiveness of the system to improve stroke rehabilitation and its ability to increase adherence to therapies.

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ClockViz: Designing Public Visualization for Coping with Collective Stress in Teamwork

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Additional information is available at the end of the chapter

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Abstract

The intervention solutions for coping with collective stress have been neglected in interaction design because of limited scalability of the physiological measuring methods. This paper focuses on exploring visual biofeedback design for collective stress in the context of teamwork. We design *ClockViz*, an augmented reality installation overlaid with static or dynamic projection to visualize three different extents of collective stress on a clock. Results of a 16-participant study show that *ClockViz* is useful to provide biofeedback data, change their internal status, and increase their mindfulness. Based on the results, we also discussed the potential solutions to collective stress sensing for designers to apply into their interactive design intervention.

Keywords: collective stress, biofeedback, visualization, design intervention, interaction design

1. Introduction

People often experience stress in the workplaces. Stress normally comes from internal stressors such as working environment, daily issues, and life changes or the external stressors such as interpersonal relationship and society. The impact of stress can be either positive or negative. Thus, stress can be categorized into eustress and distress [1], respectively. Eustress normally gives people motivation to deal with challenging routines, produces higher performance, and generates positive feelings, which can give people a sense of achievement during work. However, researchers also have found some evidence that stress can lead to illness emotionally and physiologically. Overloaded prolonged stress leads to illness like anxiety, depression, anger, headache, insomnia, indigestion, or even worse. It lessens people's resistances to diseases [2]. Helping people to adapt to the changing levels of stress is a significant challenge for interaction designers to promote healthier working and lifestyles.

Several techniques can be used as tools for designing applications of stress management. Sharma et al. demonstrated some common techniques that include analyzing physical signals such as eye gaze, pupil diameter, voice characteristic, and face movement and physiological signals such as electroencephalography (EEG), blood volume pressure (BVP), heart rate variability (HRV), galvanic skin response (GSR), electromyography (EMG), etc. [3]. With these input signals, the information can be further visualized as several forms of biofeedback [4] to raise the awareness and therefore help them deal with the stress. However, these physiological measuring methods seem to be hardly scalable because the deployment cost is directly proportional to the subjects wearing the devices. Due to the limited scalability of measurements, the designs of biofeedback mechanisms are limited to the stress sources from individuals, instead of the collective and organizational ones.

In this work, we aim to explore the visual biofeedback design of collective stress and to treat a group of people as an entity. Collective stress, as a certain type of stress, represents the stressful feelings of members in a particular organization [5]. Like individual stress, collective stress could be caused by external stressors such as natural catastrophes, economic crises, and political collapses. Moreover, collective stress may also be affected by some internal stressors like conflict or propagation between individuals. It could lead to less productivity, poor performance, strained relationship, or members' burnout. Providing suitable visual biofeedback design of collective stress help the workers dealing with the stress may increase the performances and lead healthier ways of teamworking.

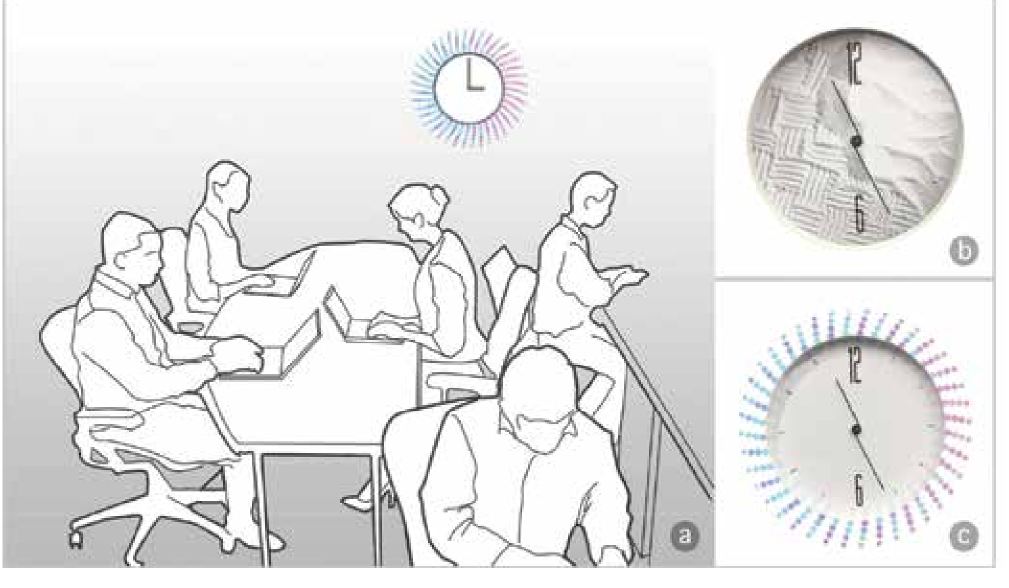

Figure 1. ClockViz. (a) Illustrations of application scenario, (b) static visualization, and (c) dynamic visualization.

Therefore, we developed *ClockViz* (**Figure 1**), a projection-mapped clock to prove the concept. *ClockViz* visualizes collective stress information by visually augmenting to a clock that has been a public display in the working space, so workers in situ can easily perceive the collective stress information visually when they are working together. Regarding simplicity, we designed a static (**Figure 1b**) and a dynamic (**Figure 1c**) projection overlays to visualize three different extents of collective stress on a clock as an augmented reality installation. Initial user feedbacks were gathered from a sixteen-participant pilot testing, which was conducted to understand the effectiveness of the provided visualization under a pressure cooker. It showed that the participants not only agree that our system visualizes their mental states meaningfully but are also willing to provide constructive suggestions for the next iteration of customization.

The rest of the paper is organized as follows. First, we review the relevant literature. Then, we explain the design, the implementation, and the users' feedback obtained from a pilot study. Finally, future research directions are discussed and suggested with our conclusion.

2. Related work

Individual stress coping strategies had been framed in the domain of interaction design. These designs mostly correlated to other domains, such as stress measurement and social science. Hence, this section will explain stress-related work in the following three sections: social factors on stress management, stress measurements, and related solutions in interaction design.

2.1. Social factors of stress management

In the domain of social science, many factors can cause stress in the context of a collective, for instance, the changing of organizational structure, leadership style, and quality; the demands of tasks and roles; the communication within an organization; and so on [6]. A majority of the previous studies on collective stress coping methods are sociological resolutions like training, rewarding, and self-developing [6], and they have also been explored extensively in catastrophic psychology [7]. However, it is infrequently approached in empirical stress research in the context of organizations [8].

2.2. Stress measurement methods

Other than physical and physiological techniques noted above, stress can also be measured through scales or questionnaires. Famous methodology to scale stress includes PANAS scale [9], perceived stress scale [10], Hassles scale [11], etc. Limited scalable methods of collective stress narrow down the interactive design solutions. Mark et al. use multi-methods that include heart rate monitors, computer logging, daily survey, general questionnaire, and interviews to measure college students' stress. She proposed that the amount of multitasking is positively associated with stress [12]. This research is one step further toward helping people change their behavior to reduce stress. In this case, collective stress information can be objectively measured which provide future researchers a way to gain collective data. Unfortunately, no possible solutions of collective stress were brought up at the end. Moreover, stress status can be created and adjusted through complete difficult tasks or challenging games, such as memory card game [13], domino game [14], soccer game [15], and first-person shooter game [16], which validity and practicability have been proven in the previous research [17].

2.3. Biofeedback for visual perception

The combination of stress measurement and interaction design has been well explored. Some artifacts had been designed to give biofeedback of individual's stress status and attempt to visualize personal biological parameters [18, 19], or do interventions [20–22] to mediate their stress through various methodologies. For instance, Van Rooij et al. [18] applied RSP data in their work, and Henriques et al. [19] offered BVP parameters. Beyond the visualization level, Yu et al. designed an auditory display providing HRV to help biofeedback training [20]. Bhandari et al. [21] also applied music biofeedback intervention to help users regulate their stress. Gaggioli et al. [22] verified that inter-reality could better manage psychological stress than traditional stress management training. Some of these studies involved solutions considering visual, auditory, and tactile perceptions of a human being. Since visual perception has less interruption and disturbance, it has been widely applied in biofeedback visualization. Thus, we will mainly discuss biofeedback for visual perception in this case. Various patterns or physical objects associated with natural patterns had been used in former studies [4, 23]. A 3D graphic serious game design on smartphone provides biofeedback and adjusts user's breath through animation, which is related to the real-time cardiac coherence level [4]. In other words, letting people acknowledge their biomedical signals with certain training exercises could help them relax. MoodLight [23] is a real-time interactive lighting system, which designed to promote even to lead biofeedback to users. Matthew et al. claimed that "promoting or leading feedback can be more helpful to make user relax than the real-time feedback" [23]. Those studies verified that present biometric information to individuals could provide a sense of control and possibly regulate themselves on their own in specific scenarios.

2.4. Summary

Our review shows that the discipline of interaction research and design has taken a great interest in stress-related topics in recent years. It has been well explored of interaction design artifacts to mediate individual stress. Nonetheless, researchers mostly use technical solutions for stress measurements on individual users instead of a group of users as an entity. Interaction designers design artifacts to deal with social issues and neglect collective stress because of practical limitations. Hence, this research focuses on seeking practical solutions for collective stress management in teamwork.

3. Design

3.1. Design considerations

According to the brief review, we assume that biofeedback visualization information of collective stress could help the team members better cope with their stress. The visualization should be "a tool that brings people together to address issues instead of isolates people as individuals" [24], based on the practical theory of social design. Thus, providing a public display is more preferable than using personal displays of individual users. Our research question is could public biofeedback visualization have meaningful influences on participants during teamwork?

In the context of designing visualization of public display, three main considerations while forming the visualization design are the choice of expression, the correlations between collective stress status and corresponding expression, and the avoidance of interruption or distraction.

On the choice of expression, we try to change the environment as least as possible so that the workers can transfer their daily behaviors to the display we provide to them. By observing common working scenarios, we found out that most of the public working spaces have a clock on the wall, which is a public display of time, allowing us to design a nonintrusive installation by augmenting a clock. Regarding a clock as a display of time, time-related collective pressures are mostly suitable to be displayed on it. To further understand the correlations between collective stress status and corresponding expression, we conducted informal interviews with several student study groups in a university and summarize three common collective stress statuses in the teamwork with time:

1. Everyone in the team feels stressed. Before a deadline, everyone feels stressed from the time pressures. When the deadline is approaching, everyone is doing challenging tasks on their own. The team that suffers from even the stress level among all team members often leads to a stressful working atmosphere. In this case, the collective stress steadily changes with time.
2. Someone (s) feel stressed, someone(s) do not. This happens when there are dependencies between the divisions of labors (e.g., one has to wait for another one's response) and uneven divisions of labors (e.g., someone's task is beyond his or her capability, but someone's task is not or even too easy). The uneven stress would lead to unharmonious working atmosphere and even drive affection between team members (e.g., members argue or blame each other). So, the collective stress unsteadily changes with time.
3. Everyone in the team does not feel stressed. This happens when the deadline passes, and the next deadline is still far away, everyone in the team does not suffer from time pressures. In this case, stress condition is affected by the individual factor, and the collective stress visualization does not seem to be necessary.

On avoidance of interruption or distraction, the clock should stay ambient in the background, and the coworkers should notice the visualization only when they look at the clock for checking the time. Therefore, the visualization should avoid attention grabbers that may interfere with user's peripheral perception, such as salient movement, startle changes of colors, and intensities. Therefore, the visual augmentation should be designed either as static as possible or consists of consistent dynamic movements.

3.2. Designing ambient visualization of collective stress

Based on this principle, we proposed two proof-of-concept visualizations of collective stress: static and dynamic. Each expression contained three collective stress statuses that we discussed previously: (S1) everyone in the team feels stressed; (S2) someone(s) feel stressed, someone(s) do not; and (S0) everyone in the team does not feel stressed.

Figure 2. Static visualization. (a) Everyone in the team feels stressed. (b) Someone(s) feel stressed, someone(s) do not. (c) Everyone in the team does not feel stressed.

Static visualization (**Figure 2**) is an ambient intervention, which is inspired by Zen garden. The sand traces changed imperceptibly slowly within a glance, so it appears to be static. When everyone in the team feels stressed (**Figure 2a**), the entire clock is covered by dense patterns, showing the even pressure of every team member. When someone(s) feels stressed, but someone(s) does not (**Figure 2b**), the sand traces appear to be bipolar: half of the clock is covered by dense traces, but half of it is not. The ratio of the two parts also displays the uneven loadings of workers. When everyone in the team does not feel stressed (**Figure 2c**), the sand traces are slowly erased, so it appears to be peaceful. With these trace patterns of the sand, the design also attempts to evoke inner peace, calmness, and tranquility of people.

Dynamic visualization (**Figure 3**) is a dynamic intervention, which is inspired by water shows. The light pattern spins, dilates, and erodes in a stable speed, which is governed by several sine functions, to provide dynamic but peaceful representation when the users take a glance at the clock. When everyone in the team feels stressed (**Figure 3a**), a colorful spiral is displayed around the clock with dense, long traces, showing the even pressure of every team member. The length of trace changes with the time pressure. When someone(s) feels stressed, but someone(s) does not (**Figure 3b**), the density of spiral varies with time to display the uneven loadings of workers. The density of spiral also changes according to the unevenness of task loads. When everyone in the team does not feel stressed (**Figure 3c**), the length of trace reduced, so it appears like a peaceful, rotating color wheel. The design also attempts to use many positive metaphors such as the colors and shapes [25] to provide cheerful experiences.

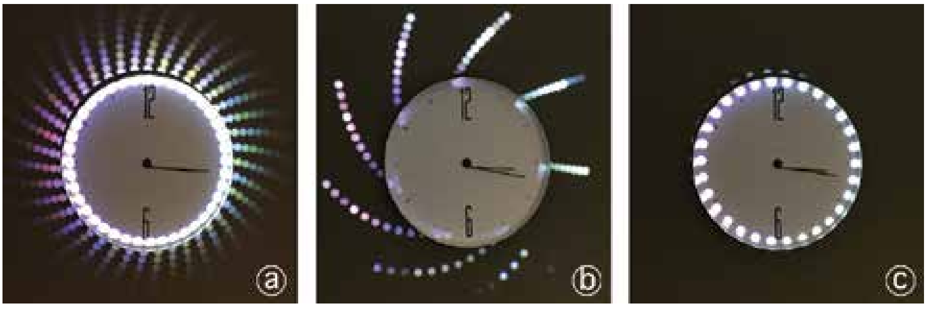

Figure 3. Dynamic visualization. (a) Everyone in the team feels stressed. (b) Someone(s) feel stressed, someone(s) do not. (c) Everyone in the team does not feel stressed.

4. Pilot study

To understand the effectiveness of our design, a pilot study was conducted to understand the users' behaviors and responses to the provided visualization in teamwork under time pressure.

4.1. Participant and apparatus

Sixteen participants (seven males, nine females) were recruited and divided into two groups: eight for the static visualization and another eight for the dynamic visualization. For each visualization, the eight participants were further evenly divided into two teams. The study is conducted in a meeting room where a projection-mapped clock was installed on the wall. As shown in **Figure 4**, the visualization of the projection is controlled by a computer.

4.2. Task and stimuli

Domino game is chosen as a pressure cooker because of the following three reasons. First, domino is a game that participants from various cultural backgrounds are familiar with, introducing immediate walk-up-and-use system to our study. Second, domino games not only require but also encourage teamwork. Third, the difficulty of domino games is easily adjustable based on the complexity of construction. By assigning different domino challenges to a team by asking them to complete it within a given period, we can test our system and obtain initial feedback with this pressure cooker.

Each team was asked to finish each of the three tasks in 5 minutes. The tasks are designed in different difficulties. The first task is to collaborate with each other and make a 2D pattern that can be knocked down in one push. This refers to an easy task that associated with low-stress status. The second task is to collaborate with each other and make a 3D round tower,

Figure 4. Experimental apparatus.

as shown in **Figure 4**. This refers to a relatively stressful task for everyone in the team. In the third task, we divide the team into two groups: one group is asked to build a 3D tower, and another group is asked to build a 2D pattern in the middle of the 3D tower. This refers to two uneven and mutual-dependent stressful tasks performed by each of the two groups in the team.

The transitions of visualization are human controlled. The stress visualization of all the tasks started from the stressless visualization (S0). In Task 1, we keep the same visualization until the end. In Task 2, we switch the visualization from S0 to the even stress visualization (S1) after 1–1.5 minutes the task started without noticing the participants. Similarly, in Task 3, the visualization was switched unconsciously from S0 to the uneven stress visualization (S2) after 1–1.5 minutes the task started. The stages of visualization quietly and gradually transit without disturbing the participants. After all the three tasks were performed, an interview is conducted to gather feedback from all participants.

4.3. User feedback

Static visualization: The static visualization brought peaceful feelings to most participants, and they reported that it has less interruption of their ongoing work. Half of the participants (4/8) mentioned that they like the feeling of the static pattern and it won't disturb their ongoing work. Comments from participants like "It looks nice. I like the natural feeling of irregular patterns than a digital one." "The thing I like more is it's different that I saw before. It's new, the material." "I can't imagine how comes up with this idea, the sand, the appearance looked more attractive." One participant (P1) commented "There's a lot of directions and lines, must indicate stress, is it?" "There's a lot of patterns over there so it's stress, but the flat one likes empty, so very peaceful." "This means half of us stressed and half are not stressed." "Right now it's all stressed!" One (P7) also mentioned "I realize this scene is much easier for me to understand the stress status." Most participants (6/8) described the influences of the static pattern to their internal activities. "I feel the flat pattern made me more relaxed compared with the striped one. Because it feels like some kind of scratches." "It has kinds of regulation, it reminds me meditation, like the Zen garden." Most participants (6/8) claimed that they can hardly associate the stress status with the static pattern without clarifying the announcement in the beginning. Since we intend to apply positive metaphors to visualize something negative in life, it is necessary to declare the initial intention of the expression in advance. Otherwise, the expressions will be too abstract to be accepted by the audiences. Overall, the feedback shows that the static visualization could help people adjust their inner peace through public display as a mean of visual intervention. The correlation between the visualization and the stress needs to be improved since most of them claimed that they did not feel connected to the visualization in the first place.

Dynamic visualization: People hold split opinions about the dynamic visualization. Part of them claimed that they like dynamic feedback, and they felt that it looks like real-time heart rate, while there are participants who also brought up that the quick changing shapes distract their attention in some way. Many participants (5/8) mentioned that the dynamic pattern looks like a symbol of time pressure. One participant (P3) commented that "Now it's like somebody is telling you that you need to hurry up." One participant (P4) claimed that it symbolizes the group heart rate "Is it the group's biomedical signal? It reminds me of heart rate." Some participants (2/8) stated that stress information is useful to themselves to better cope with it because it is unnoticeable. For example, one (P1) commented that "Stress is very unconscious, it's hard to aware of my feeling that I'm under stress, but when I think about it, I can control myself and try to manage it." On the contrary, like (P5) claimed that offering collective stress information will bring more stress. For instance, participant (P8) said "I would be more stressed if I see other people is under stress. Stress display might makes me anxious, that I should be stressed as the same." In summary, the dynamic stress visualization could easily get people's attention and accessible to provide stress information. One thing that needs to be designed carefully is to what extent the dynamic expression may produce disturbance to people.

4.4. Summary

The reactions and feedback gathered from the participants suggest the pros and cons of the two visualizations. Static visualization drives a peaceful and calmness status that attempt to balance users' inner peace, but it could be easily neglected. Dynamic visualization is more noticeable, but, meanwhile, it might produce unwanted interruption and disturbance. Constructive suggestions such as customization were also brought up. Some participants (4/16) mentioned that they expect to see the correlation between their individual stress statuses from the collective stress information. Alternative expressions in the visualization and different modalities of biofeedback as well as more applications of this visualization were also suggested in the interview.

5. Discussion

The visualization mentioned herein can be provided based on the data collected from the calendar or schedule of a team with proper synchronization between the installation and the global time. However, to tailor the visual experiences as a more proactive and adaptive design intervention for teamwork, additional sensor data should be considered to give the feedback in better accuracy and responsiveness. We herein discuss the possible sensing extensions regarding reliability and scalability.

Regarding reliability, intrusive ways to sense organizational stress through HRV and EEG could be relatively stable and reliable indicators of stress. However, their original form appears to be not very practical in the context of teamwork, because everyone has to put on the device while working, and the device's form factors may negatively affect their working performances. Therefore, future research can consider developing wearable HRV and EEG devices in better forms, making them comfortable and even fashionable to be worn in daily lives and the workspaces to facilitating data collections.

Regarding scalability, nonintrusive sensing methods such as using cameras and computer vision techniques track the emotion of multiple workers by tracking their motion and facial expressions as stress indicators. A possible way to embed sensors is to use accessories that people need inevitably in their daily lives, such as designing biosensors as smart things (e.g., pillow, mirror), to minimize intrusions and distractions. The advantages are that multiple users can be tracked using a single device and the users require no instruments on their body. However, the downsides are that the users are constrained by the sensing range and it may raise privacy concerns. Hence, the physical form and the data collection mechanisms of the stress collectors should be carefully considered and designed.

Another scalable solution is to design social interaction platform for workers to report their stress situations and give suggestions to their peers easily. For example, when the atmosphere is getting uncomfortable, workers can quickly share their feelings through a platform, and the visualization will be pushed to the potential stressors' personal devices. In this case, no extra hardware deployment and maintenance costs are required because human beings can be considered as sensors of collective stress. This solution can also be considered in the immersive AR or VR applications because the visualization can be provided to the users' wearable displays.

6. Conclusion and future work

This work presents *ClockViz*, an augmented reality installation applying static or dynamic projection overlays, which are designed to reflect collective stress through providing biofeedback visually. Both of the proposed static and dynamic visualizations can be applied in the environment as an ambient installation that expresses the collective stress information visually. The results of a pilot study with sixteen participants suggest that the visual information of collective stress status does have meaningful influences on participants. We also have discussed the sensing solutions, which may extend the proposed techniques toward more proactive and adaptive applications for interactive design interventions for coping with collective stress with time. Future work can consider investigating how the public visualization affects people's internal or external behaviors and how personalization and customization could be conducted in the next iterations. According to our literature review, there are no interactive interventions or empirical solutions in the context of collective stress. Hence, we believe that this research shed a light on a new direction that needs to be noticed and emphasized in the future research.

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Fuzzy Bird Helps Me Calm Down and Connect: Touch with Restraint in an Interactive Object for Children with Autism

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Max Rijken, Thomas Latcham and Sophie Kelder

Additional information is available at the end of the chapter

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Abstract

This paper explores the nascent concept of *touch with restraint* in the design of an interactive object. The design was developed to support children on the autism spectrum in social interaction and to facilitate a feeling of social connectedness. Throughout a constructive design case, the desired nature and interaction style of this interactive object emerged. An object that is characterized by *touch with restraint* facilitates adoption as a transitional object and mirrors passively and minimally the actions of a user. The design concept and prototype Fuzzy Bird showed the effectiveness of the concept in a user test. This strong concept contributes to the debate of how we come to live with interactive technologies, by drawing attention to the possibility of self-imposing limits on how much interactive technologies do and being respectful toward the human interactions they help facilitate.

Keywords: touch with restraint, autism, strong concept, constructive design research

1. Introduction

This paper explores a nascent "strong concept" termed *touch with restraint* in the design of an object to support children on the autism spectrum in social interaction. A "strong concept" is at an intermediate level of knowledge between general theory and specific instances; it is constructed through generative design research and can be appropriated by designers and researchers to create new instances, concerns the dynamic, interactive behavior of design solutions, and resides at the interface between technology and people [1]. The strong concept

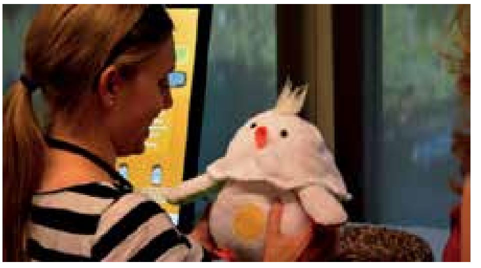

Figure 1. A user in interaction with the Fuzzy Bird prototype.

touch with restraint we propose here draws attention to minimal interactivity to be respectful toward the human interactions they help facilitate. The strong concept is explored in this paper through the case of Fuzzy Bird, a tangible interactive object that supports children with autism in involving themselves in social interaction (**Figure 1**).

2. Design and research challenges

Meet Tommy (**Figure 2**). Opening up and connecting are hard for Tommy every day. Many of the one in 70–100 children diagnosed with autism like Tommy struggle to connect socially [2, 3]. We wanted to help Tommy dare to be more open in new and unexpected situations at home and outside the home, so he can feel more socially connected. Social self-exclusion arises from overwhelmedness [4]: it is a challenge for many children with autism to integrate many sensory impressions. They frequently withdraw or get stressed in social interaction. Yet, engaging socially is beneficial and desirable to them: "*social skill interventions are important to the successful outcomes of youth on the autism spectrum*" [5]. Focused interventions can help [6], as "*children with autism appear to behave based on the same mechanisms (e.g., reinforcement, punishment, extinction) that control the behavior of children without autism*" [7]. Interactive objects can address various conditions [4, 8–10]—could one enable Tommy to feel more socially connected? This project sought to develop a support for children with autism to engage in social interaction. The main design question we posed was: how can we facilitate social connection for children on the autistic spectrum? To address this question, we sought to answer the research question: what are the effects of specific interaction qualities of an interactive object on such children's ability to engage in social interaction?, as a contribution to the debate of how we live with interactive technology.

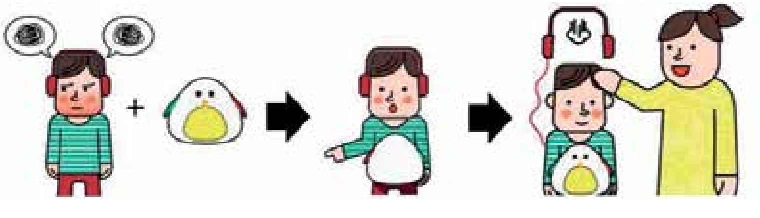

Figure 2. Tommy, a boy with autism (scenario of using Fuzzy Bird).

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3. Approach

We used a *constructive design research* approach, in which construction, in this case of an interactive object, is central and becomes the key means in constructing knowledge [11]. We developed Fuzzy Bird using a design approach of rapid, iterative prototyping. *"Prototypes let the designer communicate the (design) concept […] and give him insight on how well the designed features of the interactive product concept match the design brief. The iterative process was built up out of three main activities: prototyping (build in order to try out); concurrent reflection and testing; and theorizing (engage with literature)"* [12] (**Figure 3**).

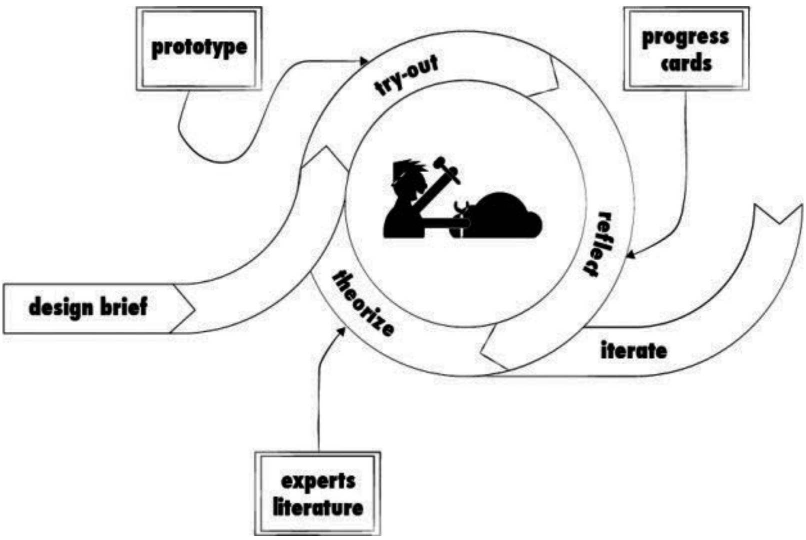

Figure 3. Iterative process of constructive research.

4. The design case

We developed a first idea and mocked it up as a rough prototype: "Eggy", an interactive object that would teach coping by demonstrating the child's own behavior, thus prompting the child to develop calming responses and thus become more ready to engage in social interaction. Eggy would move at certain moments in a distressed fashion, and by stroking it, the child could calm it down. The Eggy prototype is shown in **Figure 4**.

We tested this initial prototype in action ourselves, immersing in the Tommy persona. When held, Eggy moved as if it wanted to get away. This movement felt violent and jerky, like that of a stressed child with autism. We interpreted that the experience of other in distress would not facilitate learning but rather risk triggering distress in the child itself. The interpretation was strengthened by findings from literature, where recommendations include to "give (children with autism) a feeling of being in control," "provide a structured situation," "let them create a structure themselves," "reward them with sensory experiences," and "let them use their whole

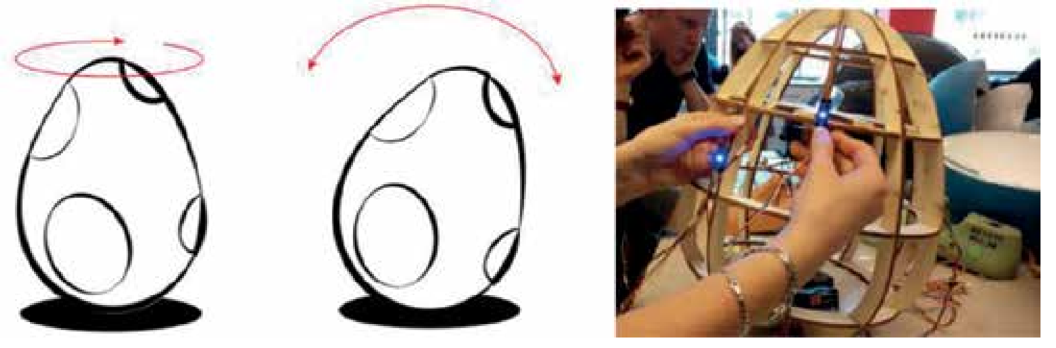

Figure 4. A schematic illustration of the Eggy prototype's actions and the Eggy prototype.

body" [13]. Eggy facilitated only the last of these but obstructed the others. Having experienced the Eggy prototype in our hands and being pointed toward sensory experiences, the importance of touch came into view. Touch, in contrast to the other senses, is an inherently *interactive*, reciprocal experience and "forms the basis for the *feeling* of being in contact" and for "the development of feelings of affection and intimacy" [14]. Touch is an important aspect of *transitional objects*, which facilitate childhood development of social connectedness. These are "objects that are not part of the infant's body yet are not fully recognized as belonging to external reality. They facilitate the initiation of an affectionate type of object-relationship (…), the handling of truly 'not-me' objects. Such a material or object (blanket, soft toy) serves as a "defense against anxiety" [15, 16]. In the case of disabilities like autism, objects can have important transitional roles way beyond the toddler age. As a psychotherapist concluded from therapy with a 9-year-old child with autism, "objects can help those children who find it hard to firstly conceptualize a relationship and then go on to feel safe and free to express the full range of feelings within that relationship" [17]. Affective touch, while an excellent means to communicate emotion, has not yet been explored widely in robot design, due to its complexity with regard to, e.g., gender, social status, and culture, yet further exploration is recommended [8].

5. Touch with restraint: Fuzzy Bird

In a next and final iteration, we drew on the above insights regarding touch, "not-me" objects, and objects that could help a child conceptualize a relationship and express feelings. In that, we focused on the principle of mirroring, which provides structure and is a key part of social interaction, and one that many children with autism find particularly hard to learn [18]. We conceptualized a support as a soft, nonthreatening, inviting, and above all, passive object inviting *touch* while also exercising *restraint*.

Fuzzy Bird is a fuzzy, cuddly, and soft baby bird. The instantiation was chosen for its huggable round shape with little definition and few but distinct movements (flapping little wings). The overall appearance and feel of Fuzzy Bird passively invite interaction, thereby *exercising restraint* and providing the reward of *touch*. An initially stressed child can squeeze and hug Fuzzy Bird ruggedly or even throw it about, absorbing initial anxiety or distress and involving the whole body. The simple responses gradually convey structure. Once calmer, or if the

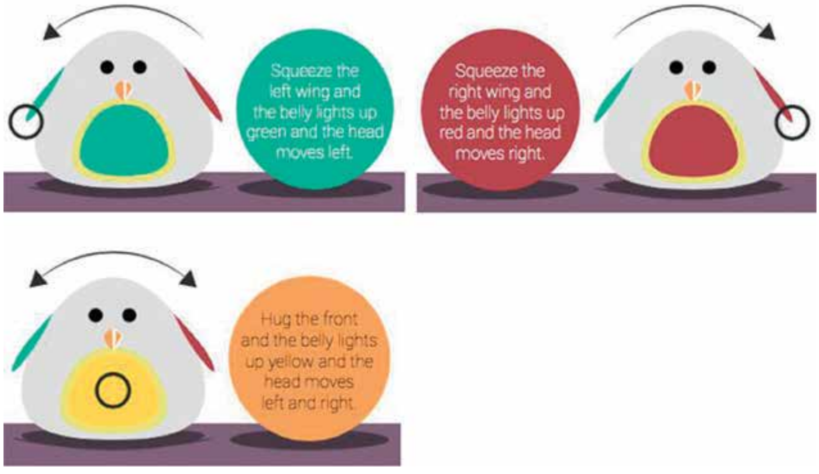

Figure 5. Fuzzy Bird's interaction possibilities.

child is already calm, Fuzzy Bird offers three direct, predictable, and minimal responses, each discoverable by touch and depending on the first move from the child, thus facilitating a feeling of control. This enables the child to create structure of its own and discover the object's response without overload. These are Fuzzy Bird's responses: its wings sport colored patches, one green and one pink; on its belly, there is a yellow patch. A child can squeeze or hit the patches. If Fuzzy Bird's green or pink wing is squeezed, its head tilts to that side and a green or pink LED light up on the belly. The yellow patch on the belly also lights up on touch, and Fuzzy Bird shakes its head left and right gently (**Figure 5**). Fuzzy Bird responds to each action with only one direct, simple response, which in turn invites a direct, simple response from the child. Fuzzy Bird mirrors and takes on the child's actions, but no longer its distress, and invites mirroring in turn, with subtle guidance toward calm.

6. Test

Five children aged 6–10 years and diagnosed or suspected to be on the autistic spectrum tested the prototype at a school for special children. We let the children explore the prototype without much interference (**Figure 6**).

The children tested the prototype in a room, one by one, with a teacher present in the background and a researcher on hand to guide the child through. Each test took ca. 15 min. Children and parents consented to the test ahead of the day. The prototype was fully functioning and attached to wires on a table. The child could pick it up and hug it. The moderator introduced Fuzzy Bird and then maintained respectful verbal contact with the child, while it was free to explore the prototype. The test showed that the principle of *touch with restraint* had the intended effect. We saw a transformation in the children's social interaction with Fuzzy Bird and the moderator: upon entering the room, the children appeared to be closed, shy, and distant. This changed throughout the session: they became more open and relaxed, with more deliberate and calm actions and starting to interact with the researcher freely and trustfully (**Figure 7**).

Figure 6. The prototype test situation: interaction, hugging Fuzzy Bird. Parental and child permission given for publication.

Figure 7. Children's reactions in the test: from stressed to open.

One child picked up Fuzzy Bird to hug it without being asked to do so (**Figure 6**). Another child said that the sound (of the stepper motor) sounded like little farts, and most children commented freely after the test on how we could improve Fuzzy Bird: indications that the children were at ease. All but one activated the prototypes' possibilities. The children discovered the direct response of the prototype and in turn mirrored the prototype's actions. The teacher who observed the test commented that Fuzzy Bird engaged the children better than other toys. However, the test method has some limitations. The children encountered an unknown researcher and object: enough reason to be tense. One of the children was too tense to physically interact with Fuzzy Bird. The researcher's satisfaction at seeing the other children interact with the prototype probably contributed to their relief. Even the teacher's response may have related to the test situation more than to the prototype.

7. Discussion

We developed the concept of *touch with restraint* through constructive design research. The concept describes specific interaction qualities of an interactive object to support the ability of children on the autism spectrum to engage in social interaction. The test showed that Fuzzy Bird supported the children in engaging in social interaction (so far, only with Fuzzy Bird itself and with the researcher) and hopefully feel more socially connected, by responding to touch with restraint, specifically mirroring, and reward. This enables the child to develop trust, learn the principle of a direct response from another, and discern structure.

These are key aspects in overcoming the overwhelmedness of children with autism in social interaction [4]. However, they should still be tailored carefully to each child, since children may differ strongly [7]. One part of our contribution is that the principle allows the child to itself initiate the beneficial effect of *touch* that has earlier been demonstrated for communication devices [9]: calming down, even physiologically reducing cortisol levels. Our contribution moreover shows how *restraint* contributes to structure and involvement of the body for the child [4, 10].

8. Conclusion: touch with restraint for social connectedness

The goal of the project was to develop a support for children with autism to engage in social interaction and thus facilitate felt social connection. We have shown an application of interactive technology to achieve this and contribute to the debate of how we will live with technology. The strong concept proposed here, *touch with restraint,* is still at an early stage and has not yet been applied or evaluated beyond the case presented. Still, we believe the case is laid out clearly enough to engender discussion on its value, novelty, grounding, and relevance in terms of generativeness [1]. Fuzzy Bird is an instance embodying the strong concept. Rather than creating special environments or products for children with autism as members of a specific group, a design applying a *touch with restraint* concept can enable the child to develop the skills to include himself in social interaction and to feel socially connected.

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Investigating and Designing the Appearance of a Device for Facilitating Pelvic Floor Exercises: A Case Study on Design Sensitivity for Women's Healthcare

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Abstract

Pelvic floor disorder (PFD) refers to a weakened or damaged muscle structure affecting the self-esteem, confidence and social participation of affected women. With appropriate training, the weakened muscles can be strengthened, but for a long-term improvement the women need to be actively engaged in the process. While there exists a range of devices that can intra-vaginally measure pelvic floor activation and help women do their exercises, it is unclear how the appearance of the devices may affect women's willingness to use them. We believe that a further understanding around the appearance of these devices may help women feel more comfortable using them, therefore helping them care for their health. We carried out interviews and online questionnaires with women (n:70) who use the devices and clinicians (n:4). We report on identified areas where the appearance of devices is important for women. We present the iterative design process and evaluation of a system aimed at facilitating self-directed pelvic floor management based on this research. We suggest that discrepancies in the responses from participants call for personalisation of the device to meet individual user expectations and increase the design sensitivity when designing for smart devices that help women care for their health.

Keywords: pelvic floor disorder, PFD, iterative design, design system, health, engagement, pelvic floor muscle training, PFMT, appearance, design and emotion, semantics of form

1. Introduction

Pelvic floor disorders (PFDs) can affect up to 44% [1] of all women and symptoms like urinary incontinence (UI) can have a significant effect on self-esteem, confidence and social participation [2]. Pelvic floor muscle training (PFMT) is the first-line conservative management programme for women experiencing PFD.

The condition is a significant healthcare concern for the affected women and has a variety of causes such as childbirth and ageing. A recent study showed that even women who do not show any symptoms do not always know how to contract the muscles correctly [3]. Reports suggest that 70% of women are unable to perform correct voluntary PFM contractions and 97% of them showed low PFM strength [3]. PFMT can increase strength and endurance, particularly when coupled with behavioural training [4–6].

There are some devices in the market that help women carry out their PFMT. The devices detect the pressure applied by the pelvic floor muscles through an intra-vaginal physical device with pressure sensors that communicate via Bluetooth to a mobile app [7]. Existing devices include the LOOP [8], the SKEA [9], the KGoal [10], the PeriCoach [11], Elvie [12] and the Kegel smart [13]. While the use of these devices has been reported as helpful, their uptake has been slow and there seem to be barriers to their adoption [7]. Currently, there is no literature that reports on how the appearance of the devices may help women feel more comfortable in using them or help them understand its use, particularly in this area where education about its correct use is essential.

There are models that can be used to increase the patient's engagement to therapies. The IMS model recommends three steps: (1) information about the condition and how to adhere, (2) motivation to participate in the training and (3) a strategy to overcome practical treatment barriers to treatment adherence and incorporate the training into a daily routine [14]. We used this model to assess women's experience with PFMT and how they perceive the appearance of devices.

2. Methods

We analysed online commentary from PFD forums, carried out semi-structured interviews (45 min) and questionnaires (A, 20 min) with health professionals (three pelvic floor physiotherapists and one urogynecologist) and women with self-reported PFD (n:70; New Zealand = 24, USA = 22, UK = 13, Australia = 5, Canada = 4, Taiwan = 1, France = 1), ages 20–69 (median 35). A total of 54 women had children. We asked clinicians to describe the process for prescribing and monitoring PFMT and the main issues they have found for women using PFD devices. We asked women to describe their overall experience of using PFD devices, including how and how often they use them and any issues they have found with them.

We defined a set of design criteria through a thematic analysis of all the data and we used an iterative research-through-design process [15] to arrive to a testable physical device and mobile app. We asked women to watch a 5-min presentation that explained our design concept through video and to answer a second online survey (B, 15 min).

3. Results

We coded the findings from the literature review, online forums, semi-structured interviews and questionnaires with health professionals and women with self-reported PFD using NVivo (**Figure 1**). Below we present a deductive thematic analysis based on the IMS model and the responses from participants.

3.1. Information barriers

3.1.1. Female anatomy

A lack of information about female anatomy can be a significant barrier in the process of women carrying out PFMT or using devices. Women often do not understand their own anatomy, are unable to locate genital openings correctly, and may feel unreceptive to looking and touching their own genitals.

> *For many ladies that area of their body is still quite sort of shameful and unknown and so I take the view that for a lot of women they have not learnt anything about their body anatomically since year 7 science when it was embarrassing to say the words penis and vagina at school. (Clinician 04)*

> *I show them what their anatomy is like cause a lot of women have never looked at themselves. They don't know where the muscles are – so I point out the hip bone the pelvic bone and the*

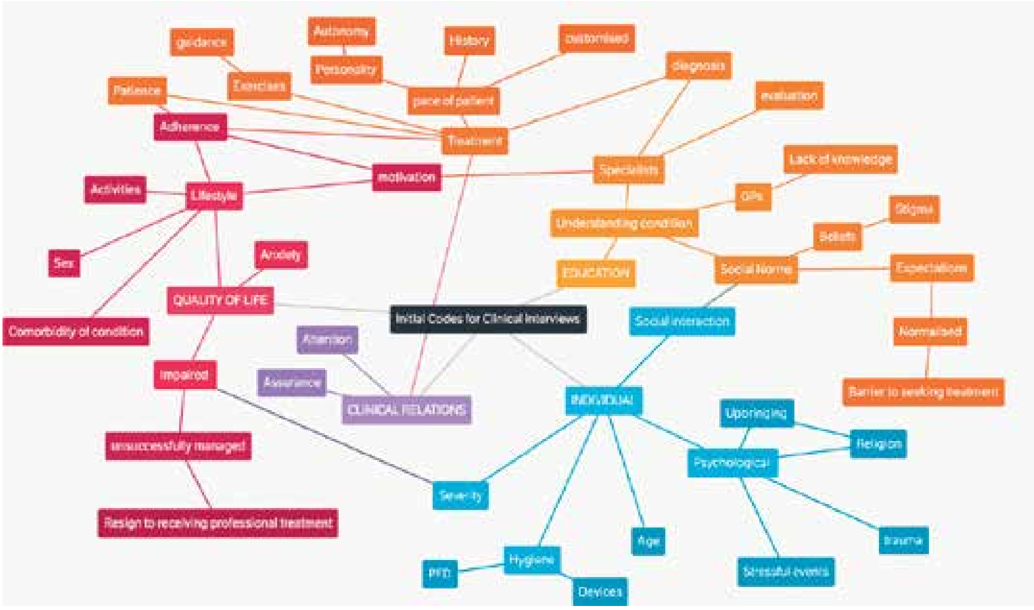

Figure 1. Initial codes from analysis of interviews with health professionals and women with PFD.

> *tailbone, I show them that the pelvic floor sits down here and wraps around inside and that it's not just some muscles sitting down there. Then I've got fairly basic pictures. Unless they have a medical background then I'd show them a more anatomical one. (Clinician 02)*

3.1.2. Appearance: clinical or like a sex toy?

Even though some clinicians use medical equipment that they rent out to women, one mentioned that sometimes sex toys get already used to relax the pelvic floor: "I buy the devices and then people borrow them off of me – I will give them out." (Clinician 01); "there are some people who actually use vibrators to relax the pelvic floor." (Clinician 02). The women favoured discreteness in form along with ease and simplicity of use. Comments given about the performance of the devices included, "good enough to lessen physical symptoms" and in turn reduce psychological distress. Some disliked their devices being too "clinical" in appearance. However, some women expressed that they did not want their device to appear too much like a sex toy because if features were too strongly associated with it, this would create a sense of psychological awkwardness for the user: "Don't like that it's so clinical, something more shapely [*sic*] without crossing into sex toy territory would perhaps make it less of an awkward experience." (Participant 04).

3.1.3. Muscle awareness and metaphors

Being able to contract the right muscles is determined by a muscle awareness that the women need to establish [4]. This muscle awareness can be difficult to develop due to the 'hidden location' of the muscles and lack of intrinsic feedback. Clinicians often use metaphors to teach women how to locate and move those muscles: "Going up in the lift… Puddle of water – sucking it in…" (Clinician 01).

3.2. Motivation barriers

3.2.1. Stigma and emotional responses

Clinicians pointed out that women can feel uncomfortable using an internal device. Reasons are the location where the device needs to be placed as well as the associated stigma with PFD conditions such as UI and faecal incontinence. Some women say: "Oh I don't like to poke those things inside of me in case I get an infection" (Clinician 01).

It was mentioned that women tend to be hesitant to talk about the condition and that once they have developed a feeling of trust they start opening up and talk about their symptoms:

> *And their GPs had sort of brushed them off. 'Oh, you know, it's just you. You just have to put up with it' you know, they trivialised it to them whereas, it's not trivial." (Clinician 03). Also, "It's just developing trust as well, people trusting you enough to say whatever the problem is, and I think when I realised there were so many people with those issues". (Clinician 01)*

As expected, more negative feelings than positive tend to be associated with the experience of having a PFD. Words such as "embarrassed" and "frustrated" were commonly used. Negative feelings contribute to the development of stigma as well as perpetuating these feelings when a condition has a stigma attached to it. Some women were worried their children might play with the device if they found it.

3.2.2. Ease of use

Respondents mentioned how some existing devices are difficult to learn to use:

> *The instructions are not clear. I have used this thing only once. A diagram would be helpful to show the correct way to insert the probe. Does it matter if the metal part is against the pelvic floor or to the wall of the vagina? (Participant 04)*

3.3. Design process

3.3.1. Design criteria

We defined set of design criteria for the form of the device and the app based on the different IMS themes. The form of the device should:

a. clearly indicate how it should be inserted and how it needs to be positioned, this may be done through familiar/related objects (tampons, sanitary pads, etc.) (information)

b. avoid the threatening appearance of some current devices (motivation)

c. express a high level of performance and professionalism that gives women reassurance (information, motivation)

d. avoid perpetuating the stigma of doing PFMT (information and motivation).

e. investigate the responses of looking medical or like a sex toy (motivation)

The app should:

f. teach women about their anatomy (information)

g. relate to metaphors women or clinicians use to carry out their exercises to facilitate muscle awareness (information)

h. present steps for carrying out exercises that use engagement principles from games and psychology (motivation)

i. present the exercises in an order and form that allows women to learn the right way of doing exercise and increase intensity (strategy)

j. develop a sense of trust through facilitating communication with clinician (motivation).

3.3.2. Design experiments

We developed different prototypes in an iterative process to address the criteria above (**Figures 2–10**).

Figure 2. Early form iterations that investigate criteria (a): forms to insert and position the device (bottom sides) and to hold it (top parts). For instance, the first form on the left has an elongated loop at the bottom that is slightly open, and closes when inserted and when applying pressure to it. The second and fourth shapes from the right intend to indicate that the bottom part is insertable by having shapes at the top that would be very difficult to insert.

Figure 3. Form iterations based on the shape of a tampon to indicate how to insert the device through the form of a familiar object (criteria (a)).

3.3.3. Testable design

The app and device we tested through online survey B is part of a system (**Figure 11**). The physical device has two parts. The slim top part is insertable and contains the array of sensors that had been developed by our engineering collaborators (**Figure 12**). This part has two states: a slim and minimally intimidating form for the insertion and an expanded form to secure the device once inserted that activates through bending the device into place (**Figure 8**). The wider part contains the electronic components. The app teaches women about their anatomy and

Figure 4. Colour variations based on devices that are currently available.

Figure 5. Experiments with an outer part that can be placed between the body and underwear to secure a stable position once the device is inserted.

creates an individualised programme based on the initial calibration of the device, which works as an assessment of the condition too.

3.4. Assessment of the testable design

Our initial findings suggested that the appearance of a device does not only involve a sense of aesthetics, but it should also communicate important issues for women that included: how

Figure 6. Iterations of regular and irregular patterns that guide the user during the insertion through tactile feedback offered by the form of the device and its texture. The textures also intend to mimic jewellery to minimise stigma (criteria (b) and (d)).

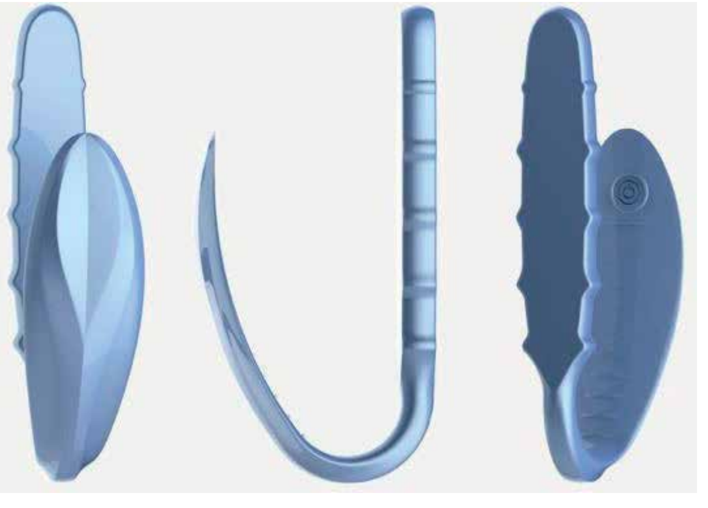

Figure 7. Once the device is placed at the right position it needs to be stable during the training. One of our iterations investigated how small wings appear once the top is bent to stabilise the device.

intuitive it is to use, how professionally it will treat women and their condition, how the sensors work and where they should be placed.

Positive feedback included the quantifiable results ("quantifiable results would be incredibly helpful", participant 4), ease of use, and the immediate assessment and feedback that the system offers during training. Some participants requested a colourful appearance while others found the paler colour more appealing. Participants understood the value of

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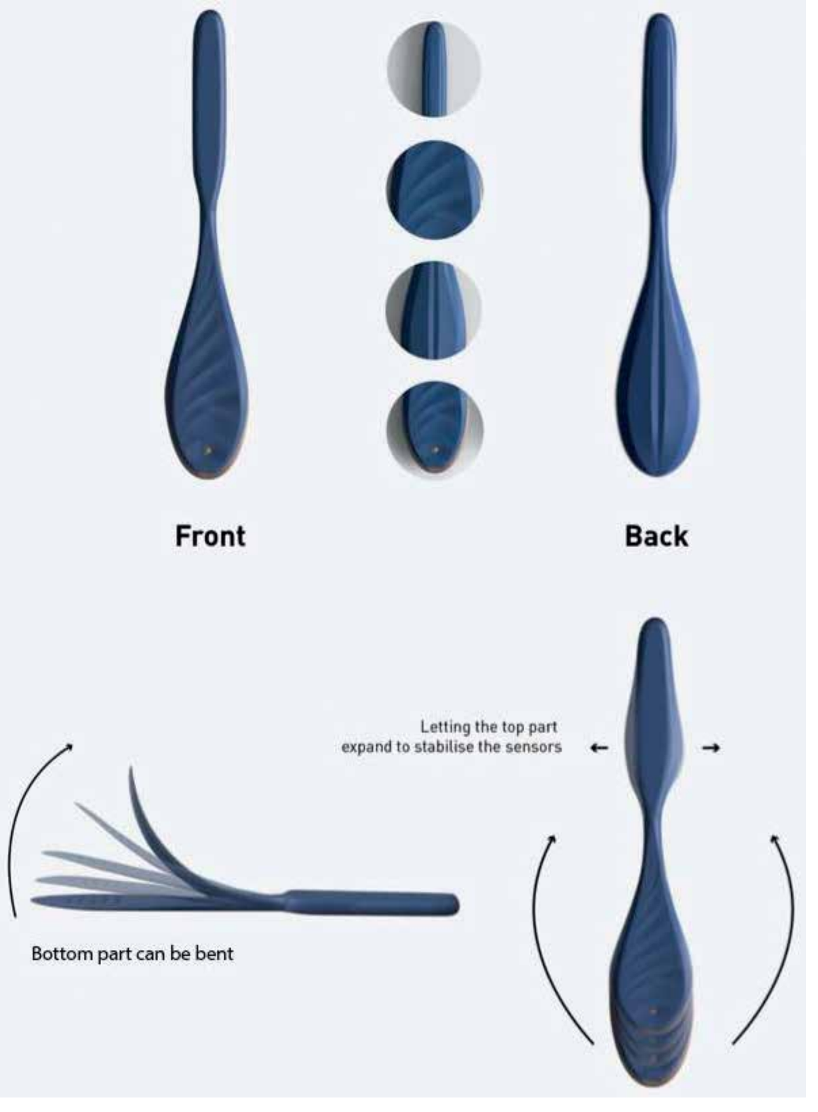

Figure 8. Bending of the bottom part to stabilise the sensors (by becoming wider) while looking as little threatening as possible (small and thin) when it needs to be inserted (criteria (b)).

including sensors: "[I like] that it shows how strong the muscles are and if you're using the wrong ones" (participant 6). Other participants liked its discreetness: "I like that it is discrete and quite private, with the training times set to suit the user" (participant 1). A participant was worried about whether the device would sit on her clitoris.

3.5. Final design

We used the feedback to define a final iteration of the design (**Figure 13**).

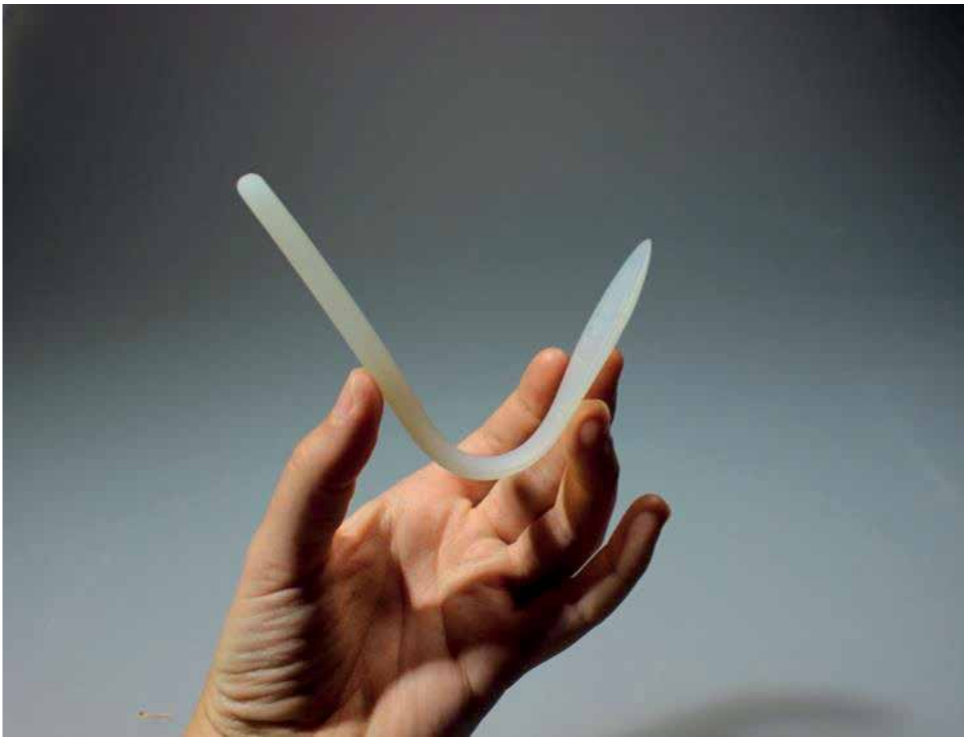

Figure 9. 3D printed prototype to test bending.

Figure 10. Tests with different materialities looking for a high performance and professional feeling (criteria (c)).

Figure 11. User scenario.

Figure 12. The physical device we tested with participants.

Figure 13. A render of the final design based on feedback from users.

4. Discussion

Women who experience PFD are a diverse user group. Depending on the severity of the disorder they can have different symptoms, be from different age groups, experience a significant degree of shame and stigma, and the dimensions of the human vagina can differ significantly. All of these questions the assumption that one device fits all [16].

Women reported different expectations on how such an intimate device should look. User feedback indicates a discrepancy of expectations concerning the visual aesthetic of such an intimate device. There were some women assessing our design who wanted it to look like a medical device while other would prefer it to be more playful and even resemble and be used as a sex toy. We suggest that further research is necessary to investigate the motivations behind these preferences and how designs may address it. Further studies could investigate from a design perspective where form-wise lies the tipping point between clinical device and sex toy; build functional prototypes and test them with women in order to assess the usability and interaction with the device over long-term use.

5. Conclusion

This paper reports on what factors should influence the physical appearance of an intravaginal device to help women carry out pelvic floor exercises. A review of the literature, interviews and questionnaires with clinicians and women with PFD helped us develop a set of criteria that we used to design a device and app for PFMT. User feedback indicates that there are different expectations about the aesthetics of such an intimate device. This discrepancy in expectations and the fact that the range of disorders and users can differ rather significantly suggest that individualising the device might be an appropriate strategy to address the demands of this diverse user group.

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Section 3

Adaptation to Interactive Technologies - Domestic Digitization

Designing for Embodied and Rich Interaction in Home IoT

Joep Frens

Additional information is available at the end of the chapter

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Abstract

Internet of things (IoT) artifacts form systems where touchscreen and speech interaction is the norm. As IoT systems are inherently open (artifacts can be added or removed, software can be updated), we observe that the natural state of an IoT system is changed, "growth." This chapter describes a designerly experiment exploring how to design for embodied and rich interaction in these "growing" IoT systems. We present four design cases showcasing four approaches to the design challenge: a hybrid, a modular, a shape changing, and a service approach. We describe and appraise the four approaches and discuss insights from the designerly experiment. We conclude that it is indeed possible to design for embodied and rich interaction in "growing" IoT systems and see our work as a first step toward diversifying IoT interaction styles.

Keywords: rich interaction, embodied interaction, growing systems, internet of things, design

1. Introduction

The design of socio-technical systems receives an increasing amount of attention. Systems concepts that have been explored in literature over the past 2 decades (e.g., ubiquitous computing [1], pervasive computing [2], ambient intelligence [3]) are now brought to the market as the "internet of things" (IoT) [4].

The primary interest of this chapter is the human-product interaction within IoT systems in home and we feel inspired by research areas like tangible interaction [5], embodied interaction [6], or rich interaction [7]. The academic community gives a range of arguments for the value of tangible, embodied, and rich interaction: Ullmer [8] argues that we have a familiarity with the physical world around us that we can capitalize on when making interfaces tangible. The field of embodied cognition adds the argument that we make sense of the world and its complexity through the physicality of it and the situatedness of our actions [9], for the latter also see [10].

Hummels and van der Helm [11] makes the argument for resonant interaction and argues that different people prefer (*resonate with*) different interaction styles, including tangible interaction styles. Finally, van Campenhout [12] argues that the value of tangible, embodied, and rich interaction must be sought in esthetics (the esthetics of the third stand). This esthetic cannot be either in the physical or in the digital alone; it only exists in the coupling of the two. Making physicality an important prerequisite for esthetics of interaction.

Despite this compelling rationale, these interaction styles are not landing in industry; neither in the interactive products on the market, nor in home IoT that is dominated by (touch)screen and speech interaction (e.g., Philips Hue [13], Reality Editor [14], IFTTT [15], Amazon Echo [16]).

Where academics and industry are currently operating in their own world, we feel that home IoT can be crucial in bridging the gap between them. IoT revolves around "*things*": artifacts that stand in the tradition of the objects that we used before the world was interactive (e.g., coffee mugs, kitchen appliances, lamps, or stereo equipment). These artifacts inherit interaction styles from this tradition; interaction styles that are familiar, situated, and that resonate with specific people because of their esthetics in interaction. As electronic "intelligence" pervades our living rooms through home IoT, we can capitalize on these qualities and explore how tangible, embodied, and rich interaction can be made to fit these IoT systems. At the same time, we consider home IoT to be an inherently complex phenomenon and see opportunity to help people make sense of it by adopting a more embodied and rich interaction style.

This leads us to explore what it takes to design for embodied and rich interaction for home IoT. In what follows, we introduce a designerly experiment and present a student design challenge that was setup to explore embodied and rich interaction in home IoT. We present four different design approaches to solve the design challenge. After discussing the approaches, the chapter concludes with a brief look into future work.

2. A designerly experiment

In this section, we introduce our designerly experiment and its theoretical backdrop.

2.1. Internet of things as a growing system

At present, the internet of things [4] is promising us a connected future, where IoT artifacts produced by different manufacturers form networks of products in the home, IoT systems. There are ongoing efforts both in academia (e.g., Semantic connections [17], Reality Editor [14]) and on the market (e.g., Home kit [18], IFTTT [15]) to truly make the connected future in home IoT, a reality, but these are not yet fully adopted.

We see IoT systems as inherently open (IoT artifacts can be added or taken away and software can be updated) and we observe that the natural state of an IoT system is a change (we label this as "growth" indicating that home IoT grows to match the preference of its user). This means that the functionality in IoT systems is not stable. The consequence of adding or updating IoT artifacts means that on a system level, functionality can emerge in unpredictable

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ways because of how the IoT artifacts are combined by their users. We feel that when IoT systems become truly connected, forming actual "growing" systems, emergent functionality becomes one of its more fascinating features. At the same time, emergent functionality will be a challenge to design for. This has consequences for the design process [19, 20] and the interaction solutions in IoT.

2.2. Embodied and rich interaction

We position the design challenge in embodied and rich interaction. Embodied interaction is defined as: "*the creation, manipulation, and sharing of meaning through engaged interaction with artifacts*" [6,p. 126]. Embodied interaction is a perspective on interaction that emphasizes that one can meaningfully interact with the world through doing rather than through knowing, resonating strongly with Gibson's work on ecological perception [21], and the research area of tangible interaction (e.g., [5]). Rich interaction [7] shares this theoretical basis and can be regarded as a product centric exponent of embodied interaction.

The rich interaction framework is aimed at designing for meaningful interaction by respecting all human skills (i.e., perceptual-motor, cognitive, and emotional skills [22]) and by designing for a unity of form, interaction, and function. This results in strong-specific [23] interactive products that express in their form what can be done with them, both from an action point of view and from a functional point of view: they give feed-forward. Below we give two examples.

2.2.1. Rich actions camera

The rich actions camera features rich action possibilities that express their functionality in form and interaction (**Figure 1**). For example, to take a picture with this camera, the user pushes the "trigger" at the side of the screen. The form of the "trigger" invites the thumb to push. The trigger

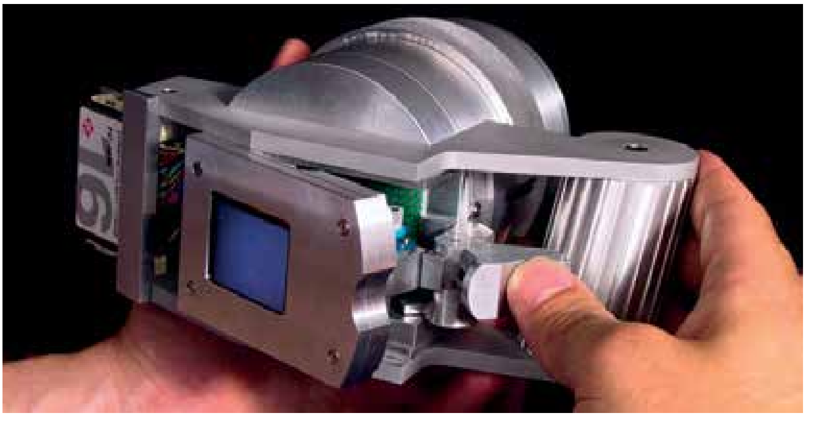

Figure 1. Rich actions camera by Joep Frens [7, 24].

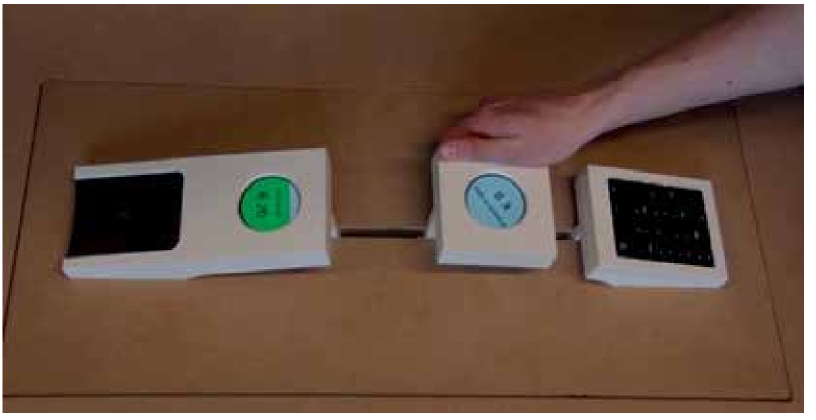

Figure 2. Third stand payment terminal by Lukas van Campenhout [25, 26]. (Photo courtesy of Lukas van Campenhout.).

is also shaped such that it keeps the screen in place. When the "trigger" is pushed, it releases the screen. The screen flips away from the lens on a hinge and a photo is taken (also see [24]).

2.2.2. Third stand payment terminal

This payment terminal (**Figure 2**) is designed to bring digital monetary transactions back to the physical. The vendor (right hand side) enters the price of a purchase and pushes the "traveler" (i.e., the construction with the round screen) toward the customer side. In turn, the customer places a payment token (not shown) on the physical drawer and pushes it into the terminal, simultaneously pushing some of his (digital) money toward the vendor. The traveler accepts the digital money and (physically) moves back to the vendor side [25, 26]. The payment terminal expresses in its form and behavior how the transaction plays out and invites for different actions during the process of payment.

2.3. Research question and research aim

When we look at embodied and rich interaction through the lens of "growing" IoT systems, they seem to be incompatible at first glance. As already mentioned, there are preciously few (if any) examples of IoT artifacts that offer an embodied and rich interaction style. Arguably, redesigning the IoT artifacts could easily solve this. But this is not where the incompatibility and hence the complexity lies. As argued above, we consider truly connected IoT systems to be "growing" systems where functionality is inherently dynamic and emergent. The result of this is that functionality is undetermined at the time of designing, the connected artifacts that live within IoT systems. This is an ill fit with the rich interaction paradigm that aims for meaningful interaction by expressing functionality in form and interaction; it is problematic to express in form and interaction that what is not known yet. To understand this better, we formulated two research questions. Our first research question approaches this "looking forward" and asks: "*how to design for embodied and rich interaction in 'growing' home IoT systems*." Our second question "looks back" and asks: *"how does the concept of rich interaction needs to change when applied to 'growing' IoT systems*."

Figure 3. A media center with dedicated remotes.

This research aims to inform interaction design within a home IoT context by example and reflection. We intent to find approaches to this design challenge but also learn from these approaches how rich interaction itself changes.

2.4. Design challenge

We chose an IoT media center as the context for our design challenge (**Figure 3**). This media center was a small media server with a range of input and output devices in a home context. At present, each (software or hardware) component that is added comes with its own dedicated remote control. These remote controls were to be replaced by a new “growing” remote control offering an embodied and rich interaction style. The “growing” media center is easily recognized as an IoT system and has a clearly visible way of how it can “grow”: by adding new (software or hardware) components. Which components are added was up to the students. Finally, the challenge sets the stage for functionality to emerge as new components combine with existing parts of the media center to create functionality that is neither present in the existing components nor in the new components alone.

3. Four approaches to design for growth

Starting in 2010 and ending in 2014, we gave our students the challenge to design a “growing” embodied and rich interface for a media center. The semester long design challenge was open to industrial design students doing their final bachelor project, first year master project and final master project. The challenge yielded over 20 cases that we have analyzed for differences and similarities. We found four patterns with clear differences regarding approach.

In what follows, we present these patterns by means of four design cases. We chose to present recent cases that demonstrated the patterns best.

3.1. Hybrid approach

Hybrid solutions are perhaps the simplest route to success in this design challenge. It comprises combinations of screen-based interaction with rich action possibilities. Typical for this approach is that it employs a screen to deal with the aspects of "growth" and change and that it makes use of rich action possibilities for the aspects of the interface that are not subject to change.

3.1.1. Ball remote

Joep Elderman showed a design for a remote control for a media center that features a ball-shaped token that is placed on top of a horizontally placed screen (**Figure 4a**). The position of the token is tracked. The user can move the ball token, but it can also move autonomously. On top of the screen, a template is mounted that has two indents and a round track where the ball can be placed to access the functionality. The ball can be loaded with multi-media content and will playback this content when placed in the circular track. Playhead control is achieved by manually moving the ball in the track (after which it moves autonomously) or by stopping the ball (**Figure 4d**). When the ball is taken from the circular track, the whole surface of the remote control shows GUI elements, by placing the ball on these elements a menu structure is entered to access more complex or emergent functionality (**Figure 4b**, **c**).

3.1.2. Appraising the hybrid approach

The benefit of this approach is that it offloads the complexity of dealing with emergent functionality to the screen and to conventional menu structures. These are good at adapting to new content or incorporating new functionality [27]. On the other hand, the potential of embodied and rich interaction to offer a more direct and less mediated interaction style that emphasizes man as a whole rather than just his cognitive skills is only partially met. The promise of a physical interaction style literally giving handles on the complexity of systems is not completely fulfilled. In this approach, it is crucial that the coupling between the physical action possibilities and that what happens on the screen is designed to fit each other specifically. Generic menu structures need to be avoided.

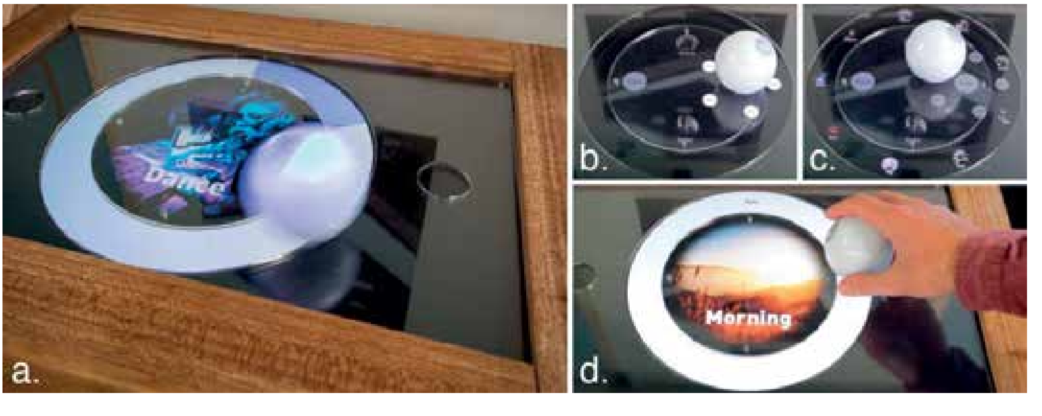

Figure 4. Ball remote by Joep Elderman, 2014 (Photos courtesy of Joep Elderman). (a) Song playback, ball is moving in a circular track; (b, c) Placing the ball on GUI elements accesses menu structures; (d) Playhead control by manually manipulating the ball on the circular track.

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3.2. Modular approach

An approach that is very prominent in the work of our students is the use of modularity. By creating inter-connectable interactive modules, each offering dedicated rich interaction, remote controls can be "composed" that "grow" together with the system that they live in. This approach takes cues from early work on modular interfaces like DataTiles [28] or more recent work on generic and modular tangibles [29, 30].

3.2.1. Tiled remote control

Jordy Rooijakkers created a series of interactive tiles (**Figure 5a**, **b**) that can be used to layout a specific multi-media system and through which multi-media content can be moved by means of an interactive viewer/selector tile that sits on top of the other tiles (**Figure 5c**). The interactive viewer/selector tile has different behavior depending on which tile it rests. It offers a rotary control at the side (**Figure 5d**) that can be used to make a media selection. If desired, this selection can be "grasped" and brought to a different tile by squeezing it (**Figure 5b**). Adding new tiles to the remote control can open up new media center components.

3.2.2. Appraising the modular approach

The modular approach is capable of responding to the "growth" in "growing" IoT systems: when the media center gets a new component, this can be matched by adding a new component to the remote control and it can do this while offering embodied and rich interaction where each component of the remote control can be designed to express its function in its form and interaction. Still, there is one challenge that it does not solve: the challenge of dealing with emergent functionality. Interactive modules open up dedicated functionality of specific components. Emergent functionality is in the combination of components and not in a specific component and that makes it difficult to grasp emergent functionality by means of a modular approach.

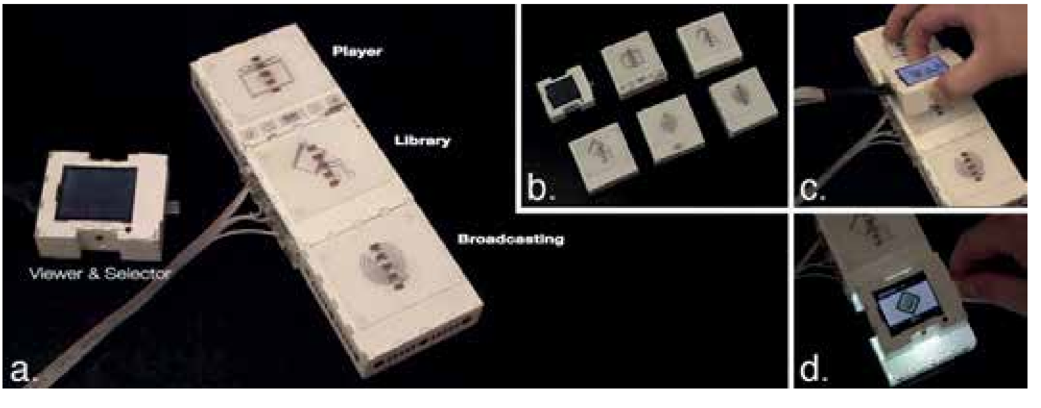

Figure 5. Tiled remote by Jordy Rooijakkers, 2014 (Photos courtesy of Jordy Rooijakkers). (a) Music player, library, and broadcasting tile and the viewer/selector; (b) A more extensive set of tiles; (c) Moving media from the library to the music player; (d) When the viewer/selector is attached to the broadcasting tile it can be used to choose a TV channel.

3.3. Shape changing approach

A promising approach is that of shape change. Where the modular approach "grows" through addition, the shape change approach is self-contained and changes shape under computational control: an interactive node could present new, rich action possibilities in response to "growth" of the systems. That our students are not alone in seeing this is clear from the abundance of literature on the subject (e.g., [31–33]).

3.3.1. Adaptive remote control

Paul van Beek designed an adaptive remote control (**Figure 6a**) for controlling a video on demand system. His remote control offered basic interactions for navigating a screen-based menu structure in its default shape (**Figure 6b**). When more specific controls were needed, the remote control responded by sliding open and offering more (physical) controls (**Figure 6c–e**), which controls and the amount of controls visible on the slider could be varied as a response to the activity of the user by sliding the remote further open or closed.

3.3.2. Appraising the shape changing approach

If we share Ishii's vision on Perfect Red [31], a programmable material that can take any shape, shape change potentially solves the "growing" IoT systems challenge. Yet, at present technology has not advanced to the point that matter is truly under computational command. Till that moment, the shape changing approach relies on mechanical solutions. These mechanical solutions toward "growing" IoT systems share a problem with the modular approach in how to deal with emergent functionality: it is difficult to design for shape change if it is not known

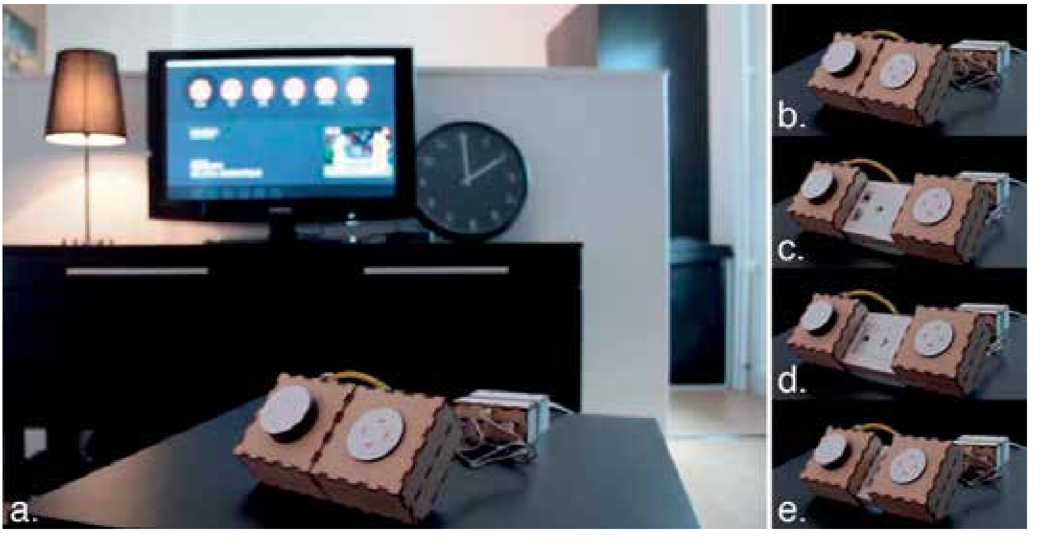

Figure 6. Adaptive remote control by Paul van Beek, 2014 (Photos courtesy of Paul van Beek). (a) The adaptive remote control in context (closed state); (b–e) Depending on the requirements of the task the remote control opens en gives context dependent controls on the slider in the middle.

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what the desired changed shape needs to be. That is not to say that in constrained situations, this approach cannot be of value: shape changing controls can be designed that do offer changing forms to express changing functionality and accommodate changing interactions.

3.4. Service approach

A final approach to deal with rich interaction in "growing" systems that we present is a service approach. This approach responds to the challenge by means of updating the interactive nodes by replacing its interaction surfaces in short cycles as a service, creating opportunities for "hyper-personalization" of embodied and rich interfaces, somewhat similar to commercial approaches like NikeID [34] and such. Strictly speaking, it is a variation of the modular approach, but it offers much more integrated solutions and hence is singled out as a separate approach.

3.4.1. Generated remote control

Tom Fejèr presented a remote control for the "growing" media center that revolved around personal media use (**Figure 7a**, **b**). He proposed a design that would follow a user's preferences in media, giving direct access to his favorite songs or series. The rationale was that as media use changed, the remote control would need to change in shape and action possibilities (**Figure 7c**). This would be done by printing new, parametrically generated shapes on a regular basis. His remote control featured a touch sensitive core where the 3D–printed shells were placed over. While the example shows a faceted touch surface, the premise was that also rich interfaces could be algorithmically generated.

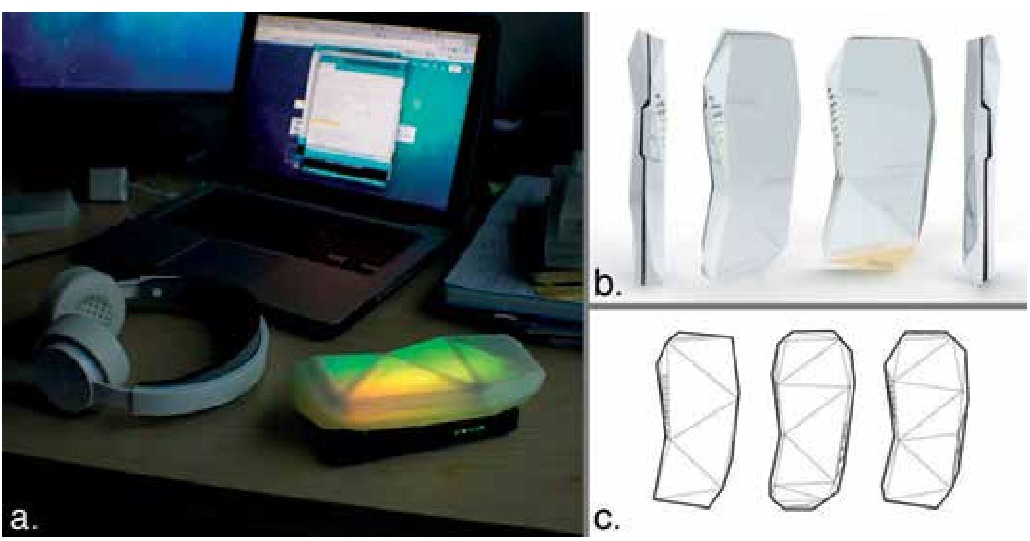

Figure 7. Generated remote control by Tom Fejèr, 2014 (Photos courtesy of Tom Fejèr). (a) A working prototype of the generated remote control in context; (b) A render of the design, the surface can be touched to access multi-media context; (c) Three different shells that can all be attached to the same sensing hardware.

3.4.2. Appraising the service approach

When interactive nodes can be updated by replacing its interaction surfaces with newly designed interaction surface, the "growing" IoT systems challenge is solved as a unity of form, interaction, and function can be guaranteed. The service approach has a solution for the changing of form and interaction to open new functionality but the challenge of designing these interaction surfaces remains. The example shows a parametrical implementation and these have similar problems as the shape change approach: the software needs to be designed to generate expressive geometry without knowledge of what sort of expressivity is needed. If the service approach follows the template of the example (i.e., a high-tech core with customizable interaction surfaces), the question also remains how to design the "interface" between the technology and the interaction surfaces flexible enough that the remote as a whole can deal with the dynamics of "growing" IoT systems.

4. Discussion

Here, we take the time to look back at the designerly experiment and reflect on our research questions: (1) *"how to design for embodied and rich interaction in 'growing' home IoT systems"* and (2)*"how does the concept of rich interaction needs to change when applied to 'growing' IoT systems."*

4.1. Designing for embodied and rich interaction in growing home IoT systems

In answering our first research question, we first look back at the design processes of our students. Our students particularly stumbled over the "openness" of the challenge that is caused by the requirement of having "growing" interfaces. It seemed that the complexity of the challenge paralyzed them and made them try and out-think the challenge rather than to tackle it through designerly exploration. A successful design strategy proved to be to artificially constrain the challenge and harness the openness by starting to design "loci of interaction" for three or four pre-defined states of "growth" (**Table 1**). In this manner, grip on the phenomenon of "growth" and emergent functionality could be acquired by studying the state transitions in a controlled manner to generalize a strategy to deal with "growth" when the artificial constraints were lifted.

Next, we look at the benefits of the four approaches toward solving the challenge that we presented. We feel that there is not one approach that can be singled out as the ultimate solution to the challenge, let alone that a "recipe" can be formulated, more research is necessary. At the same time, we feel confident in saying that it is not impossible to design for embodied and rich interaction in a home IoT context as the four approaches show promising

State 1	streaming video
State 2	streaming video + hard-disc recording
State 3	streaming video + hard-disc recording + distributed audio

Table 1. States of growth.

directions. The four approaches act as "templates" (to be used singularly or combined) to inform the design process of designing for embodied and rich interaction in home IoT (growing systems) and provide more grip on the "openness" of the design challenge.

4.2. Reflecting on the changes in embodied and rich interaction

It is clear that the openness (caused by "growth" and emergent functionality) in the design challenge goes against the grain of the designed unity of form, interaction, and function that is one of the defining features of rich interaction (as a product centric operationalization of embodied interaction). As a result, this designed unity needs to be reconsidered; the unity should be released but not left. The hybrid approach proposes to have a standard set of rich and specific controls, designed as a unity but releases the unity through screens that offer more generalized controls. The modular approach offers rich and specific modules that each can be designed as a unity but the unity is compartmentalized in modules. The shape changing approach potentially offers a unity but necessarily releases it in the design process due to the openness of the challenge. Finally, the service approach can potentially offer rich and specific controls that are designed as a unity, but this unity is likely released due to the compromises that need to be made in mating the rich and specific interface to the generic technological parts (this is particularly true in the design example that is given).

5. Concluding remarks

Lastly, we discuss the contribution of this chapter and come back to the value of embodied and rich interaction for "growing" IoT systems. We see value in the exploration of alternative interaction styles in the context of home IoT as we give interaction designers the tools and exemplars to design IoT interfaces appropriate for their functionality, context of use, and fitting the preference of its user (s). This diversify the interaction styles in IoT but also implies the promise of *multi-specific* IoT artifacts (amplifying the notion of strong-specific products [23]) that can be tuned to different tasks and that stay relevant and meaningful while the IoT systems "grow." Next to this, we see value in the framing of IoT systems as "growing" systems and the consequences this has on the design process of embodied and rich interactive IoT artifacts in four approaches.

6. Future work

The next step is to further investigate the four design approaches. The approaches themselves, with all of their idiosyncrasies, need to be better understood. Next to this it is well possible that more approaches to accommodate "growth" in IoT systems can be formulated. We imagine combinations of the existing approaches but we are also searching for new approaches.

Next to this, we are particularly interested in exploring distributed approaches toward designing for interaction in "growing" IoT systems. While the centralized approach has had its use in this research driven design challenge by offering constraints to make the approaches comparable, it is not to say that it should be copied to any IoT systems design challenge. In fact, the argument could be made that particularly embodied and rich interaction (informed by tangible interaction) takes a spatially distributed approach, necessitating the consideration of distributed schemes or mixed schemes.

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Facing Digital Dystopias: A Discussion about Responsibility in the Design of Smart Products

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Additional information is available at the end of the chapter

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Abstract

The paper investigates some critical issues connected to the digitalization of products and systems for the domestic environments involving the collection of personal data. The research focuses on the most innovative solutions, such as those based on AI algorithms for speech recognition, IoTs, wearable devices, cloud computing, and the use of smart phones and devices. These solutions require and imply the collection of personal data and their local or remote processing. The paper provides a design-oriented discussion on the features of smart products with respect to the consequences of design choices on complex dimensions of experience such as sense of self, privacy, and personal identity. The paper aims to set out the terms of a discussion about the most critical factors of services and systems involving personal data, and to create references on the responsibilities of designers acting in multi-disciplinary project teams. The research is based on ethnography at home and on a critical discussion about case studies. The results highlight the importance of considering privacy and control issues in the design of smart solutions and provide some pointers to be used in the development of smart solutions for home.

Keywords: smart products, personal data, personal identity, ethnography at home, design, automation, interaction design, responsibility in design

1. Introduction

The evolution of IoT technologies, of AI algorithms, and of cloud services allows the design of responsive products and environments, and supports the development of new approaches to the design of interactive solutions in every domain of application: human-machine, human-environment, and human-human systems [1].

These innovative solutions provide several valuable advantages for users, in terms of convenient functionalities and improved modalities of interaction between human users and technological systems. Many products and services aim to support users in the monitoring of personal well-being conditions and lifestyles, and to improve the modalities of interaction between users and the environment through the development of new control paradigms. Most of these products rely on the collection of data regarding the users and the contexts, and on their shipment to remote service providers, allowing post processing and final delivery of suitable information or other performances. Cloud data storage services, APIs offered by big companies such as Google and marketplaces such as Mashape, AI agents and other 'pieces' of technology, appear today as building blocks that designers can use to create useful interactive solutions for valuable experiences. Indeed, these creative opportunities are without precedents and open a new era for human beings. A new era, which as many other dawns before, carries shadow within as well as the light of new interesting and useful possibilities.

As designers, researchers, and educators in the field of interaction design [2, 3], we consider the recent evolutions of digital technologies as a great opportunity to invent/design valuable products and services. On the other hand, the creation of innovative solutions based on IoTs, on remote processing of data, and on cloud resources provides new challenges for designers. In terms of continuous updating of competences and techniques, the ability to deal with the progressive dematerialization of the object of design from fixed carrier to network and services [4], with a growing complexity of the designed systems also requiring the ability to re-define the role of designers in multi-disciplinary project teams. Furthermore, due to the dimension of the impact of digitalization on private and public aspects of life, we believe in the importance of developing a critical thinking and discussion on ethical issues emerging when dealing with radical innovation. We aim to entice the development of full awareness about the design factors that determine the acceptability and desirability of a product.

In this paper, we focus on the latter of these challenges. We intend to give a contribution to the related discussion by investigating the relationship between the physical and interactive features of the so-called smart products based on cloud computing and on responsive remote processing of data, and the dimensions of personal experience involving the sense of self and the sense of privacy. In our research, we investigate the topic in a wide perspective through a variety of different applications. We focus on products and services designed for domestic environment, the production, and use of personal data from a design perspective. We consider different applications: systems for home automation, devices to centralize the control of domestic appliances, and solutions for monitoring health and personal status.

2. Framing dystopias

The importance and value of data as "the new raw material of the 21st century" is now a common knowledge [5]. Defining *Personal Data* as "data that relates to a living individual who can be identified from those data, or from those data and other information" [6], we can divide information in to two categories: direct and processed. *Direct information* is the information extrapolated directly from the data. It is detected as it is and can be used as single value

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for control and input. *Processed information* is the value derived from a data processing that crosses more than a value (e.g. heart bit rate and age of the subject).

Indeed, the potentials of personal data collection is now amply recognized as a source of opportunities to generate new services and products, also to produce long-term consequences on the organization of main structural social assets, such as those concerning health care services, energy and resource management, public transportation facilities and so on [7]. On the other hand, dealing with personal data reveals critical issues involving safety, security, privacy, and others [8, 9]. Indeed, through the construction of digital networking of objects, spaces, and people, we are creating the new hybrid digital/physical environments where we will live in the future. Therefore, in the design of smart solutions, we face a double challenge: on one side, we must design safe solutions, protecting users from risks of fraudulent abuse of their data and of conditioning based on social engineering manipulation. On the other hand, we should avoid the risk of producing unwanted consequences on social and individual attitudes, freedom and mental frames through the shaping of interactive processes inadvertently inducing conditioning or limits. The physical world's way of saying "The tool shapes the function" is already on the digital domain. We receive suggestions by recommender systems according to our preferences [10], we are invited dressing clothes suggested by algorithms [11], we maintain friend's contacts under the influence of systems analyzing affinities among people, just to mention a few cases. In the current times, we no longer rely on those big social institutions (such as political or religious ones), not as much as we did in the previous centuries [12]. Automatic personal data analysis and usage present, in our opinion, the risk of shaping our life as single individual and communities, in a phenomenon that designers must be aware of.

The management of critical factors requires the joined efforts of three different domains: *regulatory laws*, *responsible technology*, and *design*. *Regulatory laws* producing principles and norms regulating the right to privacy of citizens and identifying responsibilities. *Responsible technology* producing protocols and technical solutions for the suitable management of data and of their destiny in the meanders of the cyberspace. Lastly, *design*, ideating and creating products, services and interfaces enabling the rightful control on the personal data acquired by services.

In this paper, we focus on the last one, and we argue that designers should develop a better awareness of the importance of personal data's correct handling in the development of products and services, especially for those meant for domestic use, due to the importance of home being (and being perceived as) a private and safe place, as treated later in more detail. Furthermore, we believe that the responsibility toward the correct use of personal data is one of the constraints that should be considered in the design of smart solutions, both to create suitable products and services complying laws and ethical principles, and to produce awareness.

3. Investigating attitudes and feelings through ethnography at home

In springtime 2016, we involved students (almost 100) of a university course in Interaction and Experience Design at the School of Design at Politecnico di Milano, in an ethnographic investigation of domestic environments. This activity produced a high number of cultural probes documenting behaviors, habits, rituals and attitudes at home, concerning people of different age, profession, and social conditions. The investigation has been part of an educational process including lectures on design for experience, and on emotional and cognitive processes involved in actions. It was not directly aimed to the design of a product or service, on purpose intending to demonstrate the suitability of aimless ethnography to provide suggestions for the creation of technology-based interactive solutions out of existing schemes. The observation on field focused on several daily tasks taking place in the domestic environments, such as entering/leaving home, entertainment and leisure, getting ready to go to bed, and so on. The collected documentation reports about feelings, expectations, values of inhabitants, and in the whole, it provides several hints toward designing suitable interactive services and products [13, 14].

With respect to the focus of this paper, the investigation produced some interesting results that can be summarized in the following statements. In our country, most people see home as a shelter and a space of freedom; a repository of most beloved objects and memories; a place to develop the most intimate relationships and where it is possible to develop a personal lifestyle. At home, it is possible to express personal esthetic preferences and values; the formal and functional organization of the house plays an important role in the definition of the sense of self.

The practical organization of objects and activities is tightly related to personal preferences and to those specific models ruling social relationships among the ones sharing the house. Part of observed people appears willing to have a tight control of the functional and esthetic settlement of their private environment; furthermore, they pay attention to their privacy and feel anxiety related to the moments when they leave/enter home.

The survey documents a variety of attitudes and behaviors, but also stresses the relevance of the topics we are focusing on, such as safety, security, and privacy. Privacy is a complex subject, since what we intend with this term varies with each person and each social environment. It also changes with time. Each single individual's life moment and each social era have different privacy perceptions. It is also tightly connected both with personal values and cultural belongings, as well as with other feelings and attitudes such as personal freedom and sense of decency. Digital technologies make the meaning of privacy evolve, and pose new challenges and questions in terms of civil laws concerning ownership.

In order to design acceptable and desirable home automation solutions, designers should consider reliability of products and services toward privacy needs a primary issue, to be managed through suitable design choices.

4. Personal data and information in everyday objects

We, as human, live and act in the space around us. Smart environments, smart and wearable objects, and IoTs detect precise information about us and about our behavior through sensors' data. These products have become part of people's contexts as everyday objects in the private field, at work, and in the different outdoor activities. They represent an evolution of the use of the everyday objects, driving technology, with its power and possibilities, to be imperceptible. Smart and reactive environments are made not only by integrated systems, but also by everyday objects that evolve in nodes of an interconnected network collecting, storing, processing, and spreading information. The use of these objects creates a set of personal information that is useful for various functions of the object itself and for the integration of new functions and services as well.

Although this information is undoubtedly useful for the operation of proactive and intelligent systems, it is necessary to face the effects on user's sensitivity and awareness concerning the collection and spreading of information about them.

We intend *personal identity* as the set of stigmas that allow identifying a person through their characteristic elements, peculiarities, and traces in space and time [15, 16]. The use of personal data arrives with multi-level impacts. Concerning privacy and security, the simple use of connected cameras allows the detection of personal identity [17] through facial recognition and tagging [18]. Combining this recognition with a position triangulation (e.g. based on a GPS), it is possible to associate the person to a position in space and time. Concerning the perception of self, most people nowadays are faced with identity doubling. In one hand the physical everyday life, on the other hand the digital identity that include the sum of all the information about an individual that are digitally available [17]. A scenario presenting a further complexity layer, due to the possibility of a single person having multiple digital identities; social media, MMORPGs and other community-based system allow and encourage users in creating profiles which often can grow the features of self-standing personalities. It is the well-known concept of the role mask, extended in the digital field, in which our roles might not be easily traced back to the original human beings [19, 20].

As designers, we embrace the creative potentials connected to several dimensions of existence made possible by digital technologies. On the other hand, we recognize the control of one's personal information as a natural and universal right of the ones producing them, and dealing with the design of domestic smart appliances, we consider it as a primary issue.

5. The intimate automation

The collection of data through the use of wearable devices such as smart-watches, or through the sensors embedded in most smart phones (accelerometers, audio and video recorders, light sensors, GPS, and so on), allow the processing of personal information on behaviors and contexts, producing valuable and affordable tools to monitor lifestyles and personal health conditions. The sensors integrated in devices as Fitbit for lifestyle, Beast for sport performance, and MedicAlert bracelet for epilepsy monitoring [21–23] allow these devices to constantly detect biological parameters and process data to create value for the users. These systems provide the opportunity to record information to be shared with caregivers, but also to obtain immediate feedbacks thanks to online processing of personal data and the use of suitable algorithm for the modeling and interpretation of activities and contexts.

This approach to the use of personal data on devices and IoT solutions is not strictly related to health monitoring: it is currently widely spreading in many fields of application, such as sports and work performance.

Analyzing the home automation products and services, the personal data stand out as a sort of raw material to be analyzed, processed, and crossed with other data aiming to enable functions and proactivity of the system. The user can perform different actions through the use of automated systems in the intimate context of the home. Actions spanning through the precise control, monitoring, pre-set of single activities or functional scenarios for the home ambient. The products used in the home context are not only related to the automation of home appliances or integrated systems. There are plenty of single devices that perform single or multiple functions for well-being, lifestyle, and personal health of the people living in the house. Despite some of these solutions are made to be functional in everyday life, also out of the home environment, our aim is to analyze them in the intimate context of the home to understand how they are perturbing the intimacy by managing of personal information. Personal data are collected by the devices both using integrated and connected sensors that detect precise values directly and using other devices and appliance to receive second hand information on the users' habits and behaviors.

6. Personal data as meaningful material: existing solutions

Picking devices and systems examples from market and crowd funding, we aim exploring the current methods and possibilities offered by home automation solutions concerning use of personal information and data. We consider the two main branches of home automation solutions that use personal data while controlling and managing devices and appliances. The first one includes applications that aim to provide and monitor health and well-being. The second one includes applications that aim to simplify and help in everyday and occasional tasks.

The health monitors and well-being providers such as Cubile Health and Sleep Cycle Alarm Clock [24, 25] are focusing on *physical data* collected directly from integrated sensors. These self-tracking devices can solve problems, identify glitches, or encourage habits [26]. Single values are crossed with other data to process information creating usable value. These applications provide information mainly about the span between the user value and the "normal" range. This normality is decided by designers focusing on the users' average or provided guidelines. The user is not always aware of what is the normal range and how it is decided. Cubile Health focused on collecting, monitoring, and comparing personal data to ideal standards during the night. While the elders' or ill people's data collecting can be useful for a constant monitoring of parameters to be sure they stay between safe ranges, a less motivated monitor may lead to a distorted perception of self in healthy people. The device can tell me that I did not sleep well comparing my data to a non-specified (to the user) standards without consider a wide range of different parameters that go beyond the generic age and gender. Sleep Cycle Alarm Clock app have a very similar data managing procedure returning information about the amount and quality of sleep comparing the user's data to a regular sleep cycle. However, the feedback graph shows a sleep pattern that is meaningless to users unless they are told how to interpret it. This analysis reveals two main issues related to the personal data collecting, managing, and visualization. Do the standards fit with user's specific and personal parameters? Are the feedbacks showing their real meaning according to the user's interpretation skills? Designers must consider that feedbacks from these sleep monitors (as an example) can perturb the opinion users have about themselves and make them feel sleep deprived even if they are not, but must also consider that users might misunderstand the meaning due to a lack of interpretational skills.

The controller devices and appliances aim to simplify users' task and to optimize time and efforts and they collect data directly (from integrated sensors) or through other objects and appliances. Whether they are single devices or integrated systems, they usually merge and cross different data to create value for the user performing task managing through direct control of appliances and devices or giving useful information and feedback to the final user. Modern integrated systems for home automation can control every connected device (e.g. KNX systems) and let the house act as a semi-autonomous agent acting accordingly to given presets, customized settings or even user's habits. Home automation integrated system as well as single devices mainly collect data from user's behaviors through objects using both integrated sensors or simple operation habits (e.g. timing and frequency of switching on/off for a single device) to permit customized objects' performances. Single devices as the Samsung Family Hub 2.0 [27] smart fridge collect and analyze users' foods and shopping preferences to manage purchases, storage, and monitoring actions for the users. These data reveal behaviors of the user to perform a task optimization and to give proactivity to the device. Control hubs as Amazon Echo [28] constantly monitor the environment to detect users' needs and use AI to perform personalized tasks or suggestions accordingly to his 'perception'. An Experian survey [29] shows that Echo users are likely to place the device in the kitchen. This is probably because it is easily accessible with occupied hands, so the voice recognition used as task manager (smart light and thermostat control, add item to a shopping list, provide information, play music, and so on) is probably the key of the success of its AI Alexa [30]. Amazon Echo uses on-device keyword spotting to detect the *wake-up word*. When the device detects it, it streams audio to the Cloud, including a fraction of a second of audio before the wake word. The use of voices as a control tool represent a change of paradigm in device control: natural language controls home environmental changes so that the control of the actions is still perceived but no longer tangible. As the provided definition includes the *voice recordings* in the personal data, with a natural language recognition AI, the user is less aware of the collecting, processing and storing of his personal data. Alexa is an AI made to be perceived as a personified entity and the interaction with *her* is made to be as similar as possible to a human conversation.

Whether we divided cases in the two branches of use of personal data, some of these solutions actually belong to both, presenting a data usage dual mode. One of these is Moodbox: it can simply react to movement, switching on when somebody walks across its monitored space, but also crosses data from voice analysis and favorite music, weather conditions and time of the day, using artificial intelligence to suggest music that the user will probably like being in a particular mood. All these systems and devices learn from user actions and try to anticipate them, letting users free to use and manage their time in a different and maybe more important way.

While analyzing these cases, an issue arises: is generated info value meaningful enough to absorb the privacy perturbation? The resilience of a technology can be a discriminating factor to its adoption. The real value for the user, being it monetary or service, must compensate not only the effort employed in the use of the device, but also the perception of 'loss of control' over their personal data (**Figure 1**).

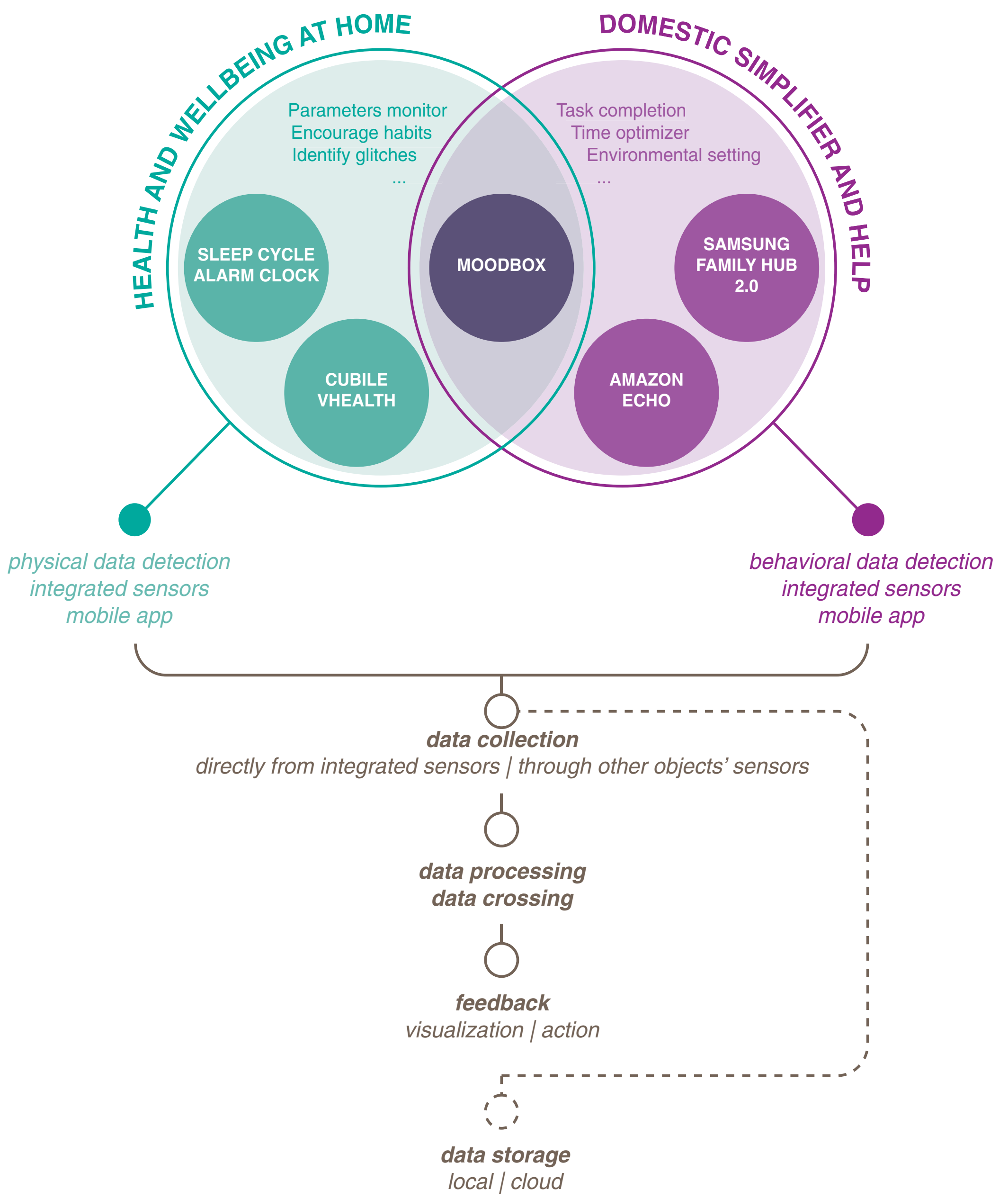

Figure 1. Personal data management and use in the analyzed home automation solutions.

7. Design principles in personal data handling

The reflections above reported lead us to define pointers we wish to discuss within the communities of designers of interactive products and services. The topic is vast and complex, and, due to digital technologies rapid evolution, it requires an open discussion capable to face the continuous ongoing change.

As temporary principles, we assume that, in the creation of interactive digital products and services involving personal data, designers should:

- Provide users with both a full and explicit information about the ways their personal data are employed by the product/service along the whole chain of exchange of information by different stakeholder and a meaningful *payback* about the data collected, giving them also the capability of properly understanding the content's value. That should be done considering both their interpretive skills and the possible short and long-term perturbation.
- Provide sufficient protection toward improper or unjustified use of personal data by third parties aiming to fraudulent actions or to exert persuasion through tailored advertising.
- Make people aware of most common social engineering use of personal data.
- Avoid reduction of resilience and robustness of home technical systems involving cloud computing and data processing, and due to the aleatory performances of the internet and to the characteristics of technological devices, such as smart phones, presenting intrinsic risks in terms of fragility and the possibility to be lost/taken.
- Provide usable and accessible means for users to enable/disable the data gathering, and to simplify the control and management of the data concerning the persons and the environment, that are exchanged by the product and system, in any time and any context.

As a last inducement, we suggest to consider as a natural human right, the possibility for the user to 'negotiate' the personal data as a matter of design: if data is framed today as a resource and a capital, everyone should be allowed to manage their own as property.

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“Mama, It’s Peacetime!”: Planning, Shifting, and Designing Activities in the Smart Grid Scenario

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Abstract

In this paper, we describe a research-through-design (RtD) approach to investigate the potential of households’ electricity load balancing in the smart grid. Through the design probe “Peacetime”, householders explore peak hours as opportunities for serene and non-electricity consuming activities. During the 2 weeks, Peacetime was deployed in the homes of three households to explore an alternative framing of non-use of electricity to the commonly used framework for prompting people with feedback on their consumption. Households’ active load balancing included planning of, replacing, reorganizing, and skipping everyday domestic activities. Results indicate that focus could be shifted from restricting electricity use to creating alternatives – leading to a positive framing of load balancing. The scenarios reflected in this paper differ from those of rational energy managers basing decisions of domestic life on complex facts and figures. Scenarios from the study portray how planning, reorganization, and time shifting of activities may be obtained with soft means emphasizing values of well-being and respect of the variation of households’ social contexts.

Keywords: sustainable HCI, sustainable design, smart grid, load management interaction design, research through design

1. Introduction

Despite significant technological progress, domestic energy consumption is still increasing. During peak hours, a large amount of CO_2 emissions affects the atmosphere, since coal-burning power plants are activated to supply the extra energy. In residential buildings, this occurs mainly in the morning and in the evening, when people get ready for work and when they come home. Moving electricity-consuming activities to nonpeak hours is called peak shaving or load management and is generally considered one trend in the smart grid scenario, which could decarbonize the electrical grid [1]. This approach is even more crucial when certain amounts of electricity are provided by renewable energy sources, which depend on weather conditions. Indeed, this introduces a variable in the calculation of the available amount of 'green' energy on the grid, making every day different from the other. On a windy day, for instance, the overall electricity consumption can be higher if energy is provided by wind power plants. 'Direct control' of load management requires customers to shift their domestic activities, which adapt to the available energy on the grid. This is challenging as it would require constant effort in re-planning even those domestic habits that are automatic, and therefore, usually demand little effort to execute (e.g., starting cooking right after coming home from work, or taking a shower after waking up). How to introduce, manage, and communicate peak hours and motivate users to perform peak shaving is challenging [2–7]. The vision about smart grids includes assumptions about households' active participation through the use of technology and the load balance of their electricity use. Some practices (e.g., preparing meals) have been perceived as "non-negotiable" [8]. However, there is a lack of knowledge regarding the design and implementation of smart grids in relation to people's everyday life [9]. Partly, this is due to the lack of approaches addressing the core questions of the social context of households. Considering this context, what factors may motivate them to be flexible about their electricity consuming activities in the future electric grid? Researchers need to focus on how households organize their everyday practices and to what extent and under which circumstances they are willing to shift and reorganize their practices. For instance, which everyday activities are static and which are more flexible in relation to the point in time when they are carried out during the day?

In a pre-study [10], we interviewed 10 households about their domestic activities, their motivations for change, and the flexibility of their domestic activities. Interview results showed that informants thought themselves to be quite flexible in their use of electricity. Some activities, however, were non-negotiable in respect of the hours during the day they would be performed. Cooking was one such activity. To be able to plan their activities differently, informants would need information about the periods of the day, during which they should avoid to use electricity and how long that period would be. They would need information in advance on when the non-electricity period would occur and also a reminder just before the onset of the period.

Our pre-study also indicated that households prefer to be actively in control of their electricity use, but in a soft way, without being told what to do and when. It also emerged that pleasant, sensory, and emotional experiences could support their engagement in a smart grid scenario. The informants react negatively to penalties as a feedback of their unsustainable behaviour. Thus, there was an emphasis on soft imperatives serving as advice rather than strict requests.

The purpose of the current paper is to describe a research-through-design (RtD) approach (see e.g., [11, 12]) to challenge the role of householders as mini-energy managers. This further explores the results from the pre-study. How can a future scenario use soft imperatives to support the non-use of electricity at certain times during the day? How can the non-use of electricity be framed in a positive manner rather than in a negative and prohibiting way? What is the nature of flexibility and innovation for householders in carrying out their everyday

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activities? These questions will be explored through designing and placing a design prototype in real home contexts of households.

2. Related work

Within human-computer interaction (HCI), sustainability has been in focus for almost a decade. Blevis [13] outlines how HCI may mantle the endeavour of environmental sustainability. Different directions follow this field, many of which aim at providing users with detailed information about their consumption, typically through management systems based on displays, numbers, and graphs, sometimes referred to as eco-feedback [14]. The view of users in this type of research has been criticized for being too narrow [15, 16]. Strengers emphasizes the importance of designing systems reaching beyond models of users as rational decision makers – addressing what she calls the 'resource man' – towards more engaging solutions [17]. Especially in interaction design, research has focused on emotional and engaging ways to provide feedback with the aim to promote more sustainable behaviour. A number of ambient and tangible interfaces for eco-feedback have been developed in the field of sustainable interaction design. The ease of measurement of, for example, electricity use has been integrated into interaction design in different forms of feedback with the aim of visualizing to users what is otherwise hidden e.g. [18–22]. However, most of the solutions developed in this field communicate through vision and a few involve other senses. Research has explored how information can be conveyed by senses other than vision, and how this communication can potentially be both emotionally engaging and effective in motivating people to act [23]. In the field of eco-feedback technologies, the main strategies to encourage new habits are *information* and *awareness*. However, researchers argue that such strategies need to be accompanied by engaging and affective guidance for users on how to reimagine and adjust their practices [8, 24]. In order to investigate the possibility to integrate load management into daily routines, we applied RtD approach. In RtD, design becomes a tool for inquiry and its outputs can be used to explore future states of things [11]. In the following sections, we briefly present the development of the design concept and the prototype. Next, we describe the user study and the results. Finally, we discuss insights and potential of this approach in the smart grid scenario.

3. Design approach

In accordance with Strengers' [17] critique, we challenge the view of households as mini-energy managers and regard households' electricity use as embedded in social practices. Conscious of the complexity of a practice-oriented approach in the smart grid, we aim to offer alternatives to numerical data in the experience of the smart grid by designing a tangible and emotional interactive object, Peacetime. It focuses on an emotional and multimodal invitation to shift domestic activities according to the energy request peaks, while at the same time evoking emotions towards the environment.

The previously mentioned pre-study [10] informed the design of the probe. Through a participatory design process, designers, researchers, and end users were engaged in ideation sessions, conceptualization workshops, and focus groups to inform and enrich the development of the design. The process led to very different designs of information in relation to load management than suggested by [2, 3, 7]. For a full account of the design process, we followed a complete description of the final design of the Peacetime prototype [10, 25].

3.1. The Peacetime concept

The Peacetime concept connects the need to shift electrical activities in the smart grid scenario to the metaphor of being in balance with nature. Peak hours are converted from a space of prohibition to a positive space of opportunity, where people are invited to take a rest and to perform pleasant activities without the use of electricity.

The Peacetime concept is composed of two parts: (i) a physical product, consisting of a tree with a nest and pinecone, a scent-releasing flower, and three associated birds, (ii) a support interface, useful to plan non-electricity consuming activities (**Figure 1**).

Figure 1. Staged photography of the physical prototype, consisting of a tree, with nest and pinecone, a scent-releasing flower, and three associated birds. Photo credit to Juha Dahlbo.

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When a load peak is approaching, the birds placed in different rooms (borrowing its aesthetics from the traditional cuckoo clock) start chirping 30 and 15 minutes before the Peacetime (**Figure 2**). The flower releases a scent in the house 15 minutes prior to the Peacetime period. When the Peacetime period begins, a pinecone drops from the tree. The length of the Peacetime period is displayed by the position of the pinecone, which slowly moves back while time passes, to show the remaining time.

The website interface proposes customized activities that can be undertaken during Peacetime (for example, alternative ways of cooking without using electricity, or ways to spend time together). It also displays the upcoming Peacetime periods (**Figure 3**). The Peacetime periods corresponding to the load peaks on the electrical grid alter from day to day during the week, as they follow the forecasts of peak hours.

3.2. The Peacetime prototype

A prototype of the Peacetime concept was built and 2-week forecasts of Peacetime periods were created. Peace hours could start in the morning, in the afternoon, or multiple times throughout the day. Forecasts were accessible 3 days in advance on the Peacetime website. A switch was programmed to activate the stepping motor of the pinecone in the nest, according

Figure 2. A chirping bird, in Household 2.

Figure 3. At the site Peacetime. The household members could see upcoming Peacetime period and get customized suggestion of alternative activities.

to the Peacetime forecasts. Birds were connected, via Bluetooth, to the tree and reproduced tweeting sounds though a speaker. The flower scent was made from an existing aroma scent diffuser.

4. Method contextual study

In order to explore households' experience of electricity load balancing, a contextual user study was conducted through the Peacetime prototype in three people homes. In accordance with RtD approach, the focus of these field studies was on qualitative data generated from the study to throw light on the issues explored – an alternative to prompt for refraining from electricity use. Thus, we did not aim for a quantitative comparison between the different households. The contextual studies were not designed as "tests", but rather as starting points for exploring basic issues regarding load balancing in the home.

Three households participated in the study, all recruited through a local business network in a Swedish town. Each household had the prototype in their homes for 2 weeks. As we aimed for different types of household constellations, we recruited one family with small children, one family with teenagers, and one family without children.

Household no. 1. The adults are in their late 40s and live with their three sons in a house with five rooms just outside the city. The twins are 11 years and the eldest child, 13 years old. The mother works as the assistant manager of a Science Park and the father as a caretaker for a cultural institution.

Household no. 2. The adults are in their mid-50s and live with their 19 year old daughter in a house with four rooms outside the city. The mother runs her own dental practice, the father works at a factory, and the daughter works as an assistant at her mother's clinic.

Household no. 3. This is a couple in their late 60s who live in a big house just outside the city. They previously ran their own business and are now both retired but active in various organizations and networks.

4.1. Preparation and implementation of contextual study

Prior to the study, we met the families to inform them about the setup of the study. To adjust the web interface to their preference, a Peacetime profile survey was filled out, consisting of five questions relating to what the families like to do in their spare time. The family members were asked to consider a place in their homes for installing the physical prototypes. When the prototype was installed (about 1 week later), the researcher presented the concept of load managing as a way to decarbonize the grid through Peacetimes (peak hours).

4.2. Procedure of contextual study

The three households participating in the contextual study lived in houses, thus, private houses constituted the site in which the study took place. Since there was only one set of physical prototypes, the three cases were studied one after the other, during 2 weeks at each site. Households were instructed in how to use Peacetime at the onset of the study.

The study had the same set up during both weeks at each site. The Peacetime periods, which lasted for 2 hours each, were distributed at different times during the days in order to highlight opportunities and challenges in relation to their domestic practices. Some days the Peacetime periods occurred in the morning, some days in the afternoon, some days in the evening, some days had two Peacetime periods, and 1 day had none.

4.3. Interviews

At the end of the 2-week test period, we conducted interviews in the participants' home. Two researchers were present and the interviews lasted approximately an hour. The entire household was encouraged to participate in the interview. The covered areas were: (1) motivation for load balancing, (2) their experience of shifting practices according to Peacetime, (3) their experience of the ambient and web interface, and (4) potential of the concept. The interviews were fully transcribed and transcripts and video material were analysed in order to identify major themes. Grounded theory analysis [8] was performed both on the interview transcripts and the households' activity books, to identify categories of concepts helpful to understand the users' reactions to the Peacetime concept, and more in general, to our approach to load balance.

5. Results

From the analysis of the interviews, five major themes emerged as the main findings of the user study: (1) General attitudes towards the Peacetime concept, (2) Planning for Peacetime, (3) Creation of new types of activities, (4) Reorganizing existing activities, (5) The Peacetime feeling and morality of leisure time.

5.1. Theme 1: Peacetime attitudes

A major finding was the participants' positive attitude towards shifting their activities according to Peacetime. The mother in Household 2 reasoned *"It doesn't take that much effort to be environmentally friendly […]".* She considered the overall concept of load managing a relevant way to decarbonize the grid. The twin boys in Household 1 were excited about the concept, shouting to the rest of the family *"It's Peacetime!"* when the Peacetime period started.

Both the tangible interface and the digital one were appreciated and were considered essential for the activity shift. The physical objects acted as reminders of the need to be more flexible and provided essential real time communication through different sensory modalities. This was considered especially pleasant. The digital interface was evaluated as valuable to plan activities in advance and to find inspiration for alternative tasks to perform during Peacetime.

5.2. Theme 2: planning for Peacetime

Informants used Peacetime for planning their activities in new ways. In both households with children, the mother took on the role of communicating peace hours to the rest of the household:

> *"I sent it [the schedule] to daddy and your big brother, because they have telephones"* [mother in Household 1]

The following shows how another household planned and shifted cooking according to Peacetime:

> *"It's been an advantage to be able to go to the Internet and check when Peacetime occurs…it's been possible to prepare for it. It would have been harder if there only would have been [the Peacetime prototype] and you would have started something… and, then, the birds would have come out: 'damn it I just put a steak in the oven for two hours'… then you would have to switch off everything"* (mother of Household 2).

5.3. Theme 3: creating new types of activities

The mother of Household 2 reported that, during Peacetime, they mostly did activities that they normally would do at other times. *"To remove dust or swab the floor"* or *"to sit and talk about everyday things in the kitchen"*. However, the parents of Household 2 did three activities that they considered out of the ordinary. One day they decided to bring out pen and paper and draw boats and roads. The daughter said: *"You made me draw […] but it was actually fun"*. They took inspiration for the drawing session from the activities suggested by the Peacetime website, but would also like to add their own suggestions to the website.

Figure 4. Household 3 used the heat of the coffeemaker to defreeze the bun instead of using the microwave.

Household 3 did not do any activities out of the ordinary *"we are not going to build a sandbox"* (this was one of the suggested alternatives for them as they expressed great engagement in their 1 year old granddaughter in their peace profile). Household 2 did many of the suggested alternative activities such as day dream, read that dusty book on the shelf, and cuddle. *"We'll keep the concept of Peacetime"* their mother said.

Household 3 planned new activities to cope with Peacetime. For instance, as Peacetime started, they finished to boil potatoes using waste heat – the final heat keeping the stove plate warm after the stove has been switched off. The household created new ways to thaw frozen bread, by using the waste heat from the coffee maker (see **Figure 4**): *"I took it out [from the freezer] before I went for my walk and I put it on top of the coffee maker, which was still hot…instead of heating it in the microwave…"*.

5.4. Theme 4: reorganizing existing activities

Households were flexible in at least three different ways when it came to reorganizing routinized behaviour. One strategy was to **shift routine activities** before or after Peacetime hours. For instance, individuals left for work earlier than usual due to the Peacetime hours. They also hurried from work earlier than usual in order to prepare dinner, so that electricity would not have been used during the Peacetime hours:

> *"I hurried home to cook before six o'clock. I fixed the minced meat-sauce .. then away.. Nobody was at home….I thought about what I had to do before the bell tolled… so to speak…Which electrical things have to be used and do I have time to take a shower before and stuff like that"* (mother of Household 1).

Household 3 clearly stated that some activities had not changed, but the time during which they are carried out did:

> *"Those activities which we have done during Peacetime…. They have not been new so to speak… it's just that we have accommodated… we have done exactly what we usually do"* (wife Household 3).

A second strategy to reorganize activities was to **replace electricity-consuming activities with activities generating similar results**, but excluding electricity use, e.g., preparing cold meals:

> *"During this period…we usually eat something light, so we don't fry… we don't cook, but we eat some salad"* (mother of Household 2).

Another example using the strategy of replacing electricity consuming activities with other but with the same result is switching off the heat pump before showering, but still using hot water left in pipes:

> *"Well I realized it's Peacetime between eight and ten and I wanted to do a few things and then I wanted to take a shower… so then I go down and switch off the heat pump and then there's still hot water in the boiler… so you can use it and still shower during Peacetime"* (Husband of Household 3).

A third type of strategy reorganizing activities to fit the Peacetime hours was to actually **skip activities using electricity without replacing them**:

> *"My husband switched on the coffee machine by mistake… but he switched it off and went outdoors to smoke instead"* (mother of Household 2).

5.5. Theme 5: the Peacetime feeling and sense of morality of leisure time

The Peacetime hours seem to have upgraded the status of leisure activities, like reading and resting, to something good and the three households experienced a feeling of loss when the 2-week period with the Peacetime prototype came to an end.

Mother of Household 1: *"we…miss the Peacetime hours… or the feelings of them.. They contributed to… not to think TV and stuff like that.. I think we did good"*. The mother of household noticed that the twin boys extended the Peacetime period and did not immediately put on the TV as the Peacetime period was over.

The wife in Household 3 indicates that doing leisure things like reading was previously associated with a feeling of guilt. However, since Peacetime hours are intentionally combined with refraining from using electricity, and thus, contributing to something good (less environmental impact) the value of reading had been upgraded. She stated:

> *"Maybe I've done some more reading… yes with a pure conscience I was really allowed to sit down and read this book instead"*.

Her husband agreed: *"It almost felt better laying on the couch when it's Peacetime (laughs)"*.

The wife agreed and also said: *"Yesterday, which was the last day … last Peacetime… so sad. I was on the couch and took in the scent and ah… it smelled so good"*.

6. Discussion

The Peacetime concept and the study reported in this paper has challenged the idea of households as rational mini-energy managers. Results from the study of the Peacetime probe in the context of households indicate that focus could be shifted from restricting electricity use to creating alternatives – leading to a positive framing of electricity load balancing. The RtD approach allowed us to critically examine the field of load balancing as envisioned in a smart grid scenario. The scenarios reflected in the Peacetime study differ from those of rational energy managers basing decisions of domestic life on complex facts and figures. The scenarios from the Peacetime study portray how planning, reorganization, and time shifting of activities may be obtained with soft means emphasizing values of well-being and respect of the variation of households' social contexts. Our study depicts scenarios where electricity use is a background priority of everyday life rather than a primary interest.

The themes presented in the results section point to several issues deserving attention when implementing smart grids in households. As general planning forms part of everyday practices in most households, the planning relating to load balancing adds on to or becomes integrated in other sorts of everyday planning. The results also show that households may be quite flexible and inventive both in creating new activities replacing the electricity-consuming ones and in reorganizing existing activities. This shows that it is possible for households to reorganize practices or creating new ones to accommodate to external conditions, such as the intermittence of renewable energy sources in the power grid. We found three strategies for households in reorganizing: they shifted times for when an activity usually was carried out to times either prior to or after Peacetime hours; they replaced electricity consuming activities with non-electricity activities generating similar results; and they altogether skipped activities using electricity without replacing them.

6.1. Peacetime practices

We challenged "resource man" [17] through the Peacetime concept communicating load management not only in a simplified manner, but also by allowing a mind shift for householders to consider actions associated with positive experiences rather than actions associated with constraints. The type of 'slow energy' uncovered by [26], when deployed and encouraged, was well received in our study. Theme 5 indicates how Peacetime not only allowed households to shift activities in time, but it also legitimized the leisure time activities. Peacetime might have substantiated the resolution of the requirements from electronically driven communication and information media. Actually, having something else proposing things to do other than routinely carried out activities appeared to be quite relieving. Introducing Peacetime might be compared to reintroducing the Sabbath – the day of rest.

The emotional ingredient elicited by Peacetime is worth noting. Surprisingly all households wanted to keep Peacetime periods. Alternative activities resulted in moments of human-to-human interaction, perceived as fun and meaningful. Alternative activities were mostly ordinary but with a twist from the participants. Especially one household considered suggested activities inspiring, and was open to new alternatives. One household could not relate to the suggested activities, but they still considered the Peacetimes enjoyable and considerate moments to them.

Designing a concept that is respectfully integrated into everyday life is challenging. Understanding domestic practices in detail and providing pertinent support in those specific situations is complex. Social aspects, including piles of dirty laundry and a stressful schedule, are the reality of everyday life. As argued in Ref. [8], we aimed to introduce tailored alternative Peacetime activities to the users as inspiration of how to rethink their practices or “reimagine themselves” [27]. However, these were just fragments of what could be. Results indicate that this approach could become even deeper, richer, and more respectful to support users in their transition towards more sustainable practices. This points to a promising direction in sustainable HCI, which considers emphasizing the key role of interpretation in HCI [28]. Sustainable HCI can open up for approaches where design centres around other issues than electricity use, such as well-being, but still reaches the goals outlined for the electric grid. While energy companies tend to approach their customers with complex and numerical information to communicate, HCI, and design provide opportunities to align with motivations for enhancing the quality of life in a wider perspective than feedback on electricity consumption.

6.2. Limits and future developments

This explorative RtD study represents a first step towards the exploration of practice-based and emotional approach in the design of smart grid communication systems for households. We have not considered the effect of users’ habituation to the system over time and the system might be ignored as time passes. If habituation occurs, the system could be used as an invitation and introduction to load manage in a positive and emotionally engaging way, and it may be replaced by a different and less intrusive system after a limited period. Effects of the use of such a system over time should be carefully explored, in order to design systems that can have long-lasting effects on the development of sustainable practices. Although the study is explorative, it shows positive results that encourage further investigation in this field. This work can inspire others scholars and contribute to the discussion of an alternative and more emotional approach to support and engage users in the smart grid scenario.

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Designing Dialogs between Users and Products through a Sensory Language

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Abstract

This paper presents a research-through-design exploring interaction as a dialog between the user and the product that are in contact for sharing something, typically quantitative and/or qualitative information (e.g., data, points of view, feelings, and so on). This exchange is made possible by the implementation of a given kind of common language. Traditionally, human-computer interaction relies on an explicit, codified language, as for example when designers use icons, text, or pictures to convey a message. In contrast, we define *empirical sensory language* as those sensory stimuli coming from an artifact, processed most often unconsciously, which play a constructive role in generating a meaningful interactive experience, yet do not require any explicit exchange of information messages. Our investigation aimed at exploring potentialities and limits of applying a sensory language to arouse meaningful interactions leading to a desired change in routine behaviors. We thus designed two product prototypes intended to lead users to decrease water consumption. Our approach opens up a new space for design that is currently not covered by explicit, codified forms of interaction. We discuss implications for a product designer to design for a sensory language and the results of an exploratory user evaluation.

Keywords: sensory language, material interaction, user-product dialog, water saving

1. Introduction

In recent years, microchips have become so small that they can be embedded in traditional materials such as wood, glass, polymers, fabrics and even more, making such materials "smart" or, as Vallgårda and Redström define them [1], "computational." Thanks to computational materials, products can now change their sensory features (i.e., shape, color, texture, etc.)

proactively and in a reversible manner, according to a specific situation. Such changes can be designed with an informative intent, i.e., a device that changes shape to communicate the temperature inside the home. This means product designers have currently new material opportunities to work on; and the industrial design field can be enriched with new forms of material interaction and novel ways to convey meanings: indeed, products are able to establish dialogs with users through their sensory features, defining a novel "sensory language." Previous studies demonstrated that the use of a sensory language instead of the traditional alphanumerical one, conveyed through digital screens, could be a fruitful strategy to engage users during the interaction with products [2]. The positive engagement and the sensorial richness offered by the materiality of artifacts might support the behavioral changes during the interaction with products.

In order to explore both limits and potentialities of applying a sensory language to the user-product interaction, we focused on the issue of water savings in the household environment. Indeed, this appeared to be a promising field of application: previous studies [3–6] stressed the importance to establish a dialog with the final user (mainly through digital screen) in order to change his/her behavior toward more sustainable consumptions.

2. Interaction as a dialog

Technological evolution makes products dynamic and interactive. Products can be designed to be responsive and able to adapt to the surroundings (environment, users, and context in general). Thus, "a domain which was once considered pure industrial design is faced with many interaction design challenges" [7].

"An interaction is a transaction between two entities, typically an exchange of information" [8]. Indeed, in the Cambridge dictionary, an interaction is defined as "an occasion when two or more people or things communicate with or react to each other"[1]. Thus, the main aspect of an interaction is that both the involved subjects have to be reactive and responsive to each other. For this reason, we assume that users and products should be related to each other in a circle of influences: the object with its (changing) material features (e.g., shape, weight, color, etc.) affects the user's behaviors and thoughts, and vice versa.

The idea of a transaction between two entities in an interactive relationship and the idea of an exchange of information over time is also at the core of the definition of "dialog": "A conversation between two or more people"[2]. To converse means to "talk between two or more people in which thoughts, feelings, and ideas are expressed, questions are asked and answered, or news and information is exchanged"[3].

In these definitions, it is possible to find several correspondences between an "interaction" and a "dialogue." Both require the involvement of two actors who are in contact for sharing

[1]http://dictionary.cambridge.org/dictionary/english/interaction.
[2]http://www.oxforddictionaries.com/definition/english/dialogue.
[3]http://dictionary.cambridge.org/dictionary/english/conversation.

something. Typically, they share information but it is also possible to enrich this relationship with emotional factors (like feelings) and personal point of view (like thoughts and ideas). This sharing creates a cycle of correspondences between actions and responses that is inherent to the human use of artifacts [9].

2.1. Language as a design matter

"Nowadays, design becomes a matter of using the right language to generate a dialogue about the functionality, intended use of the object, and to generate thoughts and meanings in the user's mind" [10].

Dialog, as a way for sharing ideas and information, requires a common basis, the language. In the interaction design field, Moggridge [11] categorized four languages according to their "dimensions" (**Figure 1**):

- The 1D language: words and poetry
- The 2D languages: painting, typography, diagrams, and icons
- The 3D languages: physical and sculptural forms
- The 4D languages: music, cinema, and animation.

The limit of this categorization is that languages are considered as separated. However, they can be used together to enrich the interaction between a system (products or digital interface) and a user. We indeed believe that any of these languages may be enriched transferring some features of one to another. Particularly, this research is based on a number of philosophical studies of the use of words (i.e., 1D language), which suggest two different ways of using them: as a *codified language* and as an *empirical language* [12–14].

Starting from the phenomenological analyses of Merleau-Ponty [15], we define *codified language* as a form of expression based on conventions/symbols/codes shared by a group of people. This language is useful to be applied when the contents of the information have to be clear and not misunderstood. For example, the traffic light informs users about their

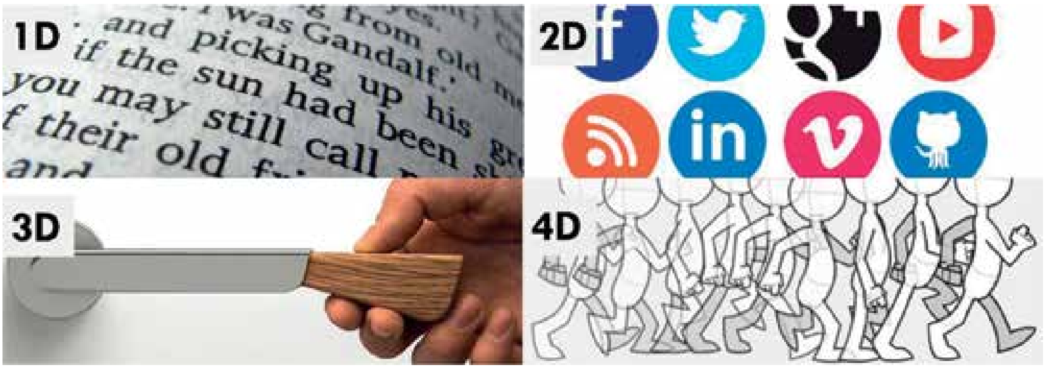

Figure 1. Representation of the four languages.

possibility to cross the street applying three colors with conventional meanings: green, red, and yellow. One important aspect of codified language is that there is an arbitrary link between the code (e.g., the shape of a letter) and what it signifies (an element in a linguistic utterance). Furthermore, when a designer uses these codes to convey a message, the meaning of each of the codes is predefined: it does not depend on the situational details of any particular interaction in which the codes figure. So, for example, it does not matter on the emotional state or the previous series of events a person experienced for determining the meaning of the "black coffee" symbol on the coffee machine: it means black coffee. It could be that the person is lead to misunderstand the correct meaning, for example when the symbol looks a bit like cappuccino and the person is tired and not paying attention. But this kind of variability in meaning would be considered an error and certainly not an intended aspect of the design.

On the other side, we defined *empirical language* a form of expression in which the contents of the dialog are not completely established a priori, but meanings are to some extent subjectively created by the user during the interaction itself. In other words, the contribution of both the designed artifact and the person determine what meaning is experienced, rather than the artifact or the person "transferring" certain predefined meanings over a codified communication channel. Empirical language is often used to elicit or catalyze meaningful experiences, which the person will have courtesy of being engaged in. Paradigmatic examples can be found in the artistic and poetic fields.

Historically, industrial designers are familiar with the physical forms of artifacts. For this reason, this research focuses on 3D languages, interpreting them not only as pure physical shapes but, more in general, as all that can be perceived by the human sensory apparatus. In other words, this research intends "sensory language" as a language based on any kind of stimuli that can be perceived by one of the five senses (view, smell, touch, taste, and hearing). The concept "Scent of Time" (**Figure 2**) is a good example: it is a clock that releases a specific smell in the environment to denote a specific time of the day.

Figure 2. Scent of time by Hyun Choi.

3. Research-through-design question

This research aimed at exploring the design qualities of a sensory language in establishing meaningful dialogs between users and interactive products, used in mundane, practical settings (i.e., not as an art exhibition or critical provocation). To this end, we delve into the differences of applying a *codified* versus an *empirical* language, also attempting to create a "cross-fertilization" between features that traditionally apply to well-separated kind of languages: the 1D language (based on words) and the 3D language (based on materiality as defined above).

As already said, nowadays, in applying a sensory language to products, any designer can exploit the new opportunities coming from the development of smart materials and new technologies.

4. Methodology

We applied a research-through-design approach: two design activities were carried out in order to develop and test design proposals based on insights coming from the theoretical investigation.

The first design activity explored the sensory language as a *codified language*, and the second activity explored the sensory language as an *empirical language*. As a result, two functioning prototypes were developed: "glass of water" and "feelings and experiences for an embodied learning" (F.E.E.L.).

The two prototypes were tested with users during three focus groups, organized with the aim of exploring the interests, feelings, and engagement of the users as well as their understanding of the information conveyed.

5. Design activities

5.1. Glass of water

The first design activity focused on the exploration of a *codified language* based on the correspondence between a signifier and significant. In the field of semiotics, this correspondence is called "code" [16]. Specifically, Lachman et al. [17] defined a code as: *"a set of specific rules or transformations whereby messages, signals, or states of the world are converted from one representation to another, one medium of energy to another, one physical state to another"* (p. 68). In brief, codes specify how information is to be converted from one form to another [18].

5.1.1. How to transform alphanumerical information into sensorial stimuli

A literature review was performed in order to define a set of specific communication parameters that can be useful for designers to translate information related to water consumption into a sensory language. The objective of this investigation was to find new ways to inspire designers in the concept generation phase. The result is a list of opportunities/limits for the application of the sensory language to convey certain kinds of information that are usually intended to be quantitative (e.g., average water/energy consumption per day/month/year).

Even if the general focus was on the exploration of tangible aspects of products, in this phase, we enlarged the research also to the field of digital interfaces, persuasive technologies, and interaction design. Indeed, in these fields, several studies have already investigated the importance of giving feedbacks on energy consumption, and some of these studies tried to give suggestions to designers facing this matter. Only studies reporting results on users' investigation were considered, since our intent was to explore the user understanding of the contents of the dialog. As a result, 13 studies [5, 6, 17, 19–28] were selected and analyzed in deep, and three main communication parameters emerged [29]:

- Metrics (related to the unit of measure). It has been observed that it is better to transmit qualitative information instead of quantitative ones (e.g., "Today your consumptions are good," instead of "today, you have consumed 120 KW of electricity.")
- Frequency, related to when and how often it is necessary to give information to users. It has been observed that users need continuous information instead of having information only when an event occurs.
- Representation, related to the "form" of the data. Some studies underlined the importance of visualizing information through metaphors or analogy (e.g., recalling the effects on the barrier reef of positive/negative consumption behaviors). Moreover, from these studies emerged the importance of giving positive information in order to support the motivation of users.

Any of this parameter has to be communicated through a sensorial language (i.e., through the products material features), to make the product itself a media for conveying information about the user's consumption.

5.1.2. Concept description

Glass of water is a tentative of applying the three parameters coming from the literature review (i.e., the first and the third one). It consists of a set of little spheres suitable for all faucets of the house. The spheres aim at reminding the user that the quantity of water at their disposal is not unlimited. To this end, they are conceived as small meters able to give information about the water consumption of the connected faucet. By means of a blue light, they tell users the correct amount of water they should use for their domestic activities (according to Gleick [30], around 50 L per person per day).

Any time the user turns the faucet on, the connected sphere gradually lose its brightness to show that the amount of water suitable for the domestic activities is decreasing until ending, when all the lights of all the spheres turn off. These changes are intended to recall the idea of a glass of water getting empty (**Figure 3**).

http://dx.doi.org/10.5772/intechopen.71127

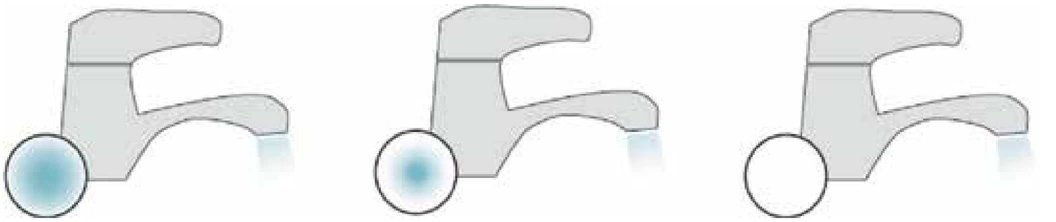

Figure 3. Concept of glass of water.

A prototype was developed, based on an Arduino board that controls the brightness of the sphere's light (**Figure 4**).

When the faucet is not used, the light is off (**Figure 5**); as soon as the water is open, the light gives (qualitative) information about the amount of water that can be still consumed. When the consumption of water exceeds 50 L per day, the light does not react anymore until the following day.

This raw prototype aims to be representative of the language. Thus, its functionality is simplified.

5.2. Feelings and experiences for an embodied learning (F.E.E.L.)

The second design activity was focused on the *empirical language*, based on the idea that meanings are created by the user during the interaction with the product.

During the development of the concept, we retained useful to apply the principles of embodied interaction. According to embodied interaction theories, there is a circle of influences among the physical properties of the products, the user's actions on/with the product, and the

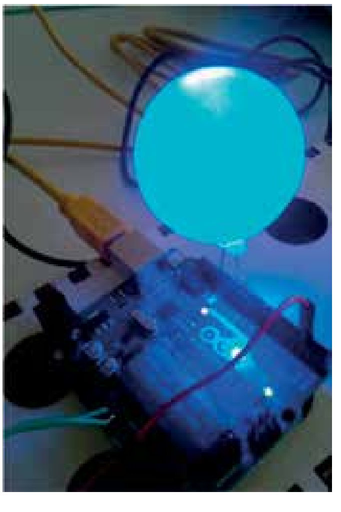

Figure 4. Glass of water prototype.

Figure 5. Glass of water storyboard.

creation of meanings in the user's mind [9]. In phenomenological terms, material properties of the world are taken up as elements sustaining stabilities in action-perception loops, which govern a persons' skilled, routine-like dealing with the world [14, 31, 32]. The sense-making process is not just based on decoding information conveyed in the products features, but it is made possible by the creation of a personal dialog between the user and the product itself. Such dialog encourages reflection-on-action and the creation of new meanings.

Due to the complexity of the process, it was decided to focus on the water consumed into the shower, and it was decided to concentrate on the tactile stimuli provided by the shower tray. The aim of this second design activity, thus, was to create meaningful tactile experiences provided by an interactive shower tray able to affect the users' behaviors, influencing them "in the situation."

5.2.1. Preliminary research

With the aim of exploring the users' behaviors and feelings when taking a shower, users' observations were performed. Particularly, three short tests with users were organized in order to gain some insights into: (i) users' behaviors, (ii) tactile feelings, and (iii) users' emotional experiences. Video recording was the tool for exploring the users' feet behavior in the shower and the tactile interaction with the shower tray.

Moreover, testers were asked to fill a 1-week diary in order to keep track of their experiences and feelings during the shower. Both videos and diaries gave us insights into the context of use through pictures and words [33]. At the end of this phase, we collected four videos and four diaries.

5.2.2. Concept description

Thanks to the preliminary research on users' habits, useful insights were gained referring to: (i) the shape of the shower tray, (ii) the materials' selection, and (iii) the design of new behaviors and scenarios. These outcomes were useful for the development of the concept feelings and experiences for an embodied learning (F.E.E.L.). F.E.E.L. is a squared shower tray able to change its shape in order to create a new routine into the shower. It is composed by an external case and a number of soft "pins." These pins pop up randomly according to different rhythms, creating each time a novel tactile experience as a sort of feet massage (**Figure 6**).

The data collected by the 1-week diary show that users take a shower with two different aims:

- as a (short) refresh activity
- to relax and pamper themselves

According to these two scenarios, F.E.E.L. is designed to change its shape in a fast and more marked way in the initial minutes of the shower, for the average amount of time that users usually spend for a short shower. Then, it decreases the speed of its movements over time until stopping at the achievement of the maximum average time usually spend under the shower, that is, the "natural" moment at which people experience that they are now finished and it is time to get out. Over time, F.E.E.L. creates a dynamic coupling between the user's action and the temporal choreography played out in the responsive shower floor. Once this coupling is in place, in order to lead users to decrease the time spent under the shower, the system will over time *decrease* the durations of the temporal pattern. The size of the decrease would be small and not consciously noticeable. Indeed, it is important that the user feels as he/she has always the same routine during the shower. As a result, the user will after several weeks reach the "natural" feeling of "being finished" minutes earlier than before, thereby saving water, without feeling forced or without feeling as if one needs to make a conscious, ethical decision to "do the right thing."

We created a raw prototype in wood, steel, and soft materials. It aims to be representative of the language, and its functionality is simplified (**Figure 7**).

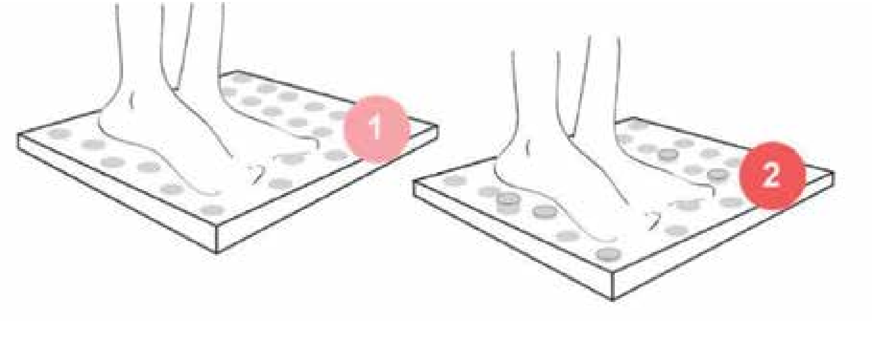

Figure 6. F.E.E.L. layout.

Figure 7. F.E.E.L. prototype.

6. Focus groups

Three focus groups with users were organized in order to collect qualitative feedbacks about the two concepts. It is important to stress that they were not intended as traditional user-evaluation focus groups, asking users whether the products would actually reduce water consumption. Rather, they were intended to extract some insights from the user's own sense making of our designs in order to answer our theoretical questions concerning the potentialities of applying a sensory language in designed interactions and the difference between codified and empirical languages. To this end, the first focus group presented to users "glass of water," that is, an example of codified language. The second focus group presented F.E.E.L that applies an empirical language. In a third focus group, both the concepts were presented in order to let users compare the two kinds of languages.

6.1. Organizations

Each focus group involved four people (two men and two women, aged 25–36). Our choice was to involve people with different backgrounds. None of the tester was a designer, since the aim of this activity was to gain feedbacks from nonexpert people. Moreover, we decided to involve people who lives alone and who already manage his/her consumptions.

All of them had the same organization: they started with a brief presentation aimed to introduce the concept/s to be discussed. During the session, videos and pictures were shown in order to describe the concepts in the real context. At the end of the presentation, participants were invited to discuss together. The discussion was guided by five open questions aimed to investigate the following aspects: (i) the engagement that they perceived with the concept, (ii) potentialities and limits of the concept, and (iii) how the concept could fit in their daily life.

6.2. Results

As a result, testers focused on two main aspects of the proposed concept: (i) the novelty factor and (ii) the clarity of the communicative intent. Both the projects were evaluated as novel, original, and unusual (compared to the objects that testers have in their home). However, participants evaluate the project F.E.E.L. as more innovative: "It proposes an unusual experience"; "This project is more cool!"; and "I have never seen something like that!"

Glass of water was perceived as less surprising and more similar to digital interfaces. During the focus groups, it was observed that the novelty factor influences the enthusiasm of the users to have a trial with the prototype in the real context.

Comparing the two projects, it emerged that the communicative intent of glass of water is more evident and immediate to users. Meanwhile, the communicative intent of F.E.E.L. required extra explanations by the facilitator. However, the concept F.E.E.L. was perceived as more able to support and motivate the changing of the users' behaviors, since the learning process was judged as subtle and more linked to personal awareness.

On the contrary, the learning process provided by glass of water was judged as cognitive and intentional: "Glass of water is telling me how much sustainable I am. In a way, it is pushing me to turn off the faucet to save water. Meanwhile, F.E.E.L. helps me to relax and enjoy my shower. Water consumptions are up to me."

7. Discussion

Several studies on smart meters providing users with alphanumerical feedbacks on their consumptions have shown that they have a limited influence on users' behavior [4, 24, 34]. More detailed investigations show that the situation is complex: numerical feedbacks may fail either in taking into account the realities of users' life [20, 21, 26] or their understanding of units and quantities [35]. Moreover, they do not help users in having a wider understanding of their behaviors [36]. Another limit of information provided through a display is that they require users to look at them regularly, checking the consumption trends. To overcome such limits, studies carried out in different domains (interaction design, esthetics of interaction, ambient display, and visualization of data) have explored more sensorial ways (change in color, in light, in form) to give information about the amount of consumed resources.

Our results show that designing for a codified (sensory) language or for an empirical (sensory) language have different implications both for the design process and for the users' experience.

From the users' point of view, it was observed that establishing a material dialog through a codified code gives prominence to the message and to the communicative intent of the product (as underlined by the focus group discussion). Thus, the designer can apply a codified language when he/she wants the user to be conscious of the informative content, i.e., when the aim of the product is to give users' information on what would be a wise thing to do, to give them useful methods for achieving a certain goal, or to give them explicit reward for good behavior.

On the other side, applying an empirical sensory language means to focus on the embodied experience of interaction with the product [37]. This experience typically does not lead to a conscious reflection in the mind of the user about what to do. We strongly believe that the empirical sensory language opens up the possibilities to design for behavioral change other than through passing on information that the user must process and make a conscious decision about. As the example of F.E.E.L. shows, we may be able to gradually change the experience of the user in such a way that the user finds himself wanting to get out of the shower. This tactic has been applied in similar fashion by Bruns et al. [35], who demonstrated how fiddling with a pen that gives haptic feedback would lead to a reduced level of stress *even when the user was not conscious of this.*

It is now important to briefly discuss what makes up for an empirical sensory language, and what would just be a natural consequence of interacting with the physical world. As a first idea, one might say that an empirical sensory language comprises anything sensed by a person that does not include explicit coding, but does help to generate a meaningful experience. This would, for example, include how the physical properties of a tennis racket in interaction with a student would help the student master the game of tennis through experiential learning. We do feel that our design examples are of a different kind. While the racket is indeed a designed artifact, it is not designed to generate a learning experience: it is designed to play tennis. The potential for experiential learning is in some sense a by-product that you get for free. More importantly, you would not be able to change such physical aspects of the product without changing the entire product.

On the other side, we consider what happens when you sit in a bath. The water slowly gets cold. This change in the baths' "behavior" leads to a temporal dynamic in sensory signals that may very well give rise to a quite similar experience as the one intended by the designed choreography of the shower tray. Processed largely unconsciously, the falling temperature will at some point make one think: I should get out now. But this is not the result of a designed experience. In contrast, in the shower floor, we were able to design the system in an adaptive way so as to first align the choreography with the natural routine of user and then gradually shorten the pattern in order to elicit an earlier onset of the experience of "being finished."

To conclude, in a empirical sensory language, rather than considering just the sensory signals coming from the physical properties of any part of the artifact more generally, there always remains to some degree an arbitrariness, or space for variation, for creating a coupling between the designed sensory signal that a person receives, and the meaning that will arise from it. This space for variation is precisely what gives designers the freedom they need to design the interaction. We say this space of variation exists "to some degree," because a complete freedom on part of the designer to determine the couplings between each sensory signal and the meaning it should generate in the user experience would of course turn the system into a codified system once more.

8. Conclusion

With our research, we aimed to contribute to achieve a "crossfertilization" between features that traditionally apply to the alphanumeric language and the sensory language. Indeed, the sensory language can nowadays exploit new opportunities coming from the development of smart materials and new technologies.

In our research-through-design case study, we applied two different kinds of sensory language (a codified and an empirical one) to the design of two prototypes intended to lead users decrease the water consumption. In general, the results show it is possible to design for behavior change using a sensory language.

Entering into the differences between a codified and an empirical language, we have noted that establishing a material dialog through a codified code gives prominence to the message and to the communicative intent of the product. On the other side, an empirical sensory language addresses our embodied experience more directly, which opens up possibilities to design for behavior change in ways other than through explicit message passing or pure physical enforcing.

One limitation of this study is that this research does not explore the users' perception of sensory codified and empirical languages overtime. In this perspective, future investigations should be set in order to test the two languages capacity to affect the user behaviors over a prolonged period of time.

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Chapter 12

Designing the Expressiveness of Point Lights for Bridging Human-IoT System Communications

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Additional information is available at the end of the chapter

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Abstract

In the last decade, the digital devices and intelligent systems are becoming popular in people's everyday lives. Many machines could communicate and collaborate as a system to provide various services. However, they seldom provide sufficient feed forwards or feedbacks to help users understand current states and aware what it is about to act. In this study, we explored the possibilities of expressiveness with the point lights embedded on ubiquitous devices. By applying the findings from related works and animation principles, we created nine basic individual patterns and composed 12 designs of group behaviors. We then conducted a survey with 69 participants to rate their expressiveness regarding nine vocabularies of the human-system communication. The results show that single light behavior and the performative group light behavior could help to convey specific state information for intuitive communication. At the individual light level, for instance, the *fade in* light behavior can indicate changes in status; *rapid blinking* can indicate important information. At the group level, the two designs developed in this study, *leading* and *simultaneous* type also can initiate human interactions and represent the machine-to-machine conversations taken place in the system, respectively.

Keywords: feedback, communication, understanding, vocabulary, LED lights, Internet of things (IoT)

1. Introduction

In the recent decade, the connected products and services are emerging and becoming more and more popular. It is estimated that by 2020, everyone would have more than 20 devices worn on the body or used in the environments [1]. When the systems run well, they can provide users smooth experiences. However, when something unexpected happens, users usually feel frustrated because they do not know how the problem occurred [2, 3]. Even when everything runs smoothly, feedbacks are also essential to reassure that this is the case. To increase users' awareness, the small light emitting diodes (LEDs) were embedded in most devices for providing information and feedbacks. However, the lighting behaviors are either ambiguous or unintuitive for understanding [4]. As a result, users are unable to obtain useful feedbacks to create the appropriate conceptual model and do not know what actions they could take.

Recently, several researchers have investigated the design of good feedbacks with lights or sounds. However, most of the studies were focusing on the interactions with a single device, for example in [4, 5], how to assist the communications between a user and system is seldom investigated. Our research aims to explore the expressiveness of light behaviors that could enhance users' awareness and understanding on the systems of smart things in the smart environments. In the study presented in this manuscript, we reported the preliminary results that focused on the expressiveness of the individual and group behaviors through the point light embedded on simple devices. Through a user survey with 69 participants, it was found that the combination of light behaviors could sufficiently convey eight of the nine vocabularies investigated in this study. The contribution of this study is a set of light pattern that could be used to provide informative clues of the Internet of things (IoT) system and facilitate the user-system interactions.

2. Related works

In an interactive system, visible lights are commonly treated as versatile mediums to grab user's attentions or provide feedbacks on their interactions. For instance, [6] installed ring lights to a flying drone and designed the light behaviors to let users understand its intentions. Although the usage of LED is a common paradigm in designing electronic devices, Harrison et al. [4] found that the expressiveness of light behaviors was either limited or ambiguous. By using the smartphone as an example, they proposed eight light designs that might provide strong and iconic indications of a particular informational state. In addition, Pintus [5] created six light behaviors to express the status that two devices were connected for transmitting the data to each other. Extending from those studies, we aimed to investigate the design of light behaviors to create sufficient feedbacks of a system with multiple simple devices.

Because the point lights are both sequential and nonpersistent [7], it needs thoughtful designs in composing multiple lights to deliver coherent messages. It is similar to the directing of actors' movements in a movie or animation. Among the well-known 12 principles of animation [8], we thought the *staging* and *timing* could be two proper strategies in designing the system feedbacks. It could direct the user's attentions facilitate him/her to perceive the smart things' states, functions, and reactions.

Finally, Deckers et al. [9] applied the concept of perceptual crossing to show the acknowledgment of a smart thing to a user's approach. With perceptual crossing, he/she not only can recognize the possibility to initiate interactions with the system but also is invited to engage in a more continuous way with something akin to an artificial living creature. In this study, the analogy of "I see you seeing me" in their study was chosen as the semantic term for evaluating the alternative light behaviors developed.

3. Methodology

To understand possible communications that will be needed between human and intelligent systems, in a previous study [10], we chose and analyze nine concept videos produced by leading companies, research institutes, and independent designers. Through the semantic analysis of the interactions between the user and a system of smart things demonstrated in the films, we extracted 43 design vocabularies and clustered them into 11 categories. Among those vocabularies, some of them were extracted from complex interactions, such as the *emotional* or *social reactions* with robots or anthropomorphic devices. For exploring the possible expressions of the simple devices with point lights, we reviewed the video clips and selected nine vocabularies that were essential for creating users' awareness of the system of smart things. This set (shown in **Table 1**) covers the basic communications between a user and a system of simple smart devices.

No.	Categories	Vocabularies included
1	Active	Booting, sleeping, join, broadcasting
2	Exchange info	Synchronizing
3	Notify	Alerting
4	Show problems	Detecting errors
5	Socialize	I see you seeing me
6	Trigger functions	Waking up everyone

Table 1. The vocabularies selected for investigation in the study presented in this manuscript.

4. Designing the individual and group light behaviors

We first explored the different behaviors of single point light based on [4] and created nine basic patterns (shown in **Figure 1**) with variations in the changes of intensity and velocity. Those designs include the two lights that gradually fade in or out, two static designs (on/off) that maintain the intensity as 100% or zero, one breathing light, two designs (blink twice/ thrice) that embedded blinking two or three times, one random brightness, and one (dark flash) that quickly blinks once when it stays as the brightest state.

For the group behaviors, we utilized the animation principles of staging and timing [8] to create six types of arrangements for a system with five devices. In the first three types, all the devices had the same individual behaviors but would light up with different time settings,

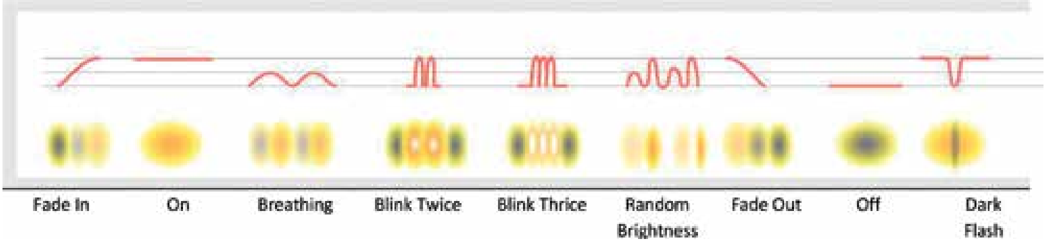

Figure 1. The nine behaviors of point light.

including *simultaneous*, *sequential*, or *random.* In the other two types, there was a device dressed with different light behavior to grab users' attentions on it, such as *leading* and *emphasizing* type. Finally, there is a *counting off* type that simulates the machine-to-machine conversations by aligning the pairing responses in the same time or with a short delay in time. Through compositing the individual light behaviors with those group patterns, we generated 12 designs with the video editing software. The illustration of the light behaviors was shown in **Figure 2**.

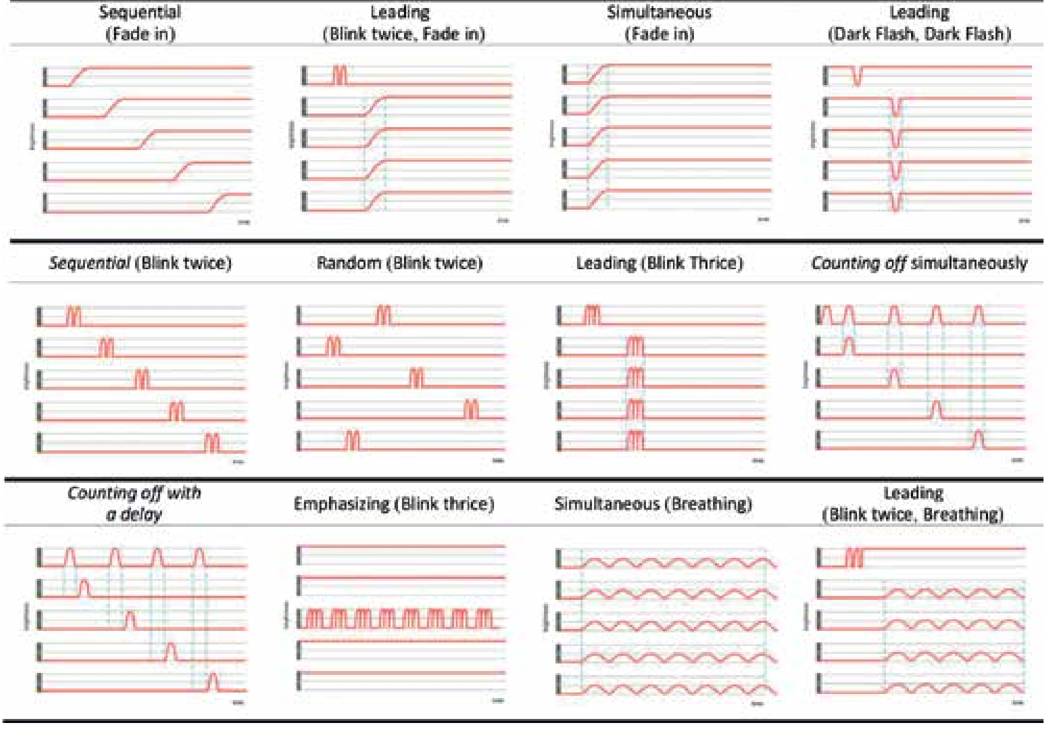

Figure 2. The 12 lighting patterns for group communications. The settings in brackets refer to the individual point light behavior on the device.

5. Experiment

5.1. Setting and procedure

An interactive survey was developed for evaluating the expressiveness of light behaviors in random order. In each round, a participant would see one of the 12 video clips (that would automatically replay) and rate the degree of their perceptions regarding the nine vocabularies shown in **Table 1**. A five-point Likert scale was provided next to each of the scale (ranging

Design/factor analysis	**Factor 1: active**				**Factor 2: interaction**			**Factor 3**	**Factor 4**
	Booting	**Waking up everyone**	**Detecting problems**[#]	**Synchro-nizing**	**Broad-casting**	**I see you seeing me**	**Joining the system**	**Sleeping**	**Alerting**
1. *Sequential* (fade in)	**	***					***		
2. Leading (blink twice, fade in)	*	*			*	*	**		
3. Simultaneous (fade in)	***	**		***					
4. Leading (dark flash)				*	**	***			
5. Sequential (blink twice)					***		*		
6. Random (blink twice)			*						*
7. Leading (blink thrice)			**		*	**			***
8. *Counting off* simultaneously				*					
9. *Counting off with a delay*								*	
10. Emphasizing (blink thrice)			***						**
11. Simultaneous (breathing)				**				***	
12. Leading (blink twice and breathing)								**	

Note: more * indicates the mean is larger; the settings in brackets refer to the individual point light behavior on the device; #, in the repeated measures ANOVA analysis, the data of "Detecting Problems" vocabulary is the only one that the light behaviors were not significant (Mauchly's Test of Sphericity, $df = 65$, $p = 0.175$); and the data of the other eight vocabularies are all significant ($p < 0.05$).

Table 2. The top three light behaviors the participants thought are relevant to the specific vocabulary.

from 1, strongly disagree, up to 5, strongly agree). There were 69 participants (52% male and 48% female, 88% aged between 21 and 30) recruited and completed the survey. A total of 70% participants have expertise related to interaction design.

5.2. Results

The statistical analysis shows that for eight of the nine vocabularies (excepting "Detecting problems"), there were several designs of the group light behaviors perceived with higher correlations to particular terms than the others (repeated measures ANOVA, $p < 0.05$). **Table 2** provides an overview of the matching. Together with the *factor analysis*, it was found that the nine vocabularies could be clustered into four groups (with 93.91% of variance explained). Regarding the first *active* factor, the *sequential* (fade in), *simultaneous* (fade in), and *leading* (blink twice, fade in) light behaviors are the three ideal designs that can express the system's working state. For the second *interaction* factor, the *sequential* (blink twice) and *leading* (dark flash) are perceived to convey the machine-to-machine communications and human-system interactions, respectively. In addition, because the *breathing* light pattern was widely used in many electronic devices, the participants could easily perceive the system in sleeping or standby status with the pattern. Finally, for the *alerting* vocabulary, the most correlated designs are *leading* (blink thrice) and *emphasizing* (blink thrice). Similar to the first *active* factor, the individual light pattern articulates to alter or notify the users an important message. Besides, the group behavior provides additional information to help him/her aware of the different levels of the communication. Based on those findings, currently, we are implementing those light behaviors with tangible prototypes. We plan to conduct contextual experience experiments to investigate how will people interpret the light behaviors in the physical world. This will help us to understand how to design intuitive feedbacks to bridge the human-IoT system communications and create natural and seamless interactions.

6. Limitations

In this study, we mainly focused on the design of light behaviors and their semantic expressions. Therefore, we chose the video simulations to explore alternative design ideas. This helped us to investigate the subtle changes of single point light and the compositions of multiple lights. In our survey, the text descriptions were presented to help users imagine the context and rate the degree of correlations between the designs and vocabularies. The preliminary results could provide designers an initial set of individual and group light behaviors for conveying specific feedbacks.

7. Conclusion

As the IoT technology is maturing, many designers are focusing on creating smart products to improve customers' living experiences. There have been many devices installed and used in many people's daily lives. However, due to the lack of communications, users often encountered frustrations to the system's unexpected behaviors. This study is aimed to explore how to design the expressiveness of point light to improve users' situated awareness to the smart things in the surrounding space. Based on related studies of the point light design and the animation principles [8] of staging and timing, we composed 24 group light behaviors for a local system that consists of five virtual devices. After evaluating the esthetic quality and the consistency of message conveyed, we chose 12 designs and conducted a survey with 69 participants. The results show that the point light behaviors and the composition of grouping performance could create implicit and sufficient communications. As a result, we recommend a collection of design strategies. With this new knowledge, designers could successfully provide useful clues for users to have the natural and seamless experience while interacting with a system of smart things in a smart environment.

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Section 4

The Perceptual and Experiential Gap - Transcending Acoustics

HAPTIC: Haptic Anatomical Positioning to Improve Clinical Monitoring

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Additional information is available at the end of the chapter

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Abstract

Hospitals are inundated by the sounds of patient monitoring devices and alarms. These are meant to help, yet also create a stressful environment for physicians and patients. To address this issue, we consider the possibility of delivering complementary haptic alarm stimuli via a wearable tactile display. This may reduce the necessity for the plethora of audible alarms in the Intensive Care Unit and Operating Room, potentially decreasing fatigue among clinicians, and improving sleep quality for patients. The study described here sought to determine a suitable anatomical location where such a tactile display could be worn. Although the wrist is an obvious default, based on the success of smartwatches and fitness monitors, wearable devices below the elbow are disallowed in aseptic procedural environments. We hypothesized that haptic perception would be approximately equivalent at the wrist and ankle, and confirmed this experimentally. Thus, for a healthcare setting, we suggest that the ankle is a suitable alternative for the placement of a tactile display.

Keywords: multisensory integration, tactile displays, medical alarms, clinical performance, patient monitoring

1. Introduction

Hospital environments (ICU) are stressful in large part due to the proliferation of auditory alarm systems, with a typical multibed care area generating 30 different alarm sounds [1]. Despite advances in medicine, the numerous alarms in the operating room (OR) and intensive care unit (ICU) are mostly unnecessary. With only 17% of alarms having clinical relevance [2, 3], these are more often the cause of information overload, clinician fatigue, and sleep deprivation among patients [4]. These problems are exacerbated by the high sound pressure level (loudness) of alarms, typically approximately 51 dB, or 15–20 dB louder than the level recommended by the World Health Organization (WHO) [4].

The excessive resulting noise in the OR and ICU can also cause physicians to suffer from alarm fatigue, the phenomenon of diminished response due to desensitization to the alarm stimulus [5]. As a result, alarms no longer serve their purpose, and instead, may place the patient's safety in jeopardy. Alarm fatigue is an issue that must be addressed: the MAUDE database of the US Food and Drug Administration (FDA) reported 500 alarm-related patient deaths from 2010 to 2015 [6].

One approach to reduce the negative impact of alarm systems would be to implement a personalized and multimodal system that would combine both auditory and haptic cues to communicate physiological information. The result of adding haptic cues to an auditory interface has been shown to increase the bandwidth of information transfer in complex settings [7]. The question then is where such a display should be placed.

To address this issue, the experiment we describe in this chapter examined human perception with haptic input presented to either the wrist or ankle. The former was chosen because of the current literature and success of wrist-worn devices, such as personal fitness monitors, in the commercial market. However, the wrist is not a feasible option for the OR and ICU setting, due to the need for an aseptic environment. Thus, we examined the ankle as a potential site, as it shares several properties with the wrist, which is easily accessible, and is not subject to the same sterility requirements.

2. Literature review

Tactile displays are tools that use vibrotactile (VT) and electrotactile (ET) stimulation technology to employ the sense of touch for the representation of information [7]. These displays are often used for the purpose of sensory substitution, that is, compensating for missing or impaired sensory functions such as sight. For example, visual cues can be provided through an arrangement of tactor pins that give feedback about the users' surrounding environment [8]. Tactile displays can also be used to augment typical sensory function, e.g., to provide an error signal in the sway of an individual, helping them correct their posture and improve balance [9]. The compensation of impaired sensory function and augmentation of typical sensory function occurs by manipulating vibration frequency patterns to give feedback and encourage a closed-loop communication of tactile input and human response. The vibrational stimuli known as tactons are essentially the tactile equivalent of visual icons. Tactons have a wide array of uses, from medical devices that help guide the visually impaired to the communication of non-visual information in electronic devices.

Both Sato and Gescheider et al. found that vibration perception is affected by two factors: frequency and ambient temperature [10, 11]. The lowest threshold of perception on the fast-acting skin receptors was measured in the frequencies of 150–300 Hz under conditions of ambient temperature of 21–26°C [10].

The method of communication via vibrational stimuli has been shown to be an effective manner of attracting attention in a subtle way, especially in loud and crowded environments without other environmental interference [12]. Although tactile displays have had success in locations all over the body, the most common commercial applications involve wearable devices on the wrist. In medical environments such as the OR or ICU, this may be problematic, since the hands and lower arm are often required to be free of any accessories. The WHO recommends surgical hand scrub/preparation using antimicrobial soap and water to maintain the least contamination of the surgical site during a procedure [13]. Any device worn from the elbow and distal toward the hand compromises the hygiene of the surgical environment and yields the possibility of contamination. This motivates our research into tactile displays that could be worn at other body locations than the wrist.

A possible solution to the concerns of asepsis in the OR and ICU with wearable devices was explored by McNulty et al. with a tactile display device worn on the upper arm. An elasticized sleeve with tactors in three distinct positions (upper, middle and lower) communicated physiologic information such as heart rate (HR) and oxygen saturation (SpO_2) to subjects, who were asked to operate a foot pedal and report the change they noticed in either HR or SpO_2 [14]. An integrated display mapped HR to spatial location of the tactor, whereas, SpO_2 was mapped temporally to the rate at which the tactors were vibrated.

One of their experiments compared two strategies for conveying heart rate, using two pairs of tactors, located at the upper and lower positions. The first strategy vibrated a single tactor in response to a heart rate that was higher or lower than normal, and vibrated both tactors in the pair for *very* low or *very* high HR. The second strategy vibrated both tactors in the pair for any heart rate higher or lower than normal. Little to no difference in identification accuracy was observed relative to the previous integrated method experiment in which both HR and SpO_2 were recorded. The differentiation of high/low and very high/very low resulted in reduced response accuracy. This could be due to the additional cognitive load of discerning whether one or two tactors were producing the vibrational stimuli. The experimenters noted that subjects experienced great difficulty interpreting the location of vibrational stimuli on the arm. This could be attributed to several factors such as tactors being placed too close together.

McNulty et al. also tested a flipped-integrated display, in which heart rate was mapped temporally to the rate at which the tactors were vibrated, whereas oxygen saturation levels were mapped to the tactor location on the arm, thus, the opposite of the mapping strategy adopted for the integrated display trial. However, the flipped-integrated display did not lead to more accurate results. This also could be attributed to issues with the discrimination of spatial information.

A study by Enriquez et al., employing the sense of touch for information representation, demonstrated that the addition of a tactile stimulus to an auditory stimulus can increase the bandwidth of information transfer in complex and data-rich environments [12]. We were thus motivated to test the hypothesis that by integrating auditory and haptic inputs, the auditory threshold of perception could be lowered, allowing for the reduction of alarm volume in the OR and ICU setting. Given the need for sterility of the wrist, we investigated the efficacy of integrating haptic stimuli at the ankle position with a non-speech (medical alarm) auditory stimulus [15]. The results, however, did not support our hypothesis. Rather, no discernable difference was observed between the measured threshold under auditory-only and auditory-haptic conditions [15].

A possible factor in McNulty's results, as well as the inconclusive results of our study, may have been the interference of haptic input with the subject's auditory perception. In McNulty's latter experiment, issues were experienced with spatial discrimination due to potential interference between both tactors. Difficulties in the task were also attributed to the interaction between the subject's motor and tactile sensory function. This suggests that interactions between sensory systems must be observed and addressed if multisensory integration is to be exploited in a wearable display device.

Sensory interference may be harder to prove as a confounding factor than finding the perfect combination of sensory input. During auditory-haptic discrimination tasks, where participants indicate perception of unisensory or multisensory stimuli above and below their perceptual threshold, there were an equal number of subjects who were biased toward the auditory stimuli as they were toward the haptic stimuli [16]. Similar factors may have been at play in the lack of significant results seen in our study [15], and we cannot yet offer a conclusion as to whether one modality enhances the perceptual effect of the second modality. This can be attributed to Bayesian inference principles—either the haptic or auditory modality may be imperfect and therefore supported by the other sense to give a complete picture. Due to the random nature of which sensory modality dominates, multisensory integrative displays may have to be tailored to the individual interacting with the display technology.

3. Experiment design

This study was approved by the Research Ethics Board at McGill University in Montreal, Canada. Before the experiment, the participants signed a consent form and completed a pre-test questionnaire consisting of demographic information and whether they have health issues affecting their sense of touch and vibration perception. The subjects (n = 9, 6 male, 3 female, ages 21–44 years of age) were members of the Shared Reality Lab in the McConnell Engineering building at McGill University and took part in the study voluntarily. The duration of the experiment was 20 min long and the participants received no compensation for their participation.

To compare haptic perception between two different anatomical locations on the body, we conducted pilot tests in our laboratory environment, using a random double-staircase method. The subject is presented with two staircases: one starts with an intensity above the vibration perception threshold, and the other with an intensity below the threshold. The superiority of this method over the upward staircase method, as used by Williams et al. [17] to measure perception thresholds, has been discussed by Cornsweet [18]. With the upward staircase method, subjects tend to be biased in their subsequent responses after several identical responses.

Each stimulus was delivered randomly within a 10 s window following the previous one. The intensity of the vibration increases when a stimulus is not perceived by the subject and decreases otherwise. To ensure fast convergence of the two staircases, the step size was relatively large at the beginning, and reduced as the two staircases approach. Subjects had to respond within 1 s following stimulus presentation by clicking on a button displayed on the user interface; otherwise it was assumed that the stimulus was not perceived. The threshold measurement was terminated when six reversals were recorded, i.e., after six negative responses followed by a positive one, or vice versa. The threshold was then calculated as the mean of the twelve intensity values over the period covered by the six reversals.

The vibration stimulus presented in each step of the staircase was generated using a 1-s sine wave at a frequency of 175 Hz, delivered by a Tactile Labs Haptuator Mark I (Montreal, Canada) [19], attached to the ankle by a Velcro strap, as shown in **Figure 1**. The motor was connected to a Sparkfun TP2005D1 audio amplifier (Boulder, CO, USA), and controlled by a script written in MATLAB R2016a (MathWorks, Natick, MA, USA).

The independent variable was the choice of delivery location of the vibration: either to the subject's leg or arm, as shown in **Figure 2**. For the leg condition, the strap was attached snugly to the ankle with the exact position of the vibrating motor, chosen to minimize discomfort caused by the vibration. For the arm condition, the position of the vibrating motor on the subject's wrist corresponds to similar placement for watches or fitness monitors. Participants were asked to keep their leg and arm stable when the vibrating band was attached.

During the experiment, pink noise, commonly used to mask background distracting sounds, was delivered to the participants through a pair of Beats Solo3 headphones.

Figure 1. The vibrating band used in the study consists of a Haptuator attached to a Velcro strap.

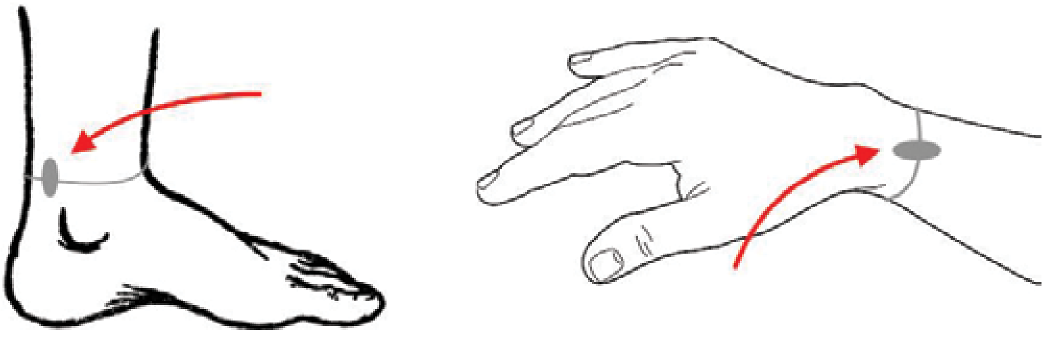

Figure 2. Position of the vibrating motor on the participant's ankle and wrist.

4. Results

Figure 3 illustrates the staircases obtained with the vibrating band attached to the ankle and wrist of one participant. Note that the units of measurement were dependent on the specific combination of equipment and software used.

The threshold and standard deviation of the intensity values over the last six reversals in both cases were calculated, as described above. An ANOVA was then performed to test the influence of position of the display device on the threshold of perception or the standard deviation of perceived intensities during the last six reversals. Excluding the data from one outlier participant who suffered from a wrist injury, the ANOVA showed that the null hypothesis cannot be rejected: device position did not produce a significant difference in either threshold ($p > 0.1$) or standard deviation ($p > 0.5$). These results support our decision to work with the device worn at the ankle position.

5. Conclusions

In the OR and ICU, an aseptic environment is required to prevent potential surgical site infections, which may harm or jeopardize the health and safety of the patient. To ensure an aseptic environment is maintained, all equipment is sterilized and any individual handling the equipment or involved in the surgical procedure must perform a surgical hand scrub. Thus, all wearable devices below the elbow are prohibited as options for a haptic display device. In this study, we have shown that the ankle offers a location for which haptic perception properties are similar to the wrist. It is therefore a more suitable anatomical position for a tactile display device because of the lack of interference with standard surgical sterilization and hygienic practices and guidelines.

Future experiments will test the efficacy of monitoring several different physiologic parameters, such as heart rate, oxygenation, and blood pressure. Communication of important physiologic data via a haptic modality may allow for fewer audible medical alarms as clinicians are aware of the trend of a patient's status and gain a new-found ability to provide proactive and safe patient care.

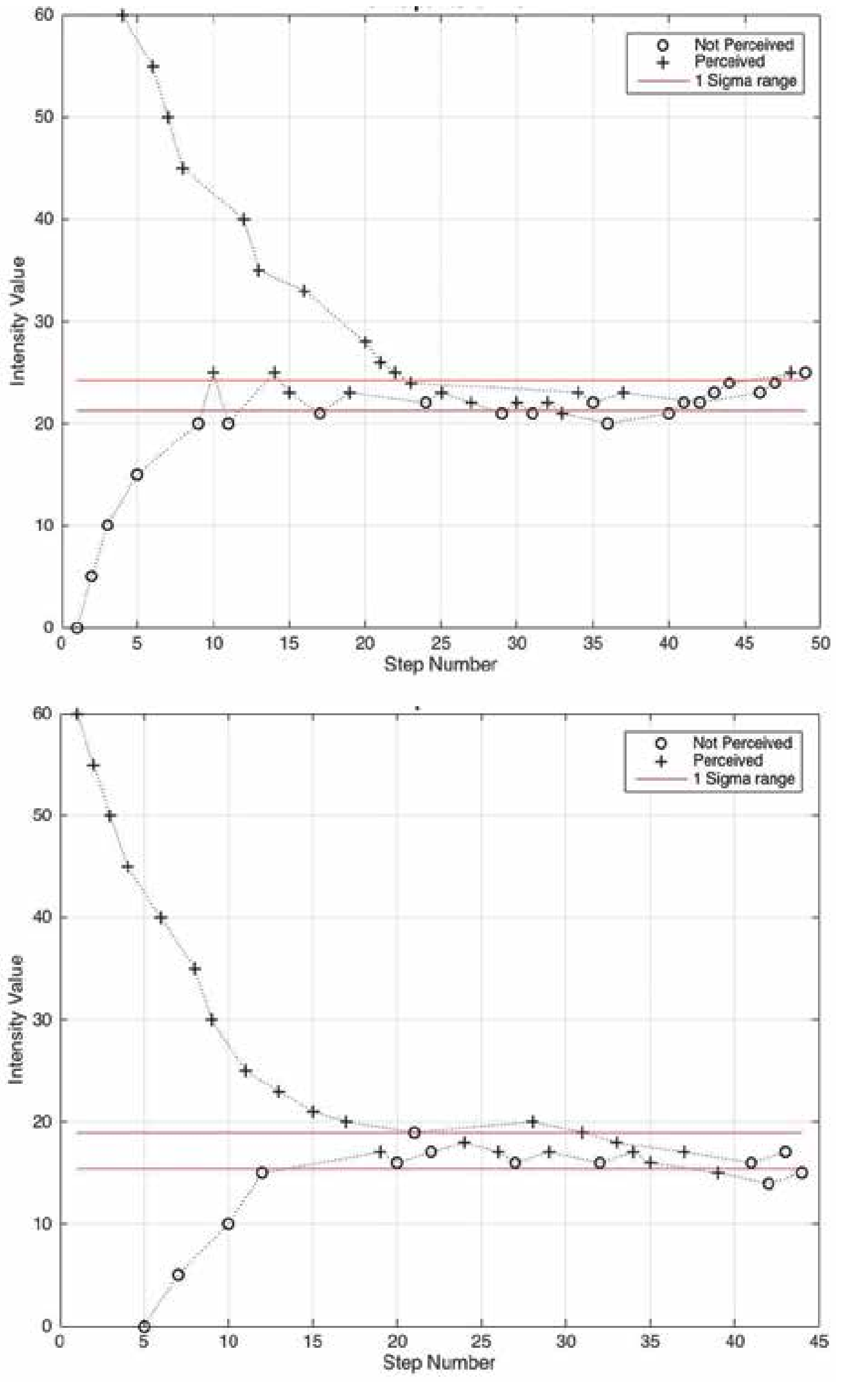

Figure 3. Sample staircase of participant's responses to the vibration stimuli delivered to the ankle (top) and wrist (bottom).

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Knowledge in Sound Design: The Silent Electric Vehicle —A Relevant Case Study

Nicolas Misdariis and Andrea Cera

Additional information is available at the end of the chapter

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Abstract

This article builds on a large industry-driven sound design experiment focusing on the underexplored area of sound signature for silent electric vehicles. On the basis of some retrospective observations, and in the conceptual framework of design research, we propose a post-analysis that leads to provide insights on sound design as a discipline, considering its status, the status of its performers (sound designers), and its specific position between science and arts. The main aim of the article is to contribute to increase the general knowledge on sound design and to study it from the perspective of its principles, practices, and procedures.

Keywords: sound design, design, science, creation, industry

1. Introduction

This paper builds on a relevant and emblematic case study, the exterior sound signature for silent electric vehicles, in order to draw knowledge on sound design as a "coherent discipline of study in its own right" [1]. We postulate that sound design is a highly polymorphous and heterogeneous practice which still suffers from clarity of definition as well as lack of theoretical knowledge. We put this issue in the larger and conceptual context of design research [2] which will help to propose a formalized approach of the science of sound design, that is, by analogy with the design field [3]—the study of the principles, practices, and procedures of the discipline.

1.1. The case study: silent electric vehicles

In sound design, a recently resurgent industrial object appears to be an emblematic case study: the electric vehicle (EV). This mechanical machine is a moving and silent object in a noisy environment, a kind of *Unidentified Moving Object*. As such, it leads to global challenges with regards to user experience: co-existence with other noisier vehicles therefore representing a danger for elements in the vicinity (e.g. pedestrians), ergonomics for drivers as no audio feedback informs them about the vehicle functioning, and drastic modification of the soundscape, especially in urban context. Despite some propositions for non-sonic solutions [4], the more broadly accepted—and even required [5]—view is that the EV's should produce appropriate synthetic sounds. This is an unexpected windfall for sound designers; it corresponds to a complex problem involving sound quality, ergonomics, esthetics, acceptability, and sound branding. However, some important issues in sound design need to be solved in a joint effort among creation, research, and development: (i) relevance, consistency, and suitability: a controlled sound for a given quiet object; (ii) innovation and creativity: a controlled sound for a fairly new object; (iii) ecology and integration: a controlled sound for a potentially controlled environment. The central question still being: what would be the most appropriate sound for a silent vehicle?

1.2. The context: science of sound design

Today, sound design covers a large range of practices and application fields. As seen on Wikipedia page[1], its origin can be traced to sound-image relationship, the field where the profession was born in the early 70s. But, it can also concern manufactured products (*tangible* world), human-computer interfaces (*digital* world), or architectural, environmental, and even commercial spaces (*spatial* world). Therefore, sound design can correspond to a multiplicity of definitions considering, for instance, sonic material as "an element of user experience" and "a specific manner of embodying design solutions" [6], or more simply, the medium to "make an intention audible" [7].

From this perspective, replacing sound design in the broader scope of design invites opportunities to put this subcategory within a broader reflexion on models of design research (research-by-project versus research-by-creation [8]), concepts of science of design (from scientific design to science of design [3]) and, more globally, issues related to the role of design between the sciences and arts/humanities (design as a "third area" or a third culture, as outlined by Archer [1]). Concretely, this attempt to transpose initial design research paradigms aims at proposing a conceptual framework for the science of sound design and at arguing in three main axes, as outlined by Cross [9] (cited in [2]):

- people: status and practices of the sound designers;
- process: innovative methods and tools in sound design;
- products: forms, formats, and status of the designed sounds.

This paper will document these parts with analyses and results of the electric vehicle sound design project that appears to be a relevant observation point for nourishing this investigation.

2. Project description: on what we build on

The EV sound design project lasted almost 3 years (2009–2012) and mainly focused on one model of Renault's electric range ("Zoe"). After a formalized presentation of its main inputs, this section will give the synopsis of its process (for further details please refer to [10, 11]).

[1]https://en.wikipedia.org/wiki/Sound_design

http://dx.doi.org/10.5772/intechopen.71120

First, the project was based on several inputs from different sources of inspiration: scientific from a state-of-the-art in the research field, environmental with regards to the context of use, and singular with regards to a specific corpus of inspiration. For the sake of formalization, these inputs may be associated with three different way of reasoning: *deduction*, *induction*, and *abduction*. Several references provide the definitions of these three concepts (see for instance, the Merriam-Webster dictionary webpage[2]) but the most concise one is seemingly provided by Cross [12], based on the work of the philosopher Peirce [13, 14]: "*deduction* proves that something must be, *induction* shows that something actually is operative, *abduction* suggests that something may be". In accordance with Cross' arguments, this distinction—and especially the statement of the abductive approach—is also a way to highlight a certain specificity of the sound design process.

2.1. Initial inputs: sources of inspiration

In reference with the seminal works of Schafer [15] and Krause [16], we first looked at the acoustic ecology theory that states the existence of a sonic organization in nature, in order to ensure the audibility of every species. Such structure is found in several dimensions (frequency, intensity, and timbre) or time scales (seasons, day/night cycle) and prevents masking or grouping phenomenons. By analogy, considering, the electric vehicle as a new sound species in a new (urban) ecosystem, we addressed the following questions: what is the structure of the urban soundscape? Are there overloaded zones or, inversely, are zones able to host EV sound signature components, allowing them to emerge in ecological conditions? From analysis of various soundscapes, we then *deduced* some basic rules either in terms of frequency zones to favor/avoid or temporal morphology to elicit, as follows: a static and ordered sound should be able to emerge by its regularity from the ever changing soundscape (mainly made by irregularities of traditional engines).

Due to the lack of scientific studies on the topic—at least when the project started—it was difficult to do a traditional state-of-the-art review. Nevertheless, we compiled a list of existing works, and in particular, two experimental studies from Wogalter et al. [17] and Nyeste and Wogalter [18] (see [11], for a more detailed review). In their joint studies, they tried to define sound categories that might provide acceptable auditory cues for quiet vehicles, respectively, in terms of object association and acceptability. From these results, we finally *induced* typical sound categories to be ideally considered: music, whistle, beeps, horn, clicking sounds, exhaust pipe, or engine sounds, and among them, the fact that engine sounds (together with hum and white noise) is the most acceptable and preferred sound type. These conclusions also highlight the difference between functionality and acceptability, especially obvious in the case of the white noise signature.

The lack of scientific references mentioned above led us to explore another source of data: the cinematographic field (science-fiction movie genre dealing with mobility). This unconventional approach was based on the hypothesis that public expectations of the EV's sound—and hence its acceptability—could partially be shaped by the work that sound designers did in this area of motion picture sound production. To a certain extent, this approach can also be seen as *abductive* reasoning, relying on Cross' comment about this concept: "[a hypothesis] of what

[2]https://www.merriam-webster.com/words-at-play/deduction-vs-induction-vs-abduction

may be, the act of producing propsals or conjectures” [12]. We focused on jet sounds of the Lola T70 in THX 1138 [19], gentle drones of converted vintage cars in Gattaca [20] and humming sounds that appear in the next generation vehicles in Back to The Future [21]. For these new forms of engines, we observed that sound designers tended to shy away from reality and gravitate toward more synthesized sounds including drone-like, continuous sounds with timbral qualities adapted to the vehicle’s shape and performance. Nonetheless, even if they could also be used for other percepts (e.g. fluidity in [22]), examples coming from motion pictures must be considered carefully. Their caricatural and ephemeral nature (conveying clear meaning in few seconds) contrasts greatly with the more ubiquitous and constant sonic presence of a car sounds in everyday life.

2.2. Project chronicle: synopsis

For the project, different modes of interaction with the industrial partner were implemented: a decision committee from different departments (Product, Engineering, and Design), an expert team involving key persons from the project and a technical group mainly in charge of the development phase. On this basis, around 100 successive propositions (see [23] for details) were made using a mixed empirical and methodological approach: on one hand, a trial-and-error paradigm mainly driven by the expert team, and on the other hand, evaluations produced by the technical group or resulting from standard experimental procedures. In fact, at a certain stage of the project, two types of listening tests were conducted in order to: (i) assess the functionality of the propositions, that is, their ability to signify the approach and the presence of the vehicle and (ii) qualify the propositions in terms of hedonic judgment, emotional response, and evocation.

From a global point of view, the synopsis of the process that leads to the industrialized solution can be described with the following steps (see [10, 23] for a more detailed description):

- *sound synthesis*: given the specifications, a four-buffer wavetable synthesis controlled by the vehicle speed was chosen. And because of the strong interactivity component of the project, a prototype of this sound engine was developed in the Max[3] audio signal processing real-time environment.
- *sound rendering*: as traditional stereo setup did not appear to be realistic enough, an immersive device was developed (quadraphony + Spat© [24]) resulting in more flexible and realistic representation of sound trajectories within urban soundscapes. However, as the visuals also seemed to be crucial—above all for sound/object association—we added graphics to the rendering system.
- *prototypes*: during the project, a mixed form of prototyping was tested out. First, we embedded the whole setup (sources, amplifier, and loudspeaker) in a common electrified vehicle. This allowed us to get actual acoustic dimension of that target environment and a direct usage feedback, especially with regards to this sound/object association. Second, we considered the successive prototypes of the target EV itself (Zoe). This allowed us to check

[3]https://cycling74.com

the control laws of the sound engine and to do the fine tuning of the sound materials, especially with regards to medium-low frequencies.

- implementation: the final results of our research results which included translation of sound engine prototypes, were embedded in a chip rendered via EEPROM native languages.

3. Post analysis: what we learned

In the previous section, we gave a summary of the EV sound design project focusing on its uniqueness and complexity. In this section, we will formalize what we learned from this experience in order to contribute to a better definition of sound design as a discipline. Our analysis thus follows a structure and research design approach proposed by Cross [9] that focuses on acquiring knowledge on "people" (sound design epistemology), "process" (sound design methods), and "products" (sound design artifacts) (cited in [2]).

3.1. Knowledge on people: status of the sound designer

The project chronicle described above shows a complex process involving human interaction and technical issues for achieving an industrialized solution. In this context, the question of the amount of space left for individual creativity and authorship naturally arises. What is the role of the sound designer in a network of people who not only decide on, but also contribute to the design process?

A first attempt to answer this question could point out the ability of opening multiple versions of a work and creating a labyrinth of links where the network can slowly navigate until a given destination is reached. This *ability to open* does not only mean that the sound designer has to create as many sounds as the collective asks for him. For some serious issues, he also has to put aside his convictions about what a *good sound* should be and to embrace new esthetic parameters, especially when a conventional valid rule could be void in a particular context. On the other hand, he sometimes has to show the ability to work pedagogically by producing sounds able to explain that what is driven by curiosity may not be optimal—in other words, convince co-workers through efficient demonstrations. In both cases, the sound designer has to approach his peers with a stealthy attitude, a self-effacing posture which assures that every voice of the network is considered and that light or heavy issues are treated with the same respect.

An example of simple *curiosity* was the request to create a musical sound-logo as the EV sound signature. It seemed clear that this request was doomed to failure for annoyance, intrusivity, and ecology reasons. Nonetheless, instead of simply rejecting this idea, we created a small number of sound-logos and had them approved by the expert team. But after having implemented them on a prototype, our partners immediately pointed out the awkwardness of the result and proposed an alternative: to use the sound-logo only when the car is at idle and to switch to a continuous sound bearing timbral similarity with the sound-logo when the car is in motion. This second idea was also rejected, but it allowed us to experiment the possibilities of a clear harmonic content in continuous sounds. Finally, some of these findings migrated to the final result: without this detour, they would not have been included at all. Moreover, the partner was definitely convinced that musical metaphors must be used very carefully.

An example of *serious issue* was the use of discrete, granular, or highly impulsive sounds (clicks). From our perspective, a sound having some roughness, granularity, micro-rhythmicity in the upper spectral registers would have been a good candidate for spatial localization. But every time we proposed these kinds of sounds, we encountered clear resistance from our partners. We understood the nature of the problem when we learned that many professionals from the automotive industry share an instinctive aversion for anything sounding like an audible vibration, regardless of sound type. In other words, this feeling seemed to be embedded in their overall evaluation system: a car has to project an aural image of smoothness.

As these examples show, the presence of a didactic and self-effacing author is essential. In the first case, to ensure a convincing quality of the sound-logos, in the second case, to rebound from the rejection of propositions, and to learn how to use scalable constraints for creating relevant evolutions of original ideas.

3.2. Knowledge on process: status of the sound design

For nearly 15 years, research in sound design has tended to formalize tools, methodologies, and concepts that enrich its disciplinary field (see [25] for a detailed review). Among these developments, a project methodology has been defined by the Ircam's PDS team. This approach, coming from a standard 'V' cycle model, is composed of three steps: 'Analysis' (of the problem), 'Conception' (of solutions), and 'Validation' (of propositions). It also involves a retroactive loop that enables the methodology to iterate the conception step from the validation results in order to propose new solutions better fitting with the initial problem (**Figure 1**). This approach turned out to be relevant from a conceptual point of view and was implemented several times in our academic research [26] and pedagogical actions [27].

Thus, with regards to its unprecedented object (electric vehicle) and its strong industrial connotation (mass production), the present study gives the opportunity to provide analytical insights into this methodology and, in a way, provide frame to assess its level of practicability in realistic contexts.

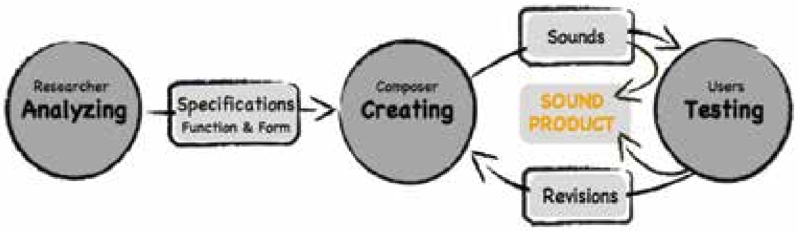

Figure 1. Sound design methodology, from Ircam/PDS team.

As previously mentioned, the 'Analysis' step could not have been achieved in a traditional manner due to the topic specificity. Getting information on what already existed in terms of the EV's sound signature was almost impossible because of the rather pioneering position of the project and forced us to look at other disciplines such as the moving image industry. Then, we did not really induce acoustic specifications from existing EV signal specimens but rather stated hypothesis from the collected marginal data. Nevertheless, this somewhat unusual approach had a positive side-effect opening up creative opportunities due to the lack of historical examples in the field. In fact, trying to expand the present is oftentimes less innovative than starting from the ground up. This is, in substance, what Hug claims—in the field of game sound design—about the "simulation of reality" and the necessity to go beyond this "unnecessary limitation" in order to propose "new directions of innovation" [28].

On another hand, the 'Evaluation' step was likewise altered due to our uniquely defined research setting. In fact, the theoretical process contains a feedback loop that increments a conception-validation module: conception being iterated in the light of validation results compared to the initial specifications. In practice, this step often mutates into a selection step (rather than an iterative evaluation), primarily due to time and cost constraints. Thus, the refinement process, expected from this loop, is more a *funnel-shaped* approach where propositions are successively selected on the basis of both objective measurements—coming from experiments—and subjective assessments—coming from decisions. To summarize, the evaluation step rather appears to be delivering advisory outputs instead of prescribing and guiding additional conception rounds, in practice.

3.3. Knowledge on products: status of the designed sound

Finally, an interesting validation of the designed EV sound signature occurred a few years after the end of the project, in 2014, showing the legitimacy of a complete and controlled sound design approach for such a complex framework.

In 2011, an important three-year European project called eVADER[4] aggregated a mixed consortium of various research labs, automotive industry partners, and suppliers to work on electric vehicle alert system for detection and emergency response. The main goal of this project was to propose and develop a sustainable answer to the issue of the EV's sound, which additionally provided an experimental framework for further legal specifications.

One specific task undertaken during this project was to propose the design of experimental stimuli built on acoustic parameters and rules based on relevant perceptual and cognitive principles including auditory sensitivity, stream segregation, masking or saliency and, more generally, on the auditory warning strategies compiled from the state-of-the-art (see [29]). The experimental part of this work conducted listening tests with regards to two main criteria: *detectability* measured by a response time protocol and *unpleasantness* assessed on a semantic scale (see [30, 31] for further details). The results of these tests finally led to locate in a detectability/unpleasantness space the basic rule-based stimuli (**Figure 2**).

[4]http://www.evader-project.eu

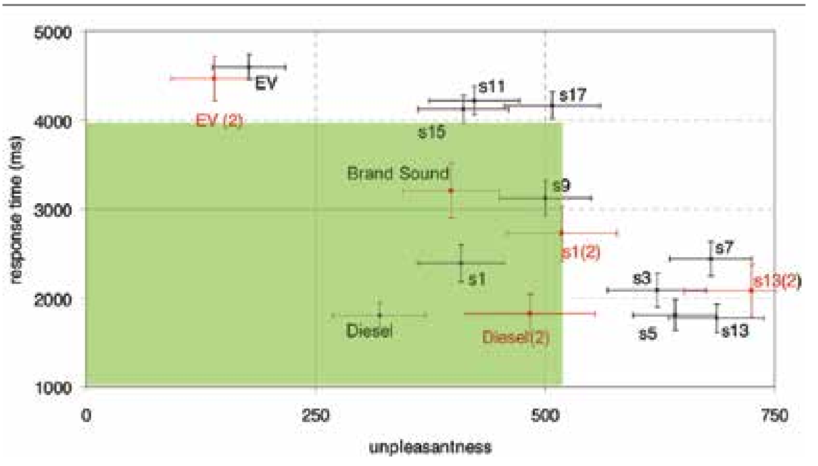

Figure 2. Detectability versus unpleasantness obtained after perceptual experiments in eVADER project (taken from [32] —with the agreement of the author). Black points (•) indicate results from a first experiment only involving basic stimuli. Red points (•) indicate results from a second experiment including the "*Brand Sound*". The *green zone* represents the "better compromise between detectability and unpleasantness".

In the final phases of eVADER project [32], the basic stimuli were mixed with the sound signature resulting from the project reported in the present article (called "*Brand Sound*"). As a result, this last test showed that the *brand sound* seemed to be better—or at least equally well —positioned in the data space than most of the inital basic stimuli enabling it to be fully included in the sweet zone corresponding to an optimal combination of both detection and pleasantness (**Figure 2**).

In a summary, these findings point towards to important observations: first, that (well) designed sounds can bear comparison with laboratory stimuli, that is, sounds designed on the basis of formal rules. And second, that the sound design process—that is, the integration of an artistic practice into a scientific/technical approach—can augment the conception of sound signals, moreover compatible with both functional and esthetics needs. This result can also promote the idea of a "*designerly way of thinking*" in sound design, inherited from the concept stated in the broader discipline of design [33]. In fact, this somewhat illustrates one argument from Cross' seminal paper: the specific values of the design culture ("practicality, ingenuity, empathy") especially compared to those of the scientific culture ("objectivity, rationality, neutrality").

4. Conclusions

The project dealing with sound signature of electric vehicle led to collaboration between partners in the automotive industry, a research team, and a composer. It resulted in the implementation of a realistic and controlled sound design solution on an industrial product.

The range and richness of this *research-by-project* approach—as defined by Vial [2]—are mainly due to the uniqueness of the topic: to give a sound to an ideally silent object. It highlights elements of an applied research in sound design by opening questions about various issues induced by the discipline, such as status of the sound designer and designed sound, or the relevance of sound design methods. Consequently, it also provides opportunities for further thought on sound design by trying to put it in the larger context of design—its founding discipline—and observing it through the prism of the science of sound design.

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Chapter 15

Sensory Augmentation through Tissue Conduction

Peter Lennox and Ian McKenzie

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.71126

Abstract

One hundred volunteers have undergone short (5 min) listening tests in a novel multi-transducer bone-and-tissue conduction apparatus for spatial audio. The subjects subsequently described their experiences in an unstructured qualitative elicitation exercise. Their responses were aggregated to identify key themes and differences. Emergent themes are: enjoyable, informative, spatial and strange. Tactile supplementation of spatial audio display was noted in a positive light. We note that some spatial attributes are more perceptible than others. The implications for perceptual augmentation are discussed, particularly in relation to conductive hearing deficits. We conclude that the technique has potential for development and discusses future research directions.

Keywords: bone conduction, tissue conduction, multimodal perception, spatial audio, augmented perception, vibrotactile

1. Introduction

Hearing impairment is a sensory deprivation that constrains the information bandwidth available to the individual. Consequences include poor speech discernment (especially in environments with high background noise), poor auditory spatial performance and lack of pleasurable access to music. Hearing impairment can be due to sensorineural or conductive inadequacies, or both. Amelioration strategies include assistive technologies to augment individuals' residual sensory capacities (for example: hearing aids) or to substitute alternative information pathways where one stage of auditory processing is defunct (for example: cochlea implants). Performance is generally better for communication problems than for spatial and pleasurable-listening problems. There is some evidence to indicate that age-related hearing deficits may play some causal role in the onset and progression of dementia, in part due to social disengagement because of increasing difficulty in disambiguating complex auditory scenes, and in a feedback effect, because neural pathways that receive little stimulus become less efficient [1].

Given that prevalence of hearing loss doubles with each age-decade [2], hearing rehabilitation techniques may be expected to become increasingly important as the average life-expectancy increases. There is a quality-of-life (QoL) issue here; as the auditory information-channel gradually falls into disuse, access to entertainment and intellectual stimulus, in the forms of conversation, music listening and television, becomes scarce.

There is a general trend towards heightened spatial competence in artificial audio, offering increased involvement and informativeness. We are investigating whether bone and tissue conduction techniques can be developed to provide increased enjoyment and informativeness through extended spatial impressions. We have developed a prototype 5-transducer vibrotactile tissue conduction system to display multichannel spatial sound recordings; our objective is to identify, and subsequently parameterise available qualia in this context. One hundred short listening demonstrations were conducted and responses were aggregated and examined for frequency of occurrence of adjectives and synonyms; these formed the basis of an initial set of themes. The cohort was then re-analysed to identify co-occurring themes.

2. Tissue conduction of sound

Techniques for utilising vibration to produce auditory percepts have been known of for centuries; 16th century Girolamo Capivaccio struck an iron rod held against the teeth to assess ear pathology; Ludwig van Beethoven used a wooden rod, with one end held between his teeth and the other resting on the piano he was able to continue his work even though considered profoundly deaf. Late 18th century saw the development of early bone conduction devices, the Fonifero in 1876 by Giovanni Paledino, and the Audiphone in 1879 by Richard Rhodes used mechanical transduction of sound to assist hearing.

These are putatively termed 'bone conduction' techniques, though this is a slight misnomer, as skin, fluid and the soft-tissue contents of the cranium also contribute transmission pathways to various extents. We prefer the term 'tissue conduction' (TC) as a more comprehensive description. There is general agreement that multiple transmission pathways are in use. Several sources record the pathways to be frequency dependant; inertial forces acting on the ossicular structure and cochlear fluids at low frequencies relative to skull vibration; high frequencies causing distortion of the temporal bone and cochlear shell. Sound generated in the occluded ear canal via Osseo-tympanic transmission provides increased sensitivity at low frequencies; contents of the skull and fluid pathways induce sensitivity at high frequencies [3–6]. The prominence of each pathways contribution remain in question; however, the resultant wave motion in the basilar membrane as a summed contribution of all pathways appears to be the same as for air-conducted sound; cancellation experiments between AC, BC and TC show this to be the case [3, 7, 8].

Cochlear stimulation through TC is commonly elicited using a vibrotactile transducer in contact with the skull; various body locations have also been shown effective [6]. Monaural and binaural presentation in contact with the mastoid, condyle or forehead have provided common TC stimulation sites; many additional locations on the skull have featured in research, all using singular or dual transducer presentation [3, 5, 9]. Until recently, TC conveyed audio signal but not spatial information, and so the experience was not equivalent (in this respect) to real-world hearing. Latterly, researchers have shown that a considerable of degree of lateralisation, in some case approaching that of normal binaural hearing, is feasible [10–12]. Nevertheless, the results lack equivalence in terms of overall spatial performance, significantly lacking spatial attributes such as externalisation, spaciousness, range perception and elevation perception.

3. Multi-transducer listening tests

3.1. Equipment

The prototype array uses five BCT-1 8 Ω 90 dB 1 W/1 m tactile transducers held in a tensioned framework exerting contact force with skull through a hemi-spherical plastic medium on each transducer. For reference, the transducer locations are numbered left to right: 1—left mastoid, 2—left temporal region above the zygomatic arch, 3—forehead, 4—right temporal region above the zygomatic arch, and 5—right mastoid. Principal design considerations were that of transducer location, contact force and surface area that would work with considerable variations in head size and shape. Signal sets were processed using Reaper DAW on mac, interfaced through a Focusrite PRO 26i/o and sent discretely to each transducer through individual 1 W amplifiers; the array has a frequency range of 200 Hz–16 kHz. A set of banded style 3M Ear Plugs were available for listeners to use and compare the experience with the plugs in vs. out (**Figure 1**).

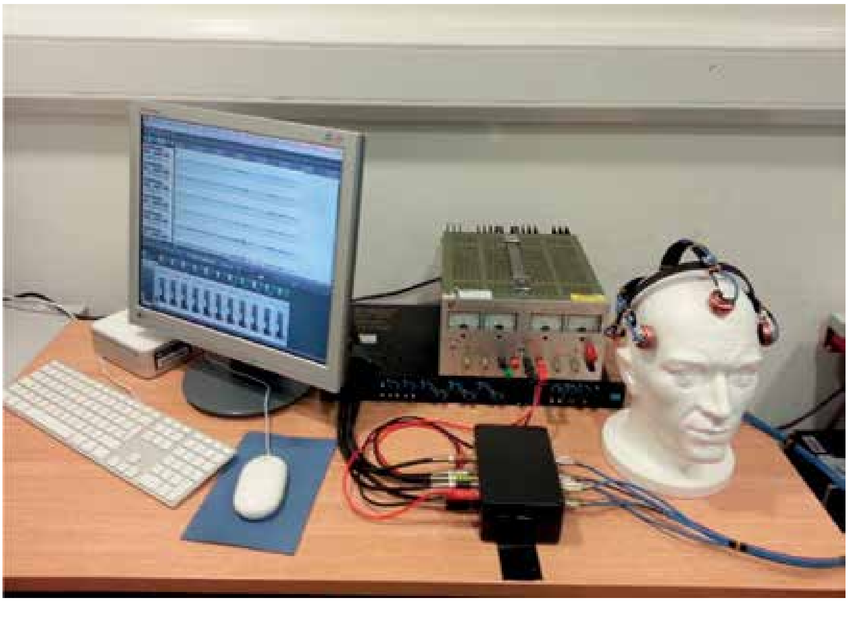

Figure 1. Prototype 5 transducer array, amplifiers, interface and DAW.

3.2. Signals

Signals were processed using Reaper DAW and spatially encoded using WigWare 1st order ambisonic panning; FX Plugins were used to construct early and late reflections and then decoded through a WigWare 1st order periphonic ambisonic decoder patched to the transducer array.

A 1st order ambisonic recording of a country park captured using a Soundfield™ microphone provided the ambient background; stereo recordings of bird sounds, voices, a steam train and music alongside mono FX clips were used to create the soundscape in which 1st order ambisonic recordings of a motorbike and aeroplane were placed.

3.3. Method

In this study, we used 100 naïve (i.e. inexperienced in TC listening) and untutored (subjects receive no instructions on target attributes) listeners, who were then invited to offer observations and comment on the experience; of the 100 listeners non-reported previous experience of tissue conducted sound. 24 female and 76 male participants took part; each was asked to record their age, sex, occupation and whether or not they were a musician alongside their comments on the experience. 24 female's age range 16–61 years, 14 musicians and 10 non-musicians, 76 male's age range 16–66 years, 48 musicians and 28 non-musicians; occupations were recorded for use in future analysis. For discussions of elicitation problems and techniques, see [13–16]. This open-ended approach does not presuppose noteworthy attributes but is used to elicit them.

The listening tests took place across three days under non-ideal conditions at PLASA London, as part of the Exploratorium exhibit we shared the space with four other exhibitors. The Exploratorium was located on the upper level of the large exhibition hall, a large footfall and other exhibitors using amplified sound produced a considerable noise floor (see Section 5.1).

Participants were self-selecting; when any interest was shown they were invited to take in the listening test before any discussion could take place. Once seated, the headset was placed on the participants head and a short piece of music played while they were shown how to increase the overall amplitude to a comfortable level; banded ear plugs were cleaned and given to the participant to use at their discretion. Each audition lasted five minutes and the volunteers were invited to record brief details and their observations on prepared forms immediately afterward. The method of recording responses proved to be suboptimal, as many volunteers went on to describe the experience in greater detail verbally during post-test discussion than subsequently on paper.

4. Responses and analysis

After the auditions, the data were collated into a spreadsheet for analysis; the transcribed responses were examined for frequently occurring descriptive terms and related synonyms. This resulted in a collection of themes, the dominant theme was 'positive' at 78% and this was then correlated with other descriptive themes to elicit accompanying qualia that might contribute to the overall impression of 'positive'.

4.1. Participant comment samples

1. Male, 23, DJ, Musician

   'Very interesting, new experience of sound. Vibrations feel slightly unusual but also add a new dimension to the sound experience. Very cool' (positive, interesting, vibrations, weird).

2. Male, 28, Theatre Tech, Non-Musician

   'Loved the vibrations of the aeroplane flying over and in general how the sound felt all around' (positive, spatial, surround, vibrations, external).

3. Male, 37, Equipment Sales, Musician

   'I enjoyed the vibrations on the pressure points. Sound has remarkable stereo/surround perception. With ear plugs in, it felt like listening to headphones. A pleasant experience' (positive, surround, vibrations, feel, external, headphones).

4. Female, 18, Student, Musician

   'Occasionally you could feel the deeper sounds as physical vibrations especially in the front central point. The higher sounds like bird song were easier to pick up what direction it was coming from. The music sounded better than it would through regular headphones as you felt surrounded by the sound as you would in a realistic setting of an orchestra' (positive, spatial, surround, clarity, vibrations, feel, external, headphones).

4.2. Emergent themes

Theme	Descriptors in class
Positive	Nice, incredible, amazing, awesome, excellent, loved, good, enjoyed, cool, wonderful, extraordinary, impressive, effective
Negative	Muddy, muffled, lacking, limited, quiet, dull, distortion
Hearing loss	Hearing loss
Spatial	Spatial, surround, 3D, virtual reality, image location, movement, image positioning, 360 sound-field, external
Clarity	Clarity, clear, crisp, pure
Interesting	Interesting, fascinating
Weird	Weird, unusual, surreal, strange, uncanny, ethereal, eerie, bizarre
Vibrations	Vibrations, tickling, tickling
Feel	Feel, felt, feeling, natural, sensorial
External	Distant, immersive, overhead, above, around, spacious, outside
Headphones	Headphones

Table 1. Emergent themes and descriptors used for each.

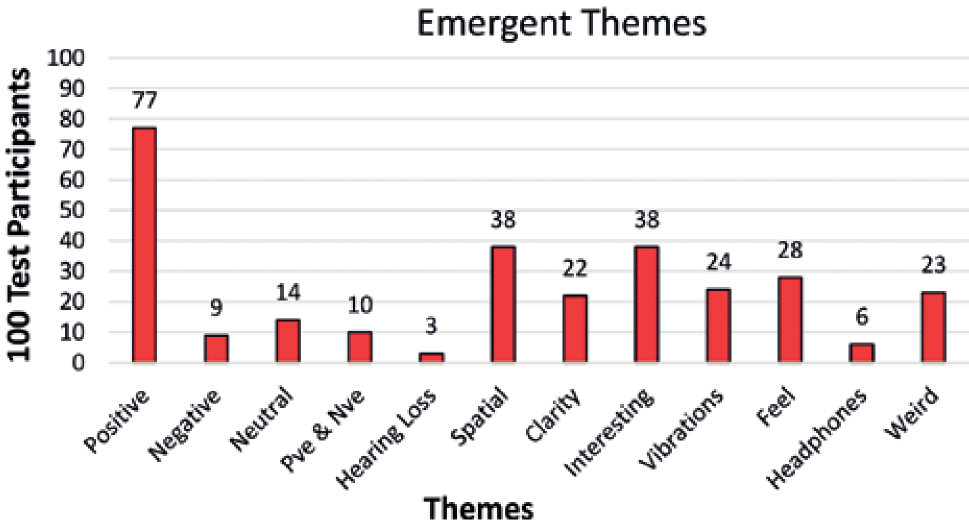

Figure 2. Emergent themes from 100 participants' comments.

4.3. Co-occurring themes

Themes were cross-correlated to elicit what impressions might contribute to overall positivity (or not) of the experience. So, for instance, 'interesting' mapped significantly to 'positive'; **Figure 3** shows themes mapped against positive and **Figure 4** shows themes mapped against vibrations and positive combined as this forms an area of future interest.

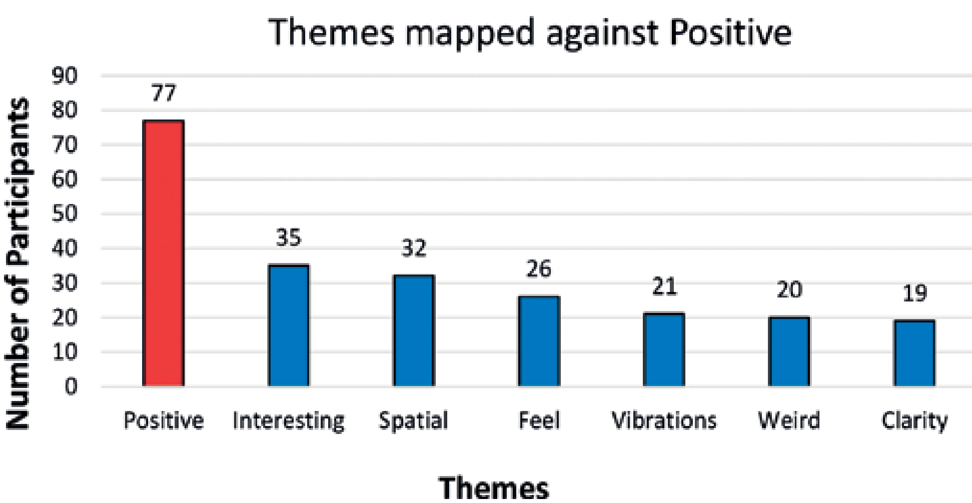

Figure 3. Emergent themes mapped against positive.

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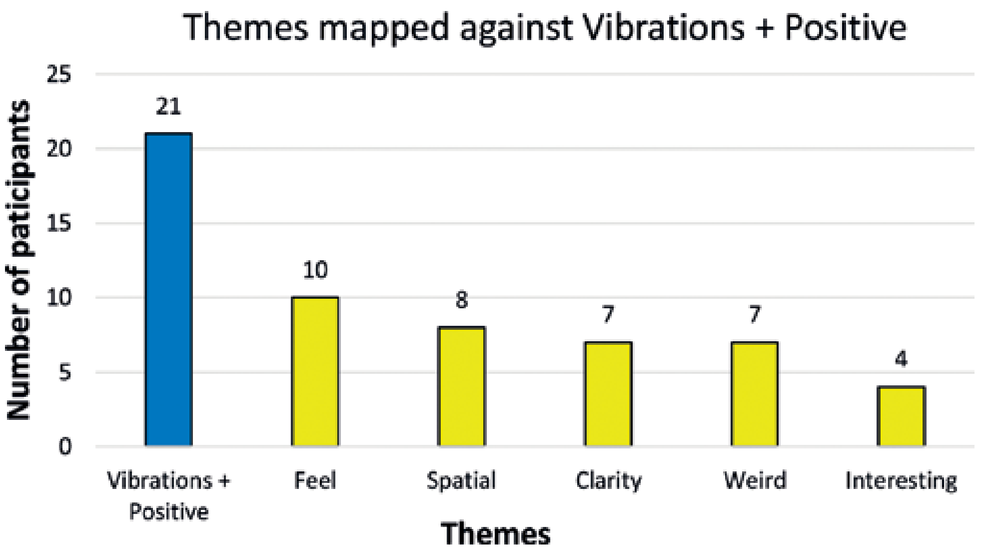

Figure 4. Themes present when mapped against vibrations + positive.

5. Discussion

The high incidence of 'positive', 'spatial' and 'interesting' descriptors indicates the technique is worth investigating further, while the significant correlations between 'spatial' and other categories suggest that the potential informativeness may extend beyond that for single or twin displays.

Some listeners (19%) specifically commented in terms of 'clarity', which was interesting in the context of the background noise in the listening venue.

It is plausible that the experience is unfamiliar and not completely understandable in the short time frame, 58% (3% overlap) of listeners comments contain reference to 'weird' or 'interesting'. Another, commensurate explanation is that this constitutes a different kind of experience, an artificial *exaptation* [17].

In respect of reports of spatial impressions, we are currently reviewing the question of whether we are actually presenting signals that are physically equivalent (to the spatial signal set one would normally apprehend via air conduction), or whether we are presenting something which achieves a degree of perceptual equivalence through more abstract relationships. In the first case, what would be implied is that we are, inadvertently, providing equivalents to those aspects of the head-related transfer functions (HRTFs) that would bear strong relationships with perceptions of externalisation and elevation. Because of the multiplicity of signal paths inside the cranium, which vary with frequency and transducer locations, differences in frequency component arrival times within grouped and segregated sensory data [3–6, 18] may induce interaural time difference fluctuations and hence elicit some sense of spacious envelopment [19]. We are not yet able to model the complex signal arriving at the cochleae, and in any event, it is exceedingly unlikely that we are precisely mimicking the *individualised* HRTFs of all listeners.

If, on the other hand, more abstract perceptual equivalence is in evidence, it is puzzling that spatial impressions are elicited in such short exposures. Informal listening tests of prolonged and repeated exposures do seem to indicate that spatial judgements improve; small sample size and uncontrolled test circumstances constrain conclusions.

An intriguing alternative possibility is that we are actually generating non-audible cues that are perceptually interpreted as auditory spatial cues. A significant (and unanticipated) contributor to the experience is that of vibration, which, in 24% of comments appears in a neutral or positive context, and in 12% is positively associated with comments on spatial impression. The vibrations are due to listening-circumstance inadequacies; the ambient noise floor was high, the transducers have limited dynamic range and modest frequency range. We assumed that vibration would be strongly associated with negative terms, but this only proves to be the case in 3% of responses. The tentative inference is that coherent (i.e. covariant with modulated auditory input) tactile input is potentially perceptually assimilable; this would exemplify multimodal perception.

Multimodality of perception has received increasing interest in the last four decades. The ubiquity of multisensory neurons (that can receive inputs from two or more sensory domains) in the brain indicates that multisensory integration is not limited to 'higher' cognitive processes but can occur at more fundamental levels. For instance, neurons in the primary visual cortex receive inputs from the primary auditory cortex [20]. Multimodality can be discussed in terms of *cross-modal effects* (where stimulus input to one modality alters the perceptual conclusions in another), for examples, the motion bounce illusion, see [21] and the McGurk effect [22]. It can also be discussed in terms of *super-additive effects*, where application of concurrent multimodal stimuli produces more disproportionately more robust perceptual conclusions than for unimodal stimuli [23]. For discussion of multisensory interplay, see [24].

The key observation in the question of unimodal and multimodal perception is that, while brain-region specialisation is well documented and unimodal perception is known to occur, perception in one modality *can* be affected by input to another and further, if stimuli to one modality are impoverished, input via another can be effectively cognitively utilised [25].

5.1. Limitations

The transducers have restricted frequency response of 200 Hz to 16 KHz and component matching is problematic.

The generic headset could not be calibrated for consistency of transducer location and contact force for each individual in such a large cohort, leading to inconsistencies in the sensory experience across the cohort.

High ambient noise levels in the listening area probably interfered with subtlety of detail in the programme material.

Although listeners were unsolicited, some arguably had prior knowledge and possible expectations borne from previous listeners' comments. The 'interesting' category should be considered with caution, since, by definition, volunteers were interested enough to come forward.

Respondents were generally more fluent in their verbal descriptions than their written responses; only the written responses were recorded for analysis.

Variations in descriptions were noted; for instance, while some commented on a startling degree of clarity, others observed the opposite. Such variation may stem from variations in 'degree of fit' of the prototype apparatus, variations in physiology (skull thickness, for instance) or variations in biomechanical and/or neurological auditory processing.

An important limitation is that we did not categorise responses in terms of degree of emphasis, due to intrinsic uncertainties of use of language; for example, 'very spacious' and 'spacious' were categorised similarly.

6. Conclusions and further work

The initial qualitative investigation indicates that the use of multiple transducers, decoded to so as to display spatial and musical information, is worth further exploration. The areas of interest are: externalisation (i.e. not 'in the head'), control of spaciousness, range perception and tactile augmentation.

In terms of informational bandwidth, there seem to be several justifications for using multiple transducers: dynamic range and frequency response of the apparatus is improved simply because more moving mass (in the transducers) and power are deployed. A general improvement in sense of spatiality is indicated, though the spatial impressions evinced are not precisely the same as for real environments, or other artificial means of depicting spatial sound. This is uncontroversial, since spatial qualia for headphone, in-earphone and loudspeaker presentations also differ. Headphones can give impressions of 'in the head' intimate sound fields but are correspondingly poor in producing the impression of externalisation and range-perception, while the reverse is true for loudspeaker presentations. The tissue-conducted sound fields do, reportedly, convey some sense of spaciousness, envelopment or immersiveness, indicating externalisation, though it is unclear whether range perception can be coherently controlled. Directional localisation of sources appears to be imprecise; while some remarks suggest impressions of elevation, this requires more precise investigation.

The question of whether (and how) tactile stimuli interact with auditory stimuli requires elucidation as this has valuable implications for normal and hearing-impaired listeners; auditory spatial perception might actually be augmented with coherent tactile input. There is evidence that tactile stimuli can affect auditory conclusions [26, 27] and visual perceptions [28]. To investigate this, we shall have to improve the transduction of audio signals to an extent where spurious vibrations are minimised, while additionally utilising transducers specifically manage tactile input.

In the present context, multimodality has this implication: in conditions of suboptimal conditions such as hearing deficits, background noise and display limitations, it might be possible to utilise cross-modal and super-additive effects to enhance auditory perception. Enhancements could include improved source segregation and intelligibility, along with more holistic qualia such as immersiveness and enjoyability.

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Chapter 16

SLAAP: Silencing Loud Alarms to Attenuate PTSD: Frequency-Selective Silencing Device for Digital Filtering of Alarm Sounds to Enhance ICU Patient Recovery

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Abstract

Free-field auditory medical alarms, although widely present in intensive care units, have created a number of hazards for both patients and clinicians in this environment. The harsh characteristics of the alarm noise profile combined the frequency at which they sound throughout the ICU have created discomfort for the patients and contribute to psychological problems, like post-traumatic stress disorder (PTSD) and delirium. Thus, this frequency-selective silencing device seeks to attenuate these problems by removing the alarm sounds from the patient perspective. Patients do not need to hear these alarms as the alarms primarily serve to alert clinicians; therefore, this device, through the use of a Raspberry Pi and digital filters, removes the alarm sounds present in the environment while passing all other sounds to the patient without distortion. This allows patients to hear everything occurring around them and to communicate effectively without experiencing the negative consequences of audible alarms.

Keywords: digital filtering, in-ear device, clinical alarms, wearable technology, ICU patient recovery

1. Introduction

Major issues inhibiting successful patient recovery in intensive care units (ICUs) are the frequent occurrence of clinical alarms and the harsh, shrill noises that generally characterize these sounds. Alarms sound frequently to alert clinicians of physiological aberrancy that exceeds a threshold, yet many alarms have low-positive predictive value [1]. As stated by Edworthy and colleagues, multiparameter auditory warnings can be combined to create varying degrees of urgency [2]. Although the implementation of these results has proven useful to alert clinicians of possible danger, the potential negative consequences from the piercing alarm sounds were not considered from the patient perspective. While clinicians can suffer from alarm fatigue and desensitization, in this project, the patient-specific consequences are of the utmost concern, as patients commonly experience sleep deprivation, post-traumatic stress disorder (PTSD) anchored to critical illness, and delirium after a stay in the ICU [3]. Despite surviving an ICU stay, 88% of ICU patients experience hallucinatory/delusional intrusive memories related to ICU care for up to 8 months after hospital discharge [3], and the incidence of cognitive impairment as a function of ICU stay increases from 6 to 25% of patients [4].

While the underlying causes of these neuropsychological outcomes are not determined, the frequent, loud noises produced by clinical alarms often disturb patients' sleep patterns and sound for extended lengths of time with no explanation to the patient, the reason behind the alarm. Compared to other high-consequence industries, health care suffers from poor positive predictive value alarms, as 67.2% of the alarms of the ICUs are false positives [5].

Our approach of sheltering the patients from alarms is accomplished by the creation of a wearable frequency-selective silencing device which silences the frequencies corresponding to the alarm noises (primarily patient monitor red/crisis alarm) and will allow the passage of all normal sounds (speech and other environmental stimuli), while maintaining their quality to reduce the likelihood of delirium.

1.1. Subtypes of PTSD anchored to critical illness: impact of sound

Research is still ongoing to determine the specific sound exposure level of sound and the impact on neuropsychological outcomes in the ICU; specifically, the fractionation of sound into alarm and nonalarm contributions and the psychoacoustic features of sound (e.g., roughness, sharpness, and amplitude envelope) that may be deleterious to the patient. In the case of passive noise cancellation, sound source localization from a point different from the patient's ears could lead to spatial disorientation. Within the DSM-5 types of PTSD, there is a dissociative subtype of PTSD that is defined by symptoms of derealization and depersonalization [6]. The depersonalization experience could be an "out-of-body" experience, which could exacerbate the PTSD symptomatology. In an effort to not solve one problem and make manifold problems in the process, our approach and design will build from a single microphone passive cancellation process to a microphone array active cancellation process as described below.

2. Device design needs

For patient-specific needs, the wearable technology must be user-friendly and comfortable to allow for continuous patient wear, especially while the patient is asleep. It must block alarm sounds while allowing the passage of all other environmental noise, such as speech and TV sounds. It is important to note that overstimulation of the auditory sense as well as a complete lack of stimulation of the auditory sense can contribute to PTSD and delirium, which is why noise-canceling headphones and/or simple earplugs that dampen all environmental noise entirely are *not* the desired solution.

2.1. Wearer comfort and sound reproduction

Although patients can have full degree-of-freedom head movement, patients and clinicians may be concerned that wearing headphones or earbuds would be uncomfortable to wear for prolonged periods of time; thus, future iterations of our design will incorporate the work by Voix and colleagues to develop comfortable wearable devices [7]. With wearable devices, there is additional concern of microphone placement and sound localization. With respect to the concern of the microphone being overly sensitive and amplifying environmental sounds that would be otherwise filtered by the human ear, we attenuated this difference by the application of an Audio-Technica (Tokyo, Japan) AT8131 windscreen. An additional concern was the quality of the audio path and exacerbation of spatial disorientation. As an initial step, a single microphone was used. However, future iterations of our design will use a microphone array with digital signal processing (DSP) tools for the real-time synthesis of a 3D sound pressure field using Ambisonics technologies to achieve the spatialization of monophonic signal or the reconstruction of natural 3D recorded sound pressure fields as guided by the work of Gauthier and colleagues [8]. As the focus on a "ground-up" ICU design from a multisensory aspect flourishes, ICU rooms are made to be quieter and more anechoic. As that is achieved, wave field synthesis (WFS), an open-loop technology, can be explored in concordance with environmental design. Specifically, adaptive wave field synthesis, combining WFS and active control to reproduce the spatial character of natural hearing, will ameliorate concerns of patient dissociative subtypes of PTSD symptomatology [9].

3. Digital signal processing

To remove the alarm sound, MATLAB (MathWorks, Natick MA) digital signal processing was utilized to initially implement and test our digital filters. A spectral analysis was performed on a single alarm sound to obtain its frequency components. Then, an Infinite Impulse Response (IIR) Elliptic bandstop filter was created to block the frequency that specifically dominated in the spectral analysis. The width of the stopband had to be optimized so that the alarm component was completely blocked, yet the effect on environmental noise was minimized. This led to the creation of filters targeting the common red/patient crisis alarm with the most important ones focused at 960, 1920, 2880 and 3840 Hz.

The dynamic digital filter was then generated in Simulink (MathWorks, Natick MA) using the filter specifications determined in MATLAB. The design is two-fold in that it contains both a detector and a series of filters. The detector continuously processes all incoming environmental sounds and determines the power present in the unfiltered environmental noise as compared to the power present in the filtered version. If this difference exceeds a predetermined threshold, this serves to indicate that an alarm is present in the environment. If the alarm sound is detected, the detector switches on the digital filter, and the filtered version of the noise is passed to the patient.

This switching mechanism is critical to the design as it ensures that unnecessary processing and potential distortion will not occur for the patient if no alarms are sounding in the environment.

3.1. Auditory masking

When auditory filtering is used, there is a concern of inadvertently filtering desired auditory stimuli. This is especially important when one needs to respond to the auditory stimulus. A relatively understudied source of response failures deals with simultaneous masking, a condition where concurrent sounds interact in ways that make one or more imperceptible due to physical limitations on perception. Bolton and colleagues have developed a novel combination of psychophysical modeling and formal verification with model checking to detect masking in a modeled configuration of medical alarms. This builds on previous work by adding the ability to detect additive masking while concurrently improving method usability and scalability [10]. The psychoacoustics used to describe masking represent frequency on the Bark scale, which maps a frequency (in Hz) to a location on the basilar membrane where the sound stimulates the receptors the strongest. Frequency to Bark conversion is calculated as z_{sound} = 13*arctan (0.00076*f_{sound}) + 3.5*arctan ((f_{sound}/7500)^2). As the alarm we filtered, the "red" high acuity patient alarm has a spectral component of the peak frequency of its narrow bandwidth outside the range of other typical environmental stimuli (e.g., speech), we did not pursue further model checking for additive masking. However, this approach can be used as other patient alarms (e.g., ventilator and infusion pump) are added to the alarm filtering schemata.

4. Device components

The hardware portion of this device continuously completes the digital filtering task during the device's operation. To do this, the Simulink code for the detector and filter has been uploaded onto a Raspberry Pi (Raspberry Pi Foundation, Cambridge, UK) to allow for alarm filtration. A microphone connected to the Raspberry Pi obtains and passes the environmental sound to the digital detector (**Figure 1**).

Figure 1. Depiction of design prototype.

5. Proof of concept

5.1. Experimental design and testing

To prove objectively that the device accomplished our aims, an experiment was performed to prove that the frequency components specific to the alarms were missing from the filtered sound. In the initial stages of the project, a Fast Fourier Transform (FFT) was performed using MATLAB on the unfiltered alarm sound sample and the filtered alarm in order to compare the magnitudes of the frequency components present between the two sounds (**Figures 2** and **3**).

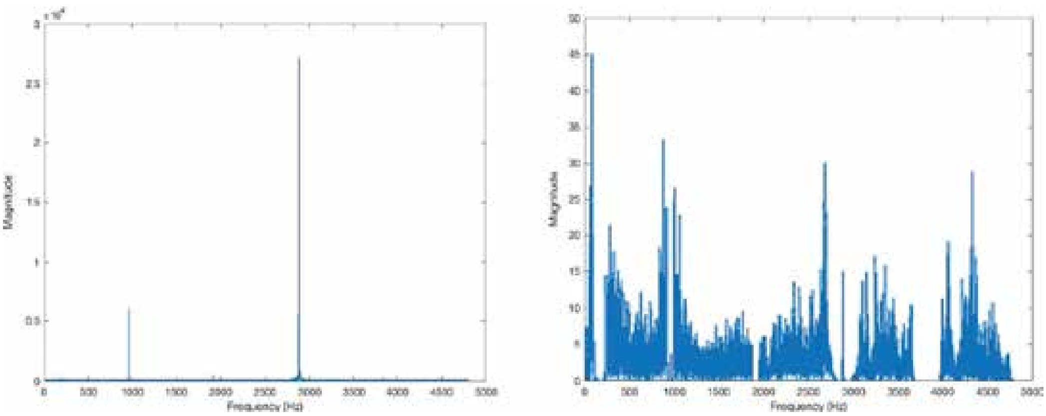

Figure 2. FFT of a single unfiltered alarm (left) and the same alarm filtered by a series of bandstop filters (Note: The Y-axis values are different to display the present spectral waveform after filtering).

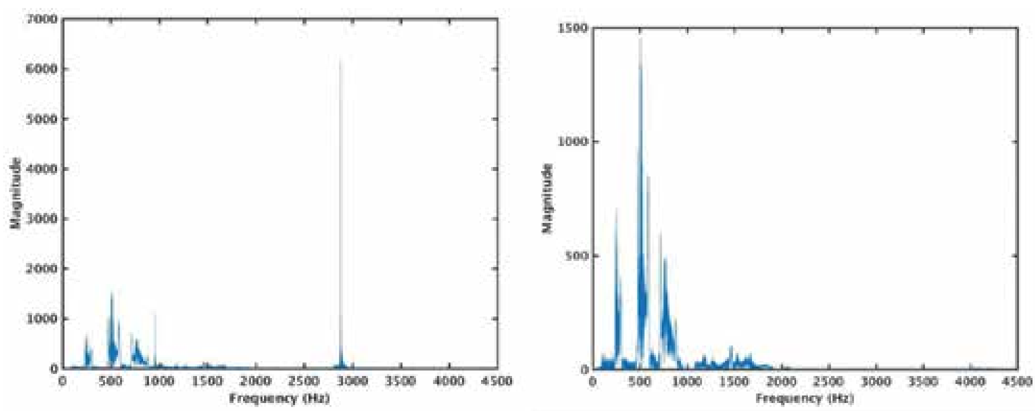

Figure 3. Alarm filtered by a series of bandstop filters in Simulink (Note: The Y-axis values are different to display the present spectral waveform after filtering).

5.2. Results

In the objective testing using MATLAB, the series of bandstop filters created on MATLAB dampened the magnitudes of the frequencies present in the alarm in the order of 10^3, as seen in **Figure 2**.

Once the filtering on MATLAB proved successful, Simulink (Mathworks) was used to compile the software and deploy the data onto a Raspberry Pi device. By inputting a file (.wave) with both the alarm sound and environmental noise present, it was proven that the Simulink software was able to successfully filter the alarm frequencies as shown in **Figure 3**.

6. Limitations and future directions

As of now, this device relies on the use of noise-canceling headphones to transmit the filtered sound to the patient. Future designs will incorporate a wireless, in-ear device that can perform all the necessary filtering functions and transmission of the filtered sound in the device itself. With an aggressive goal to reduce cost and time of development, our first model uses passive filtering; however, further developments will incorporate active noise-cancellation which will obviate the need for the passive device to activate (~100–300 ms) and avoid a slight perceived auditory click of activation. With evolving design, this technology-centered initial approach will require FDA exemption status, so it can be studied in the clinical environment.

7. Conclusion

Audible medical alarms are the cause of a number of hazards in hospital and ICU settings. Their shrill acoustic features and the frequency at which they alarm (both in sheer number and frequency spectrum) are responsible for a number of negative consequences, especially for patients. Patients can experience PTSD and delirium secondary to sleep disturbance from alarms and health care providers' divided and diminished attentional resources allocated to alarms. This frequency-selective silencing device was created to alleviate these problems and create a more comfortable environment for the patients during their length of stay in the ICU and promote patient safety.

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Section 5

The Perceptual and Experiential Gap - Sensory Engagement

Modified Social Benches: Exploring the Role of Aesthetic Interaction to Placemaking

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Additional information is available at the end of the chapter

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Abstract

This paper discusses some aesthetic and social aspects that involve interactions with urban art installations. The aim is to better understand how, and to what extent, aesthetic interactions with art installations can transform an urban space into a place. The discussion is based on a case study of the *Modified Social Benches*, a series of outdoor, interactive artworks that provide different types of bodily engagement, social encounters and aesthetic experiences. A detailed empirical analysis is carried out, emphasising the social roles around the installations as well as the most salient aspects regarding the bodily, the spatial and the experiential qualities of the interactions. The results suggest that urban installations affording playful, action-oriented and sensorimotor encounters are more effective to placemaking than installations that encourage static modalities of social activities.

Keywords: aesthetic interaction, placemaking, embodied interaction, interactive installation, social roles, engagement, play, urban space, place

1. Introduction

In the last decade the theme of embodiment has received a growing attention among researches and practitioners from design and related fields. Research on embodiment is primarily concerned with how we use our bodies to shape the ways we perceive, feel and think [1]. A variety of disciplines, spanning from Philosophy to Human-Computer Interaction (HCI), have addressed different aspects of embodiment, and this has led to the emergence of more specific approaches. One of these approaches, known as *Aesthetic Interaction*, focuses on the experiential aspects of people's interactions with artefacts [2–5]. Emphasising the experience and the aesthetic dimension of interactions means adopting a holistically-oriented approach that considers the rich and complex nature of the whole human body—including the sensorimotor skills, the cognitive and emotional dispositions—that people use to make sense and produce meaning about an artefact, its context and ultimately about themselves.

The present discussion takes Aesthetic Interaction as a conceptual and methodological tool to analyse and better understand the process of placemaking. As a general notion, the term *place* refers to a physical space imbued with social and cultural meanings, values and traditions [6–8]. Unlike an abstract space, a place has its specific life, character, and identity, although all these qualities are more or less dynamic, that is, they may change according to the set of cultural, social, economic and political forces at play [9]. Then, placemaking can be interpreted as the process of giving life to a place, or infusing some qualities in a specific space so that it becomes a place: a spatial setting where people feel stimulated to come and to stay, where they can live a particular and enjoyable experience that cannot be lived elsewhere in the same way.

In order to analyse the relationships between Aesthetic Interaction and placemaking, this paper presents an empirical study on the series of interactive artworks *Modified Social Benches*, designed by Danish artist Jeppe Hein and installed in Southbank Centre, Central London during the Summer of 2016. The next section comprises a literature review on Aesthetic Interaction, placemaking and related concepts, bringing some relevant aspects as well as potentially fruitful connections between them.

2. Background

As the concepts of Embodied Interaction, Aesthetic Interaction and placemaking are essentially interdisciplinary, this section draws on different disciplines to outline the main characteristics of these concepts and their contributions to the study of urban interactive installations. Within the field of HCI, Dourish authored a seminal work, *Where the action is*, where he defines Embodied Interaction as "the creation, manipulation, and sharing of meaning through engaged interaction with artefacts" ([10], p. 126). For Dourish, Embodied Interaction is a valuable approach "to illuminate not just how we act *on* technology, but how we act *through* it" ([10], p. 154, emphases on original). Dourish's position highlights the experiential and meaningful dimension of interactions: we act by means of our own bodies, and this encounter between ourselves and technological artefacts is the source of meaning. This idea of interaction as meaningful action also underpins the concept of Aesthetic Interaction. According to Petersen et al. [3], Aesthetic Interaction is about aesthetics of use, rather than aesthetics of appearance. They contend that Aesthetic Interaction involves the entire human body, that is, intellect and all the senses, aiming to create involvement, experience, surprise and serendipity in interaction [3].

The growing interest on the experiential and corporeal realms of human-artefact relationships has inspired a range of subdisciplines to emerge [5]. Especially related to the case study of this paper are the fields of embodied engagement, whole body interaction and kinesthetic interaction (e.g., [11–13]). What these fields have in common is the consideration of the interacting, living, active human body as the main source of analysis and design; such idea is opposed to Cartesian and cognitivist approaches that tend to reduce users as disembodied information processors [1, 14].

Interestingly, the main ideas and concepts outlined above have also informed research and design in Architecture. While Interaction Design takes the notion of embodiment from the perspective of a *user in action through technology* [10], some architectural thinkers have focused on embodiment as a source of meaningful experiences of places [15, 16]. In particular, Phenomenology and Neuroscience have provided important insights to both architects and interaction designers, leading to more holistic accounts of interactions. According to these accounts, people's interactions with objects and places are as much about corporeal, tangible encounters as they are affective, symbolic ones [5, 17–21].

Several disciplines have discussed the concept of *place*—its definition, its qualities, and how it is manifested and lived. What seems to unify the understanding of place is its *human dimension*, both in an individual, subjective level, and as a shared, communal experience. Places are regarded as spatial settings that provide people with feelings of well-being, safety, security and orientation [22]. This general notion of place, and the related concept of *placemaking*, gained traction in the 1960s, through the work of Jane Jacobs and, some years later, William Whyte. For Jacobs, successful places are characterised by intense and diverse social encounters, like casual meetings and chattings, which help enhance the security of urban communities by encouraging their members to naturally engage in a dynamics of mutual surveillance [23]. For Whyte, lively places are those where people find urban amenities—such as sitting spaces, food, water features, varied shops and businesses—that make them stay and enjoy a public space in an everyday basis [24]. It follows that placemaking is about turning segregated, lifeless environments into lively, satisfying ones.

More recently, placemaking has been regarded as a collaborative process which aims to maximise the "shared value" of public spaces, by focusing on its social, cultural and physical identities [25]. The two core principles of placemaking have been summarised as (a) focus on designing cities for people; and (b) inclusion of citizens in the decision making process of design [22]. Such principles highlight the role of local communities in the planning and design of places. What makes communities key elements in the process of placemaking are their unique attributes—for example, trust and support networks, common experiences and interests, types of transactions, history and proximity [7]—attributes that, together, help to constitute and qualify places over time. In a certain sense, communities make their own places by imbuing their everyday environments with shared values, habits and identities; when "material and spatial elements are given life by the meanings, associations and experiences people inject into them during daily life" ([26], p. 141).

Urban art installations can arguably contribute to the process of placemaking by enticing a broad variety of interactions. People may interact not only with the installations themselves, but also with other people, for example, by starting a conversation prompted by the installation—the process known as *triangulation* [24]. Moreover, interactive installations can make people stay longer in the area for different reasons: directly engaging with the installation, observing it from a distance, photographing or filming the actions around them or simply talking to people nearby. Altogether, these social activities or "social buzz" [27] tend to create a very particular and lively atmosphere of enjoyment, which helps to characterise a place.

Not surprisingly, embodied, playful and aesthetic modes of interaction have been employed for many years in urban spaces, especially in the context of parks, playgrounds or seasonal initiatives such as funfairs, action- or adventure-themed events and, more recently, urban

Figure 1. Left: Charlotte Ammundsens square, image courtesy of Danish architecture centre; right: *Rock Rock Around the Block,* a prototype presented at the market street prototyping festival 2016, image courtesy of market street prototyping festival.

prototyping festivals. What seems to be singular in the current turn to embodiment in Urban Design is an emphasis on the *hybridization* of concepts and typologies. Instead of discrete, self-contained facilities designed for specific publics and activities—for example, a fenced playground where children play while adults watch—a range of contemporary urban projects have assumed a multifunctional character, fostering physical activity, playful behaviour, community participation and aesthetic interactions in a more fluid, open-ended way [28].

Part of these new initiatives has been built as permanent additions to the city: such as the *Superkilen* park and the *Charlotte Ammundsens* square, in Denmark, which features a rocky landscape that can be used for climbing, skating, biking or simply sitting or lying [29] (**Figure 1**, left). Other projects have been temporarily installed as part of events, such as Portland's *City Repair Project*, with its strong emphasis on community engagement for placemaking, and San Francisco's *Market Street Prototyping Festival*, in which artists and designers reinvented the concept of the urban bench by employing playful and striking forms to entice social encounters and new ways of experiencing the urban space (**Figure 1**, right).

However multifunctional, playful or enticing these contemporary projects are, they all seem to share an underlying principle: they seek to bring life to the city by proposing spatial and social experiences that are fundamentally rooted in the human body. In other words, these projects explore Aesthetic Interaction as a platform of placemaking. The *Modified Social Benches,* object of the present study, can be approached as part of these contemporary creative efforts. By extending the concept of Aesthetic Interaction to the urban scale, the following analysis aims to clarify how the bodily engagement with outdoor installations can contribute to the process of placemaking.

3. Modified social benches: a case study

This section presents an empirical study of the *Modified Social Benches*, a series of temporary, outdoor and interactive installations designed by Danish artist Jeppe Hein. The installations borrow their basic form from well-known park benches and alter their design to various degrees, transforming the act of sitting into a "conscious physical endeavour" [30] (**Figure 2**).

Figure 2. Two versions of the modified social benches.

Besides their sculptural quality that sparks people's attention, the *Modified Social Benches* can also be approached as a playful and performative experiment on bodily engagement and social behaviour in the urban space. By blurring the boundaries between Art, Interaction Design and Architecture, Jeppe Hein's installations offer a valuable context for analysing the process of placemaking in light of Aesthetic Interaction.

3.1. Methodology

After a bottom-up, exploratory approach of the installations in Southbank Centre, 4 out of 10 different versions of the *Modified Social Benches* were selected for this case study. The principal criteria for selecting the four benches were the following:

a. they were installed in the same area, so all of them could be captured by a single photograph taken from a distant, inconspicuous position, as shown in **Figure 3**.

b. the designs of these benches present significantly different bodily and social affordances—some benches encourage a playful and exploratory behaviour, while others invite people to relax and socialise (**Figure 4**).

Figure 3. Overview of the area highlighting the four art installations.

Figure 4. Different behaviours towards the benches, from playing (left) to chatting (right).

The primary methodological tools used for this study were on-site observations and time-lapse photography. Observations are an important tool because they allow a gathering of data that might be considered as an objective view of human behaviour. By observing we can learn about the environment without taking account of people's intentions—something important, given that social activities in urban contexts give rise to patterns of use and movement that are independent of the intentions of individuals [31]. Time-lapse photography was used to record and analyse the interactions. Since the study did not focus on fine details of discrete interactions, but rather on patterns of bodily engagement and social behaviour on the broader urban scale, time-lapse photography seemed a suitable alternative to video recording, while being a technique that has been adopted by influential studies on human behaviour in outdoor settings [24].

The data collection was mainly conducted in August and September 2016, with a total of 15 recording sessions. Each recording session lasted between 30 and 35 min and employed a small action camera. The camera was positioned at the same spot in all sessions, and it was set to take one photograph at intervals of 60 s. The sessions took place at different times of the day and different days of the week, so as to capture the varying conditions of the urban and social setting.

3.2. Social roles around the installations

In order to analyse the bodily, social and spatial interactions around the benches, the people recorded in the area of study were classified in three main categories: players, participants and spectators. Each of these categories tries to address the distinct ways in which people seemingly experience the art installations, both from a bodily, social and spatial perspective.

3.2.1. Players

The category of *players* describes people who were observed engaging in any kind of performative movements with Jeppe Hein's benches. Playing, in this case, denotes a conspicuously active, corporeal and dynamic engagement of one's own body with the installations. For players, the bench is first and foremost an urban sculpture to be physically and sensorily explored and revealed. More than sparking visual attraction, for players the meaning of the sculptural bench can only be utterly realised through an engagement of their whole bodies, in a playful, physical, performative inspection of the bench's surfaces, structure and balance. Players seem to be driven by an instinct to bodily and sensorily unveil the bench's affordances for action, movement or pure play.

The images captured in Southbank Centre suggest that this playful behaviour is motivated by two main reasons: first, one's own curiosity to explore and to test different movement possibilities, that is, the bench's affordances for action and play. In this group were recorded the most performative people, who engaged in all sorts of acrobatic movements and postures, such as climbing, hanging or sliding on the benches. The second important motivation for adopting a playful behaviour is to pose for photographs or videos. Playing with the benches to have one's portrait taken was more frequent among adults (**Figure 5**).

Unlike conventional sitters who pose on conventional benches, most of the people being photographed amid Jeppe Hein's artworks deliberately adopted an unusual or "funny" body posture, so as to reflect the playful and liberal character of the installations. In either cases—playing for the sake of playing or playing to be photographed—the interaction of players was markedly dynamic and fleeting.

3.2.2. Participants

Some people were recorded at the benches for a relatively long time—typically more than 3 min—though they were not regarded as players. Unlike players, the category of *participants* describes those who did not use the benches to engage in performative or exploratory movements, but rather were there primarily to chat and/or to rest. The term *participant* is borrowed from literature on HCI and public interfaces, where this category has been used to describe subtler forms of engagement between an individual and an interactive installation [32, 33].

Figure 5. Different motivations among players: playing for the sake of playing (left) and playing to be photographed (right).

Participants' behaviour points to a significantly different relationship to the art installations and the space around them, with respect to the bodily, the social and the experiential realms. If, for players, the benches stand out as urban sculptures calling for sensorimotor explorations, participants seem to regard Jeppe Hein's artful installations as a set of conveniently located urban furniture, where one can sit to wait for a friend, use the mobile or simply to enjoy the panorama of river Thames while resting the legs or chatting with another participant.

Nevertheless the distinction between players and participants is not always straightforward. Part of the recorded people manifested postures and behaviours seemingly located somewhere between the performative actions of players and the more relaxed forms of engagement commonly found among participants (**Figure 6**).

In such cases, *time* was the decisive factor to characterise a person as a player or as a participant: for the sake of the analysis, interactions sustaining the same body position for more than 1 min were regarded as participation, whereas the more fleeting bodily interactions, that is, those lasting less than 1 min were classified as play. The threshold of 1 min to distinguish players from participants is methodologically informed, as it coincides with the intervals of the time-lapse photography used in the study.

3.2.3. *Spectators*

The category of *spectators* includes people who were observed in the immediate vicinity of a bench (up to around 4 m) while satisfying the following criteria: (a) they were not captured in a walking position; (b) their attention is visibly turned to the bench or, alternatively and (c) they form part of a pair or a group, of which at least one other member is physically engaged with the bench. During the analysis of the photographs a specific class of spectators stood out: those who were noticeably capturing images of people engaging with the installations. Even though this latter class of spectators could form a category of their own—arguably that of "active spectators", since they are assigned to a functional, specific social role in the context—they were subsumed under the category of spectators so as to better fit the broader scale of the study, namely the urban scale of place (**Figure 7**).

For the purposes of this study, the most important characteristic shared by spectators is that, although referring to people who are not physically engaged with the art installations at a given time, spectators are potential players, that is, they may become active players, either in a

Figure 6. Bodily engagements at the boundary between participation and play.

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Figure 7. Multiple social roles in a snapshot: two persons sit (participants); a kid climbs on the right of the bench (player); four spectators stand nearby (two at the front and a couple behind the bench). Four passers-by can also be seen on their way.

matter of seconds or in their possible next visits to the area. What distinguishes spectators from mere passers-by are the bodily, temporal and social relationships between the person, the art installation and the place. Firstly, beholding implies some duration—for this study, at least a few seconds. It also entails bodily and social dimensions: it is a physical posture, a gesture which signals to nearby people that something interesting might be going on. By gazing at the benches, spectators not only stimulate passers-by to do the same. In fact, spectators help feed the whole cycle of social roles around the installations: some of the passers-by may stop around to observe or photograph the benches, and part of these people may go one step further and become players, eventually creating a "social buzz" in the place [27].

Especially during busy recording sessions, several people were observed at the vicinities of the benches, either leaning against the railings or sitting on the ledge beneath them (**Figure 8**).

Figure 8. People standing and sitting by the railings.

Importantly, most of these individuals remained at the same spot for several minutes, and they were not identified as part of a group engaged with the benches. In such cases, these individuals were not included as spectators, because their behaviours seem to best characterise the act of resting or waiting—but one that would apparently take place irrespective of the presence of the benches.

3.3. Main findings

In order to present and analyse the data collected on-site, the four versions of the "Modified Social Benches" are identified as A, B, C and D, as shown in **Figure 9**:

A first glance at the striking shapes above suggests that each design affords different types of bodily and social behaviour. Likewise, each version of the bench may also result in particular forms and levels of aesthetic interaction. This section aims to clarify how these different forms of aesthetic interaction may affect the dynamics of placemaking. **Chart 1** presents a synthesis of the findings, with the distribution of players, participants and spectators around each bench throughout the 15 recording sessions of the study.

The data above reveal that benches A and D share a similar character: in addition to encouraging playful, performative movements, these benches also succeeded in attracting a significant number of spectators around them. An average of 22.67 players per session were registered on bench A, and in only one session (7th September) no players attended. Bench D achieved a slightly higher average of players (22.87 per session), who were also consistently present throughout the study. As for spectators, bench A attracted the largest number of them —an average of 52.87 spectators per session—which, in most occasions, surpassed the number

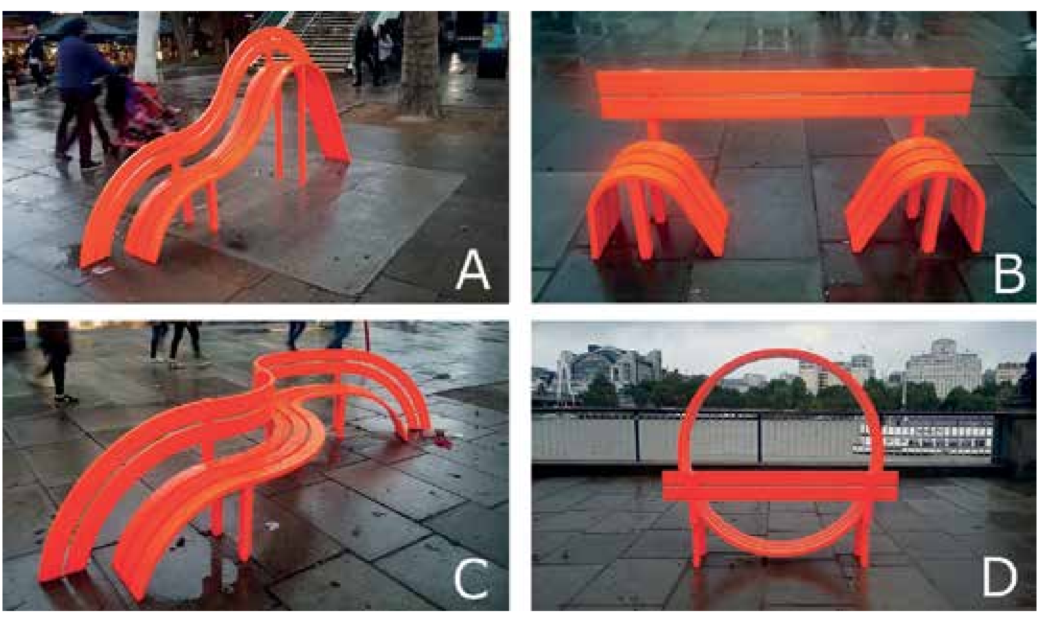
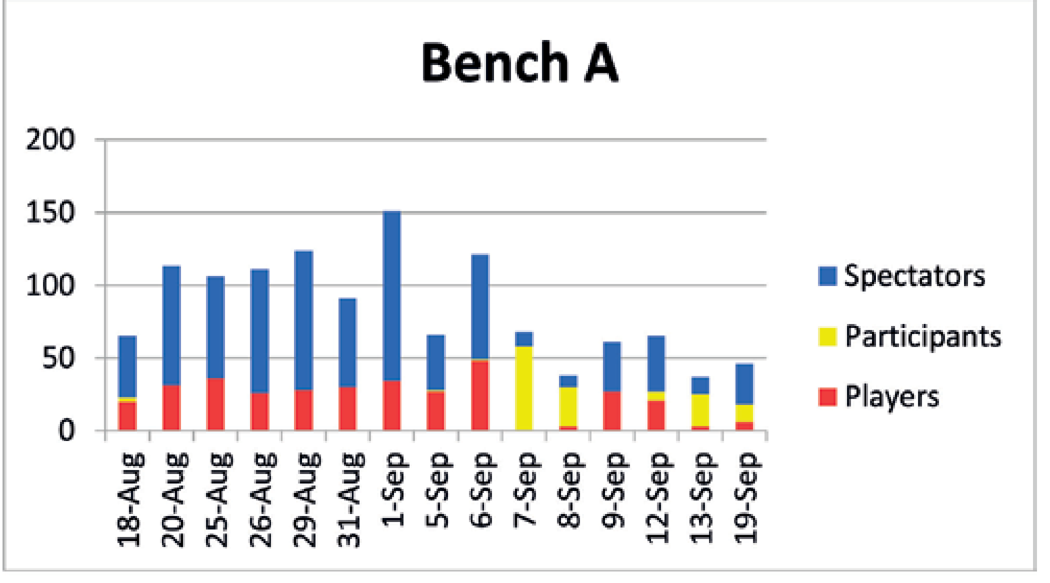
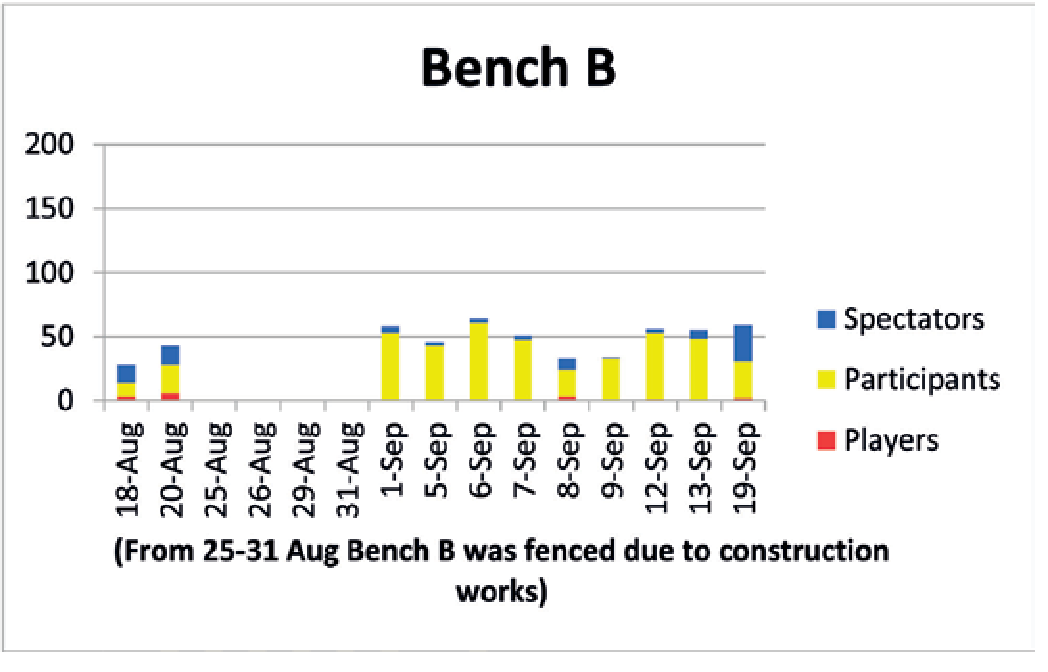


Figure 9. The four versions of the benches analysed in the study.

of players and participants altogether. Bench D saw an average of 32.40 spectators, and their distribution was not so dominant as that verified in bench A.

There is an important qualitative difference that helps explain the quantitative data outlined above. Among the players who engaged with bench A, most of them were children, who found in the slope-shaped installation a particularly amusing affordance for sliding. Thus, for the larger part of the players on bench A, the installation was literally a toy, a piece of





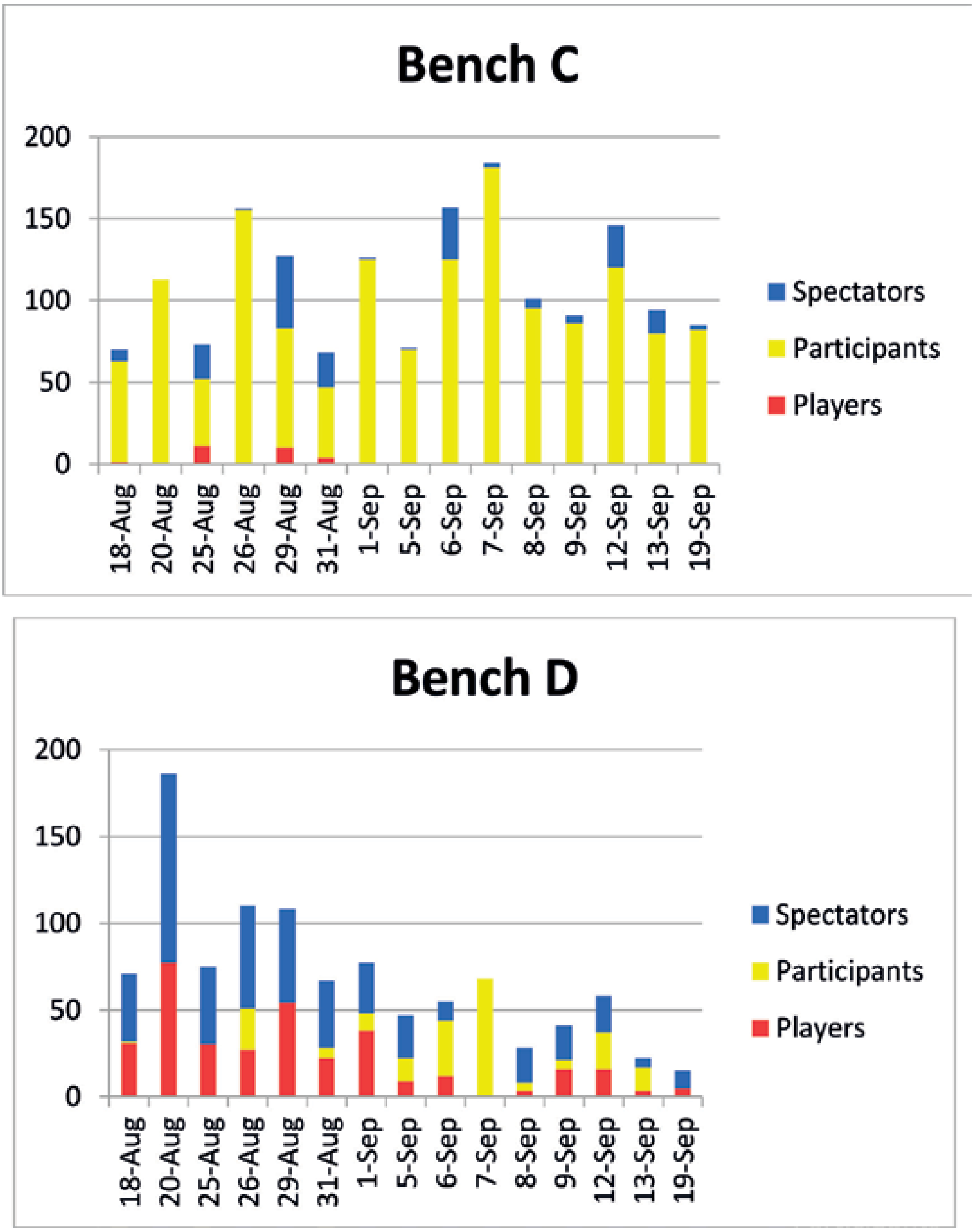


Chart 1. Distribution of social roles for each version of the benches.

playground. And, as one would expect to find in an ordinary urban playground, these young players were accompanied by their parents, relatives or friends, most of whom added up to the number of spectators around the bench (**Figure 10**).

Figure 10. Social gatherings around bench A as a result of children playing.

Bench D, on the other hand, presented a rather distinct profile of players. Children, adolescents and young adults likewise experienced bench D by performing a wide variety of corporeal movements and postures. And, while the steep shape of bench A imposed serious difficulties for more than one person to play at a time, the circular design of bench D allowed two, three or even more players to explore the installation simultaneously (**Figure 11**).

All these factors contributed to a smaller proportion of spectators around bench D if compared to bench A. In fact, with regard to the social roles, the design of bench D proved to be the most versatile one among the four versions of benches analysed here, as, in most sessions, the three social roles described in this study—players, participants and spectators—were recorded around bench D (**Chart 1**).

Benches B and C also function as platforms for social encounters, but they share a different character if compared to benches A and D. As shown in **Chart 1B** and **C**, the large majority of people recorded at benches B and C were qualified as participants. With regard to Aesthetic Interaction, this finding points to a very different experience, in terms of its bodily, social and spatial aspects. Firstly, the participants recorded at benches B and C found themselves in relaxed sitting positions: their bodies were laying on Jeppe Hein's art installations as they would be on any other conventional bench. Secondly, many of these participants remained sat for several minutes, while resting alone or talking to other people in different social formations (**Figure 12**).

Thirdly, the spatial and social logic of the behaviours observed around benches B and C can be described as self-contained and contemplative: people did not feel compelled to engage in any

Figure 11. A young couple (left) and a group of children (right) playing simultaneously with bench D.

Figure 12. A mother rests on bench B (left) while the "social character" is evident at bench C (right).

sort of play with benches B and C, and only a few of them were recorded as spectators, with averages of 8.27 spectators for bench B and 12.33 for bench C (**Chart 1B** and **C**).

4. Discussion

The main findings summarised above suggest that some correlations between Aesthetic Interaction and placemaking might exist. It was argued that a place consists of a spatial setting where people feel stimulated to go and to stay. Then, based solely on **Chart 1A–D**, one is tempted to conclude that bench C is the most successful in terms of placemaking, simply because bench C attracted the largest number of people (average of 110.80 people per session). However, the data compiled on **Chart 1A–D** refers to discrete occurrences of interaction, and not discrete persons, which means that the same individual recorded for, say, 8 min resting on a bench corresponds to eight participants. Considering that many participants captured at bench C remained sat for several minutes, in fact the total number of *different participants* on bench C was significantly lower than that presented on **Chart 1C**. Hence the placemaking qualities of bench C are twofold: on the one hand, by allowing several people to sit in a variety of social formations, bench C does contribute to placemaking, with a design that encourage people to *stay at the place* often for a relatively long time while resting and/or chatting (**Figure 13**).

Figure 13. A group of ladies with a baby settle on bench C: from 12.03 pm (left) to 12.30 pm (right) these participants remained unchanged.

On the other hand, precisely because bench C encourages people to stay on it, other people often find no space to sit, interact or socialise on bench C, thus limiting the potential of this bench to create more fleeting modalities of social encounters.

Bench B shares with bench C the elementary character of "a bench to sit on". Nonetheless, the study shows that, compared to bench C, bench B presents a rather distinct quality with regard to social gatherings. The sitting surfaces of bench B are curved and discontinuous; as a result, bench B is not as comfortable as bench C, and it accommodates only two individuals at a time —whereas up to six people were found simultaneously on bench C. Encouraging neither extended permanence nor different social arrangements, the design of bench B turns out to be the weakest of the four analysed versions with respect to placemaking. In addition, Bench B resists easy classification: although visually striking, its design makes bench B something in-between urban sculpture and urban furniture. In light of Aesthetic Interaction, this generates a problematic situation where people do not feel sufficiently compelled to engage their bodies in playful, movement-based experiences, and, at the same time, they do not feel so much compelled to sit and to stay.

The case study suggests that benches A and D are the most effective in terms of placemaking. These benches attracted high numbers of people (averages of 84.2 and 68.53 people per session, respectively). Most importantly, benches A and D revealed the highest distribution of players, participants and spectators across the recording sessions, which means that benches A and D provided more variegated experiences of bodily and social interactions around them. Not displaying a highly dominant presence of participants—such as those verified on benches B and C—means that more people were given the opportunity to experience benches A and D in qualitatively different manners, such as playing, resting or observing the activities around the benches. Unlike bench B, the striking shapes of benches A and D are unambiguously aimed at playful, exploratory sensorimotor encounters. This versatile, playful and action-oriented character makes benches A and D work in favour of placemaking, by imbuing the urban space with a very particular identity and life through social activities.

5. Conclusion

This paper presented a case study of the *Modified Social Benches*, a set of sculptural benches designed by Jeppe Hein and installed in Central London through the Summer of 2016. After an extensive fieldwork employing time-lapse photography and observations, three main social roles were identified to describe people's behaviour around the art installations: players, participants and spectators. Each of these social roles refers to a specific level of bodily and aesthetic engagement with the benches, ranging from the performative actions of players to the more constrained attitudes of spectators.

The mapping and analysis of the diverse social encounters and bodily actions triggered by the art installations suggest a correlation between Aesthetic Interaction and placemaking. Drawing from the main findings, it is possible to argue that urban installations encouraging playful, action-oriented and sensorimotor encounters tend to be more effective to placemaking than installations affording static modalities of social activities. If place is characterised as a lively setting offering different modalities of social encounters and meaningful experiences, then urban artefacts that provide people with a broader variety of social and sensorimotor experiences (like benches A and D presented in this study) seem to better define lively places in comparison to other types of artefacts (like benches B and C).

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Chapter 18

MindFull: Tableware to Manipulate Sensory Perception and Reduce Portion Sizes

Helen Andreae

Additional information is available at the end of the chapter

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Abstract

Rising obesity levels across the world are a major threat to health, well-being and the economy. Reducing the amount we eat is difficult. This is partly because consciously controlling our eating typically increases the amount we eat. The paper presents the MindFull tableware—a new design for tableware to help people to reduce portion sizes effectively and unconsciously. MindFull designs exploit a range of features of our sensory perception identified from psychological research literature. Initial experiments show encouraging results for the design and suggest several directions for future development, research and applications for the design findings.

Keywords: perception, portion size, tableware, sensory illusions, design psychology

1. Introduction

Psychology's understanding of sensory errors and our eating experiences when combined with design can be used to help people control their portion sizes. This paper reports on some relevant aspects of psychology research, how they can be applied to the design of tableware, along with the results of preliminary tests of the tableware (**Figure 1**).

The worldwide prevalence of obesity has more than doubled since 1980 due to the increased availability of calorie dense food and the decreased need for physical activity. The increase in obesity is pulling on our society's resources both directly and indirectly. Cawley and Meyerhoefer [1] estimate just over 20% of US health expenditures are on obesity-related illness costing $209.7 billion. Also, those who are obese are more likely to miss days of work, costing $4.3 billion in absentee-related costs [2]. Many also struggle to perform some job demands, resulting in 4.2% loss in productivity in jobs such as manufacturing [2]. Obesity and depression are also strongly linked [3] adding to individuals' pain.

Figure 1. MindFull tableware, photo credit to Jessica Noone, Daphnee Belleil, Isla Davies and Lucy McMaster.

There are many strategies to lose weight: various exercise programmes, diets including low fat and low carbohydrate diets and reductions in meal frequency, to name a few. In the end, weight loss works if energy intake is less than energy output. One of the simplest and most effective ways of doing this is through the reduction of portion sizes [4]. Our standard portion sizes have been consistently increasing which makes it easy to mindlessly overeat [5]. Portion control can be hard, particularly when adherence requires attention. Unfortunately, consciously restraining eating makes you more likely to eat the food you are purposely avoiding and increases the risk of bingeing [5, 6]. However, when people are unaware, smaller portions have very little effect on reported satiety [7]. Portion size reduction lends itself to long-term adherence, particularly for people who are not actively restricting their food intake.

Importantly, outside extreme levels of hunger, satiety is more strongly influenced by our expectations and our memory than physiological signals [8]. There is a strong body of evidence supporting the impact of memory on our appetite and subsequent food intake. Simply remembering a recent meal can reduce how much we eat during the next meal [9, 10]. Our implicit memory of recent eating strongly affects satiety. Patients with anterograde amnesia would eat their normal meal up to three times in a row, when the control group ate one [11]. In addition, many studies have confirmed the effectiveness of recalling a recent meal, see Refs. [10, 12] for meta-analyses. The same was found in Wansink's bottomless soup bowl study, where bowls could self fill and empty [13]; regardless of the amount participants consumed, satiety was governed by how much they perceived they had eaten.

Expectations are equally as important as memory: if we expect a meal will satisfy then usually it will [14]. Labelling food as high calorie lets people feel fuller and eat less than the same food with no labelling [15]. Furthering this line of inquiry, Brunstrom et al. [16] tested whether expected satiety could be manipulated without drawing attention to it. Participants were shown either a large or small quantity of fruit under the guise of checking for allergies. They were given identical-sized smoothies. However, those who saw the larger amount of fruit felt more satisfied and reported lower hunger levels throughout the 3 hours of testing. Our expectations of satiety have little relation to actual calorie content: high-fat or dense-calorie foods are expected to be less filling per calorie than carbohydrates. For example, potatoes were rated as five times more filling than cashew nuts [17]. Because the volume-to-calorie ratio differs between foods, judging how filling food will be is difficult. Past experiences make it easier to accurately judge food that we are familiar with and have eaten to a level of fullness [17]. For unfamiliar foods and meals with several different foods, we tend to rely on a volume heuristic to judge quantity [18]. There is also a high correlation between familiar foods and satiety [17, 19].

These findings led the team of four undergraduate students, supervised by the author, to focus on creating designs which would manipulate users' expectations of the amount of food they were eating and help them pay attention when eating. To drive design decisions, the team chose to investigate common sensory perception errors.

Our sensory perception of volume is important when judging portion size. To enable faster thinking, our cognitive processes rely on heuristics of many kinds to quickly understand the world around us. From an early age, people estimate volume using height, width and length [20]. For young children to be accurate, the forms must be simple, as shown through Piaget's work with volume consistency [21, 22]. Surprisingly, our volume estimation of complex forms only becomes slightly better with experience [20]. Volume accuracy is much better with rectilinear and cylindrical forms [22, 23]; people find it much harder to judge the volume of complex and curvilinear forms we are unfamiliar with. The design implications are to cause perception errors in volume estimation by using non-standard, complex forms.

Nonvisual senses are important. When containers are tall and thin visually, people tend to misjudge them as having a greater volume. But when using haptic senses, the bias is reversed [24]. This could be because, in the hand, the width dimension is more prominent compared to the height [25]. This same reversal was found in Pechey et al.'s investigations into the effect of 'glass shape' on volume judgments of wine [26]. Designs must consider both visual and haptic cues, using forms that feel wide, yet are visually perceived as large.

Weight impacts on volume perception. Heavier containers are perceived as larger [30]. Piqueras-Fiszman and Spence [27] found participants expected food to be more filling when presented in heavier but visually identical containers. Intriguingly, it is not only just straight mass that changes perception but also the effort exerted in our muscles [28]. It is important to note different manipulations allowed different cues to become more salient; holding an object to throw lets people feel more than just lifting it up and down, thus allowing the brain to account for the sensory input [28]. There are some odd aspects to weight heuristics: even when we have experience with an object, if it is large but light, we will still exert extra force when manipulating it [29]. If weight is being used to manipulate perception, the handling of the object must be considered.

The size-contrast illusion is also important: our size judgement is altered by comparisons with contextual cues. When applied to eating, participants (even nutrition experts) serve themselves more ice cream in a larger bowl than a small bowl [30]. In Mindless Eating [5], Wansink discussed experiments showing larger plate size can affect perception of portion size. However, Penaforte et al. [31] did an experiment with identical portion sizes of plain pasta on different sized flat plates and found plate size did not make any difference. Our team found these findings provocative, as they did not fit with previous literature. We postulated two possible explanations for the results. Firstly, pasta is a very familiar food to many people, making judging the portions easier. Secondly, a pile of pasta on a flat plate is a simple shape, so simple cognitive judgments can accurately estimate portion size. This highlights the need for complex and deceptive forms.

Three other relevant points emerged from the research. A smooth cube is perceived as being larger than a rough one [22]. Reducing eating speed results in lower food intake [12]. A cute/ baby schema helps to narrow and focus attention during unrelated tasks [32]. All of these could be factored into a design.

2. Design

Many current designs overtly address the issue of portion control. For example, they simply visualise how big portions should be or create segmented plates (reminiscent toddler plates; **Figure 2**). The image in the bottom right is a piece of strategic design by Fajar Kurnia, Jeremy Chia and

Figure 2. Current portion control plates. Photo or Design Credit to: (from top left to bottom right) Health.com, Precise Portions: Nutrition control system, Calorie Queens: 3D dinner Divider, Meal Measure: portion control plate, Zak’s Moso: bamboo divided dinner plate, Halved by Fajar Kurnia, Jeremy Chia and Jo Djauhari.

Jo Djauhari which has a lovely playful approach but still does not address the psychological aspects of portion control. Problematically, these approaches remind people they are being limited in what they are eating; which makes it harder for people to sustain their portion control. Rather than this explicit attention-enhancing approach, Wansink argued [14] that we should seek.

> *"…small changes in the eating environment (such as package downsizing, smaller dinnerware and reduced visibility and convenience) that can be easily implemented … to help solve mindless overeating."*

and claimed

> *"It is easier to change our food environment than to change our mind."*

The team created a range of concepts, each with the aim of making the food on the plate or bowl seem larger (**Figure 3**). The idea of a humped base to make the pile of food seem larger was developed further into the MindFull bowl and plate. The MindFull solution addresses the design implications from the literature review (**Figure 4**). It uses heavy materials to create a false sense of density, and the design is wide to activate the haptic cues for size. The round curved form and asymmetry makes it harder to judge the volume accurately. The shape of the bowl forces users to hold the bowl flat on their hand or stretch their grasp, which enhances the sensory cues for size. The lack of a raised rim obliges the user to scoop their food slowly to stop the food from spilling. Similarly, the angles of the bowl's interior make it easy to chase food around in circles; slowing consumption. The surface finish is smooth rather than textured, to add to the impression of size. Finally, the rounded forms have association with a baby schema, hopefully, activating the attention bias to avoiding overeating due to distraction (**Figure 5**).

Figure 3. Development. Photo credit to Jessica Noone, Daphnee Belleil, Isla Davies and Lucy McMaster.

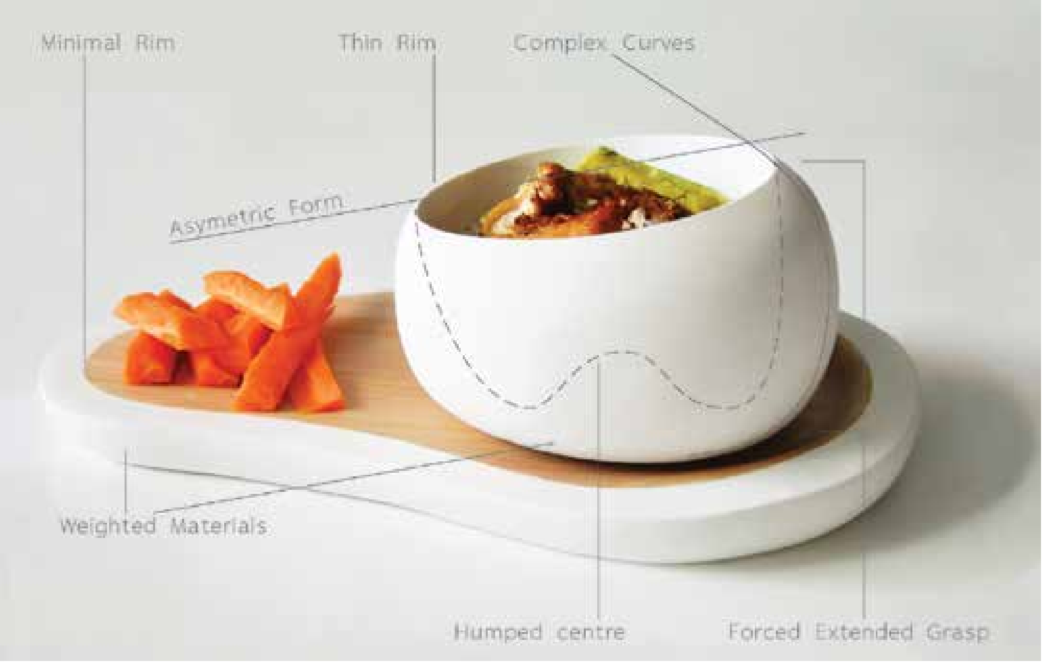

Figure 4. Design solutions to manipulate sensory perception. Photo credit to Jessica Noone, Daphnee Belleil, Isla Davies and Lucy McMaster.

Figure 5. MindFull details. Photo credit to Jessica Noone, Daphnee Belleil, Isla Davies and Lucy McMaster.

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3. Testing

To see if there were indications that any of our assumptions might work, we put the design through two preliminary user-testing sessions.

3.1. Test 1

The first test was a between-subjects test comparing the portion sizes of self-served portions of rice in the MindFull bowl and plate with portion sizes in a standard bowl and plate.

3.1.1. Participants

A total of 44 undergraduate students between 18 and 21 years were approached at the University between 10 and 11:30 am to volunteer for 2 minutes in a food experiment. They were asked their current hunger levels: hungry, content or not hungry. Each group had an even split of gender and were matched on hunger levels.

3.1.2. Apparatus

The testing environment consisted of a partitioned-off area within a studio environment (**Figure 6**). A video camera was set up to record the process. One table held a large bowl of rice with a serving spoon. The MindFull bowl and plate and a standard bowl and plate were placed out of sight behind a box. On the second table, a sheet of plastic was laid out with a camera on a tripod above to photograph the portion sizes.

Figure 6. Photograph during test one. Photo credit to Jessica Noone, Daphnee Belleil, Isla Davies and Lucy McMaster.

3.1.3. Method

Participants were asked their hunger level ("hungry", "content" or "not hungry"), handed a plate or bowl from either the standard set or the MindFull set and asked to serve themselves what they considered their normal portion of rice. Once they had served themselves, the rice was tipped out and photographed from above with the chosen hunger level label and a small note of what plate or bowl it came from. The participant was thanked and given a small sweet. This process was repeated for each participant.

3.1.4. Results

The photographs of the rice portions were collated and processed by dish type to create **Figure 7**. The number of spoonfuls each participant served was recorded and independent sample t-tests were conducted to compare. There was a significant difference between the amount of food served in the MindFull bowl (M = 2.5, SD = 1.11) and the standard bowl (M = 4.8, SD = 1.09) conditions; t [15] = 3.23, p = 0.003. However, there was no significant difference between the amount of food served in the MindFull plate (M = 2.62, SD = 1.09) and the standard plate (M = 3.5, SD = 1.65) conditions; t [12]=1.60, p = 0.12.

3.1.5. Limitations

These results indicate aspects of the MindFull bowl may be effective; however, there are many limitations to study. It would have been much better to conduct within-subject experiments or to have matched the participants in each group by size and BMI. More accurate measurements of the servings also would have given more accurate results.

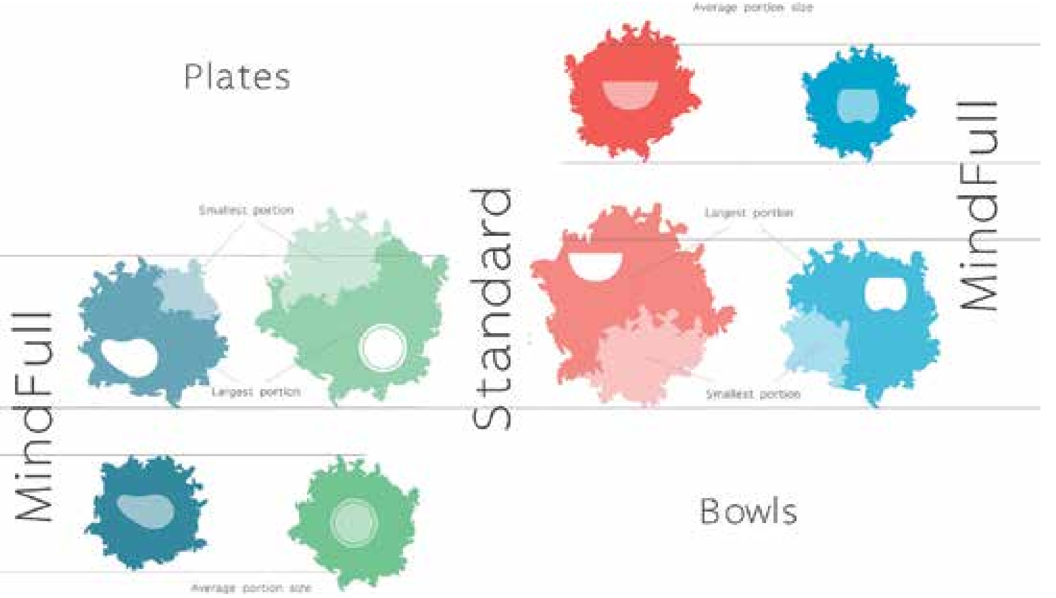

Figure 7. Infographic showing the largest, smallest and average portion sizes served in each dish—made from photographs of the rice portions.

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3.2. Test two

This study took a qualitative approach. It used a within-subjects design to compare people's experiences with the MindFull dishes versus standard dishes.

3.2.1. Participants

Participants consisted of two males and two females all aged 19 years, who were not aware of the details of the project. The four participants were told they would eat two lunches on separate days and be asked about their satisfaction levels. They were asked to choose 2 days where they would wake up at the same time and to have similar breakfasts each of the days. They were also asked about any food allergies and preferences. In return for their time, they received two free lunches, which were eaten in the course of the testing.

3.2.2. Apparatus

The bowl and plate, designed by the MindFull team, were used during the first test, and a standard white bowl and plate set were used in the second. A questionnaire asking about food consumption that morning, their satiety and satisfaction levels and their thoughts on the experience was given at the end of the testing process. A video camera was used in order to film the participant during the experiment. A knife, fork, table and chair were provided in a portioned-off section of a studio space. The meal provided was a fresh vegetable pasta salad with sliced cucumber and carrot offering a variety of flavours to reduce the fullness being reached due to flavour fatigue [33] (**Figure 8**).

3.2.3. Method

Participants were asked what time they had woken up, what they had for breakfast and what time they had eaten it. They were also asked to rate their hunger levels on a scale of

Figure 8. Food served in test two. Photo credit to Jessica Noone, Daphnee Belleil, Isla Davies and Lucy McMaster.

0–10: 0 = full, 4 = content, 8 = hungry and would eat if food was available, 10 = extremely hungry and would go out of the way to find food. The food was laid out on a table as shown in **Figure 8**, and they were invited to start eating. Participants were engaged in conversation while eating and were encouraged to verbalise how they felt during the process, employing aspects of the 'think out loud' method [34] (**Figure 9**). The first day, they ate from the MindFull bowl and plate. The second day, they use the standard set. The tests were 2 days apart. Once the participant finished the meal, they were asked to rate their fullness levels from 0 to 10, 0 = hungry, 10 = over full, 7 = comfortably full, their satisfaction levels, 0 = unsatisfied, 10 = very satisfied, 5 = neutral, and to add any comment about their experience. After completing the second test, they took part in a semi-structured interview asking their impressions of the design, how they would compare the two experiences?, would they like to have it in their home?, could they see themselves purchasing the design? and any frustrations or joys they experienced while eating.

3.2.4. Results

There was no difference in the satisfaction or fullness levels between MindFull and the standard tableware.

A deductive thematic analysis was done of the conversations, questionnaire comments and semi-structured interviews looking for comments related to the perception-based design features and opinions on the design. The videos of the sessions were also analysed for behaviour and body language.

Figure 9. Photographs taken during test two. Photo credit to Jessica Noone, Daphnee Belleil, Isla Davies and Lucy McMaster.

Generally people found the MindFull set more exciting and special.

"Oh it's [Standard set] not as exciting this time"

"It is interesting how a meal is displayed makes such a different to how much you want it"

"I really like the other plate [MindFull]… I would just want to have it displayed on my bench.., I particularly like the wood"

"The other one is too special for every day, I only get it out for special things."

"Funny, the food seemed more interesting in the other plate [MindFull]"

There were only a few comments on the portion sizes, two participants thought the MindFull set had more food, one could not tell and the last thought it had less.

"Is it more food this time? It feels like more" [Standard set]

"Do I have to finish all of it?" [MindFull]

"The bowl was quite fat looking I thought it was going to be too much" [MindFull]

"Is it the same portion sizes?"

In their written comments about MindFull they said

"I thought the bowl was super full and I wouldn't be able to finish, but it was actually a good serving size."

"It was nice, filled me up. Took my time and enjoyed it."

Two participants mentioned how the different tableware changed what you could see of the food.

"It was sooo round and cute, the food was more 'in' the bowl so you couldn't see how much there was."

"the food is more on top of this bowl, you know, you can see it."

Interestingly, these were the two participants who had strongest opposing perceptions of portion size. The one who said you could not see how much food thought MindFull had a big portion size and the one who noted you could see the food in the standard set thought MindFull had a smaller portion size. This could indicate one read the portion size only as the food he could see, while the other added the bowl into the equation.

When looking at the behaviour, participants very seldom touched the MindFull set, but they often repositioned and held the edge of the standard set. They also tended to take more time getting the food onto the fork in the MindFull condition, and the amount of food on each forkful was generally less. This could be because the design features were effective, or it may be because they were more concerned about damaging the design. Three of the four participants commented they had to be careful not to spill the food when eating with MindFull.

"There is a knack to eating with that one, but for me I don't mind 'cause it feels so much nicer"

Participants also seemed more relaxed with the standard set; however, this may have been due to having completed the test before. A larger sample size controlled for order effects would have been beneficial to address these issues. When commenting on the design two participants, expressed storage could be an issue as MindFull does not stack tightly. Three of them mentioned if they had the set they would want it on display. All of these findings only offer initial insights due to the small sample size.

4. Discussion

People use a variety of heuristics to estimate size from a range of visual and haptic perceptions. These heuristics are not accurate in all circumstances and can lead to very inaccurate estimates at times. The MindFull bowl and plate were designed with a number of features that exploited the limitations of these heuristics to present an illusion of larger portion sizes in order to assist people to unconsciously reduce and control their eating.

The experiments reported in this paper give a preliminary indication that the design may be successful. In particular, the MindFull bowl merits further investigation, as it significantly alters the perceived portion sizes in comparison to a normal bowl. However, more rigorous testing in a greater range of situations and with larger sample sizes would be needed to confidently validate the design.

The MindFull plate did not appear to be as effective. We postulate this may be because the mound on the MindFull plate is visually prominent, resulting in users being more aware of it and not deceived by the illusory perceptual consequences. The MindFull bowl, on the other hand, has a less visually prominent mound, making it much harder for the user to be aware the perceptual manipulation. The food also hid the shape of the internal walls making it difficult to judge the wall thickness and know how much was food and how much was bowl.

Furthermore, the shape of the MindFull bowl meant less of the food portion was visible than on the MindFull plate, so the container itself had a more dominant effect on the perception. The bowl also incorporated more identified design implications than the plate. It had a more unconventional and complex shape, which may have directly defeated many of the standard heuristics for estimating size. Unlike the plate, the bowl gave a haptic sensation of a larger container, as it was unwieldy when held in one hand, adding to the illusion of a big portion size. The difference between the weight of the MindFull bowl and the standard bowl was much higher than the difference in weight between the MindFull plate and the standard plate. This could mean the illusion of the weight-to-size ratio was stronger in the bowl making it more successful. Since the weight-to-size heuristic is particularly robust against cognitive awareness, we suggest this factor was particularly important in preventing people from using slower (but more accurate) thinking processes to overcome the deceptive sensory signals. To determine which of the strategies were most effective, the variables would need to be isolated in further testing.

The way participants served their own food in the first study was a significant limitation because they could feel the weight of the food in the serving spoon as well as count the number of spoonfuls. This process probably reduced the effectiveness of the sensory manipulations by the bowl or the plate. To truly test the effects of the design features, future experiments should modify the way the food is served to remove this limitation. However, serving food would happen in regular use of the tableware, which suggests a further design opportunity to create a weighted and/or complex shaped serving spoon that employs similar sensory illusions. Additionally, after eating, the shape of the bowl is made visible, so the perceptual illusions are more obvious, possibly inducing the user to reassess their expectations. This may have been a factor in one of the comments in the second study: "I thought the bowl was super full, and I wouldn't be able to finish, but it was actually a good serving size". It is unclear what effect this post-eating change in expectations would have on satiety, but it could be a severe design limitation.

The results of the second study were not as rigorous but did give indications for design improvements. Generally, the responses and satiety levels did not contradict the effectiveness of the MindFull approach. A big flaw in this study was not having participants pick up and handle the tableware, since many of the features targeted haptic feedback. A study with more participants and a setup where tableware is handled would be beneficial.

Overall, we conclude it could still be worth exploring MindFull and additions to the MindFull range of items, such as serving spoons, cutlery, glasses and serving bowls. The MindFull range of tableware is but one design approach to helping people control their eating; yet it demonstrates the potential of good design in this area. Due to the enormous cost of obesity to our society, investment into design which could help us eat less is of immense worth.

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Chapter 19

Felted Terrain: Interactive Textile Landscape; Transforming the Experience of Knitted Textile with Computation and Soft Electronics

Yihyun Lim

Additional information is available at the end of the chapter

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Abstract

This paper presents Felted Terrain, an interactive textile with embedded soft electronics, that creates a sensorial experience with tactility, sound, and esthetics. The project takes the traditional craft of knitting and applies computation at different points of processes, from pattern generation with parametric scripting to integration of conductive and flexible electronics for creating user interactivity. With digital design and fabrication tools, the sensor-embedded textile is produced to be experienced at the spatial level of the interior. The paper discusses the design processes of the project and the potentials of embedding unexpected interactivity to the everyday object of the knitted fabric to provide opportunities for multi-sensorial experiences.

Keywords: Interaction design, design methodology, computation design, esthetics of interaction, tangible interaction, haptic interaction, sensible interface, flexible electronics, soft computation

1. Introduction

Knitting, creating fabric from weaving of worsted fibers, has been with us since the old days. As a material at the scale of our body, we are familiar with its touch, use, and experience. Textiles have also been used at the scale of the interior as wall tapestries and affect our experience with the space through esthetics. Through its interlaced yarn and colors, textile wall hangings were important elements of story-telling, communicating stories to the inhabitants of the space [6].

With the advent of soft electronics, there is an opportunity to take the experience of the textiles to the next level of multi-sensoriality. This project aims to explore two aspects of 'craft research' in interactive textiles; the generative design/craft process of textile and creation of spatial experience through public exhibition (reflective-on-action). The first part discusses the production process of an interactive textile using embedded soft electronics, computation, and generative design that "focus on aesthetics, personal expression, and the idea of play, as opposed to the prevalent utilitarian focus of wearable technology design on universal connectivity and productivity applications" [2]. The slow-paced craft process of the felted textile embraces the practice of 'reflective-in-action', where final interaction design of the project was continuously designed and iterated throughout the process of making [11]. The second part of the project focuses on the experience of interactive textile in a spatial (exhibition) setting where it becomes a mediator of experiential elements, that transforms an everyday space into a multi-sensorial 'practice space' [5]. The combination of haptic, visual, and auditory experience that is placed throughout the exhibition space provides users to 'reflect-on-action' [11] and discover the various interactive elements of the textile.

2. Design, computation, and production of Felted Terrain: an interactive non-woven textile

Felted Terrain attempts to subvert the notion of primitive handcraft in knitted/felted textile through its integration of soft electronics, computation design, and fabrication method. Using traditional textile techniques such as knitting, embroidery, and felting, the project aims to create textile of an 'ambient display' [14] that sense, transmit data, and create spatial sensory effect by presenting information within a space through subtle changes in the background of awareness (in this case, sound) (**Figure 1**).

There are two parts to the creation of 'Felted Terrain'—designing of knit pattern to create three-dimensional knit structures with parametric computation design tools, and making of the electronic textile "that incorporates capabilities for sensing, communication, and interconnection technology" [2] with soft computation. Felted Terrain is a result of this two-part process and aims to present a seamless integration of technology and interactive experience in a knitted woven textile. As a handcraft process, the slow pace of the design and production of the textile enables 'reflection-in-action' [11], to continuously reflect on the project as a whole and also at every stage of the process to ensure the integration of design, craft, and intended user interaction in the production of the interactive textile. The following documents every step of the design and making process, that involves both digital and manual methods.

Figure 1. Felted Terrain—an interactive sensorial textile that generates sound and visual graphics upon touch.

2.1. Creating the pattern

2.1.1. Generating dynamic three-dimensional knit patterns with computation

As the initial inspiration from the project came from the rolling mossy landscape of Iceland (**Figure 2**), creating a three-dimensional pattern to express the soft terrain was the first step in the process. To generate pattern, a circle packing Grasshopper script for Rhino 3D was used. The size of the circles varied from large to small (which corresponds to the pitch of the musical notes). The script also allowed easy planning in mapping of conductive areas, as shown in **Figure 3** (the red circles indicate where the conductive thread will be added to create a capacitive sensor tips). The parametrically generated pattern was then overlaid on a grid to translated these into a knitting pattern. The pattern used in this project was one of many iterations generated from the computational design tool, which opened up a wide possibility to quickly generate variations for different visual effects.

2.1.2. Designing soft circuitry embroidery patterns

Using the same pattern, a soft circuit diagram was made to plan out the embroidery of conductive circuits on felted textile. The curved lines indicated the circuit that links all of the conductive tips (gray-shaded area) to the Lilypad microcontroller (**Figure 3**). Soft circuits were

Figure 2. Interpreting the mossy terrain of Iceland to a knitted pattern.

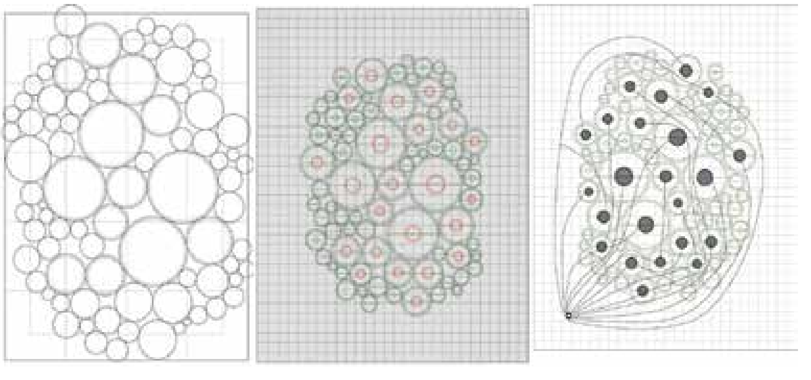

Figure 3. (Left) Circle-packing pattern generated from parametric scripts. (Center) The pattern was overlaid on a grid to create a knitting pattern, and red circles indicate where the conductive thread should be added during the knitting process to create capacitive sensor tips. (Right) Gray-shaded area indicates the conductive tips, with circuit path showing its connection to the central microcontroller placed on the bottom left corner.

embroidered along the designated pattern using conductive stainless steel thread. The Lilypad microcontroller and x-Bee wireless modules were also hand sewn using conductive thread, creating a full e-textile.

2.2. Embedding conductivity to knitted textiles

2.2.1. Knitting with two types of fibers

The knitting process involved using two different types of yarn, a regular wool yarn and a conductive stainless steel yarn. As seen in **Figure 4**, stainless steel yarn was knitted together at the tips of the bumps to give "electro-mechanical properties" that will enable the fabrication of complex textile with interactivity [1]. This allowed integration of flexible sensors to build electronic circuits on soft substrates, and enables a move away from traditional electronics, of using PCB boards and hard materials, to an exploration of emergent flexible materials to create interactive physical designs [2]. When connected to the microcontroller, these tips can be programmed to become touch sensitive through capacitance. In this project, a low-profile stainless steel yarn was used instead of visible silver or gold metallic threads in creating soft circuits, so it could be blended in with the wool fiber and create a seamless look, paving its way for unexpected interaction in the final stage.

To produce a textile at the scale of the interior, yet using a domestic scale of the knitting machine, the project was made in small size patches of 1 m × 1 m as shown in **Figure 5**. Knitted patches were stitched together to create a large wall-sized piece woven textile with three-dimensional 'bump' forms. The process produced a loosely knit woven textile with areas of embedded conductivity where stainless steel yarn was added to the wool yarn during the knitting process. Hand stitched seams and stainless steel yarn at tips of the three-dimensional bumps were still visible at this stage—in order to create a seamless esthetics of a non-woven textile, the completed knit textile went through the multi-step process of wet-felting.

Figure 4. Knitting with two different types of yarn to create a conductive 3D structure knit. Conductive fibers are embedded in each tip of the three-dimensional forms.

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Figure 5. Knitting in 1 m × 1 m patches to produce a spatial-scale of knitted textile.

2.2.2. Transforming woven textile to non-woven: felting

Wet felting shrinks the knitted textile by 30–40% from its original size (**Figure 6**). The felting process is a result of the 'tangling of wool fibers', due to the reptile-like scales on the surface of individual fibers. These scales are the main reasons in giving traditional wool its abrasive texture. When washed with hot water, these scales interlock and become lighter and tighter causing shrinkage, becoming a non-woven felted textile (**Figure 7**). Using this natural mechanism, the above knitted textile went through the wet-felting process, where it was agitated multiple times in the washing machine with hot water and soap, until the knitted structure was no longer visible and became a homogenous texture of felted fabric. Afterwards the entire piece was formed, flattened and then air dried to retain the shape of the bumps.

2.3. Actuating sound and visual interactivity

The previous section explored the use of computation as a tool to generate design for the three-dimensional pattern of the knitted textile. Computation can go beyond the role of design tool, and become 'part of the designed things themselves' [12].

Figure 6. Felting process shrinks the woven wool textile by 30–40%. Felting transforms a woven knitted fabric into a seamless non-woven fabric.

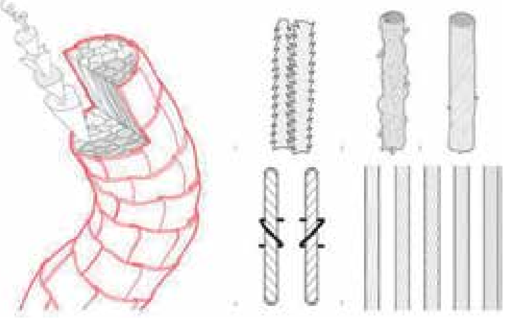

Figure 7. Diagram of wool fibers and the interlocking mechanism of wool scales in felting.

The three-dimensional form of the felted textile is designed with an intention to draw users touch, squeeze, and stroke each of the bumps. In addition to the apparent visual and tactile experience of the textile, auditory experience was programmed to the textile as an output of the touch interaction. In this project, a Lilypad microcontroller, an Arduino variant that is designed to be easily integrated with flexible circuits on textiles through sewing with conductive threads, was used along with a wireless x-Bee module to transform the experience of the everyday textile into an interactive e-textile.

2.3.1. Creating intuitive interaction: textile keyboard

The interaction had two parts to the design. First was leveraging on the expected behavior of people with textiles (especially since the bumpy form intrigued users to touch) and second was designing an interaction that is intuitive for users to find out the rules of the game after a short engagement. In this project, a simple music notes were assigned to selected bumps on the felted textile. The size of the bumps corresponded to the pitch of the notes, for example, large bump played a lower octave note, and the note/pitch of the sound would go up the scale as the bump sizes get smaller (**Figures 8** and **9**).

2.3.2. Real-time visual feedback of sound and touch

In order to enable the textile as a simple sound keyboard, Lilypad microcontroller was loaded with a modified Capsense Arduino Code. The received serial data was then transferred to a

Figure 8. Lilypad microcontroller was sewn onto the felted fabric along with x-Bee module for wireless transmission of data to the main computer.

Figure 9. Using Arduino and Processing, touching of the conductive felted tips produced individual sound of piano notes, at the same time visualizing the pitch through real-time projection of the sine wave curve on the wall.

Processing script (adapted from MIT Media Lab High-Low Tech Group's Piano Code). With these codes each touch on the tips were translated into a sound, which was then played through a speaker placed in the room. To create a visual connection to the sound the textile was producing, a real-time projection of the sound pitch was projected on the wall, in a form of a sine curve. Through this tri-part experience, a tactile touch could be both felt acoustically and visually.

3. Interactive textile as mediator of experience: creating opportunities for 'practiced space' through exhibition

Felted Terrain was installed at the MIT Keller Gallery for open interaction with visitors and passersby. The exhibition context could influence how one experiences the material of the exhibit [9]. With the design of the layout, the exhibitor can guide the visitor to engage with the material in a specific way and order, adding additional interaction element to the whole experience (**Figure 10**).

The exhibition was designed to invite visitors to reflect-on-action [11], to unveil the experiences of the interactive textile by engaging with it step by step. The square felted textile was placed on a clear table with a spotlight providing visual focus. A circular shiny mirrored film was placed beneath the table to enlarge the presence of the felted textile as well as providing additional view of the textile (negative space of the three-dimensional pattern). Upon entry, the three-dimensional form and fuzzy texture of the felted textile lures users to engage in touch. Each touch of the capacitive sensor tips, produced different musical notes, which was played through embedded sound system in the gallery space. By touching various sized tips, users could gradually understand the connection between bump sizes and sound notes, where the pitches of the notes correspond to the size of the bumps. Over time, one could make the parallel analogy of the textile as musical keyboard, and many of the users started to play a tune with the felted textile bumps. Various touch gestures were observed during the exhibition—in addition to lightly tapping the bumps, other gestures such as stroking, squeezing, pressing, and pulling of the bumps were made. Regardless of the types of gestures, in this version of the

Figure 10. Exhibition of the textile—it was placed on a custom designed clear table with reflective film on floor.

Figure 11. The tactility and three-dimensional design of the textile invites users to touch, which generates sounds and visualizes the pitch of the sound on a nearby wall.

textile, the touch was accompanied by real-time visualization of the sounds, which was a wall projection of a sine wave curve.

The interactive textile also became mediator of experiential elements, and as a result it created an opportunity for a 'practiced space' by bringing meaning to a static space [5], where one's actions and engagement with the textile produced different perception of space (from space of sound, space of visual movement, and space of tacility). The interactive textile influenced how people experience their surroundings (**Figure 11**).

4. Potentials/future applications

The Felted Terrain project explored the creation of different sensorial experiences to the everyday surface of textile through computation-based design and integration of soft electronics. The exploration described in this paper is just the beginning, as many variations, effects and experiences can be created. For simplification, there are three components to the project for further exploration. First is in the design of the esthetics through pattern making. Through generative computation design, many dynamic and diverse designs can be made for application on textile. When combined with traditional techniques in knitting (such as creating "bumps" in this project by adding and decreasing stitches) the parametric design tool can quickly generate iterations of design forms.

Second, design of the interaction can be explored further. The project engaged few sensorial experiences, from auditory to visual, however, multitudes of combinations of experiences can be designed. The sensorial output from the touching of felted bumps are unlimited; further exploration can be made to produce other outputs such as changes in lighting of the space, temperature, haptic vibration, etc. Interaction modes are another part of the interaction design that can be modified. Additional touch behaviors on fabrics, such as stroking, squeezing, pushing can be studied to embed actuating sensors (conductive areas) to encourage other modes of engagement with the textile.

Lastly, the scale of the textile experience can be varied, from a scale of the body to the scale of the interior and building, to produce different emotional effects and affect understanding of the space. Other production methods and tools, such as thermo-forming of non-woven textile on digitally produced forms (CNC milled form base as an example), or using an industrial scale knitting machine to scale up and automate the process can produce the soft, responsive, sculptural textile surface at a scale of the interior. The e-textile surface can also be modularized in a form of e-textile for application on larger surface. The placement of tiles can produce different overall visual patterns as well as sensory outputs (**Figure 12**).

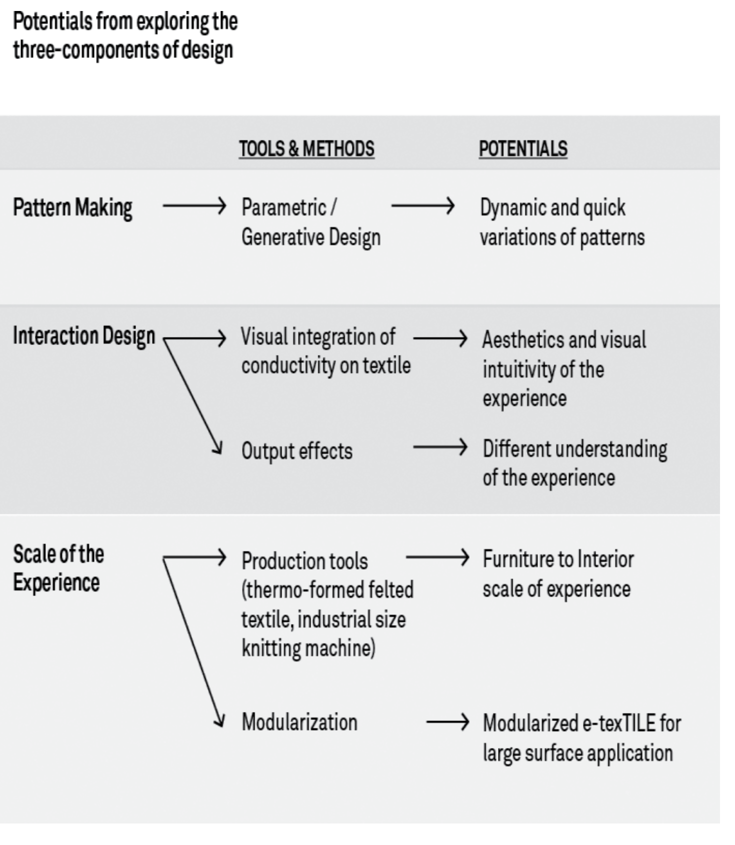

Figure 12. Diagram of components to be further explored.

5. Conclusion

The Felted Terrain project is an exploration of creating a soft textile surface that creates rich interaction and activities between people, computer, and the physical space to be expressive, unexpected, and enjoyable.

The slow crafting process of designing and making the interactive multi-sensorial textile provided many moments of 'reflection-in-action' [9], where the designer-maker can reflect in each action of the process to inform the experience of the whole and design decisions of parts. The exhibition context provided opportunities for 'reflection-on-action' [9], by allowing visitors to unveil layers of experiences and figuring out the pattern (rule) of interaction by reflecting on past experiences, knowledge and actions.

Textiles have a "uniquely intimate relationship with the human body" [1]. We wear them as clothing and also live around them as interior furnishing. We are naturally drawn to touching and feeling the tactility of the textile. What further explorations can be made to create soft surfaces that intuitively draw people to feel, respond, and interact? Would production at various scales, from the body-scale wearable to the level of interior and building produce different experiential effect of the interactive textile surface?

Textiles, whether knit or woven, worn on body or hung in space, is ubiquitous in our lives. The everyday presence of textile surfaces and its application to create soft, fabric-based computers embody Mark Weiser's vision of ubiquitous computing [13]: providing functionality while disappearing discreetly into the soft surface of the 'textiled' space. The esthetics, material qualities, and flexibility of the textiles present large possibility for embedded computation [4], or as a medium to form 'computational composite' [9] to create a pervasive, playful, and theatrical interactive experience for all.

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Igeni: Reinforcing Hygiene Practices in Children Through Dynamic Products

Marta Taverna, Sara Colombo and Lucia Rampino

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Abstract

Igeni is a set of dynamic products designed to lead children towards autonomy in their personal hygiene practices. The set is composed of three objects: the Billy Brush toothbrush, the Wally Wash faucet-ring and the Fanny Flush toilet reminder. These interactive products are designed to enhance skills of personal hygiene in preschool children, thanks to sensors and actuators for multisensory communication. In this paper, we present the design process that led to the creation of this set of products and we describe the design outcome, consisting of a setoff objects aimed at exploiting the child's senses to convey messages, to create engaging experiences and to encourage healthy practices. We also present and discuss preliminary tests with users.

Keywords: dynamic products, non-verbal communication, sensory communication, health, hygiene habits, children

1. Introduction

This paper describes Igeni, a set of dynamic products designed to educate children in preschool age (3–5 years) to be more autonomous in personal hygiene practices. The paper intends to add to the field of dynamic products through a practical design case, showing how dynamic sensory features can be designed to communicate with children and affect their behaviour. It identifies and explore a potential application field for dynamic products and provides design clues that can inspire the use of dynamic features in other contexts.

Parents daily struggle with reminding children of basic hygiene practices and a lot of time and effort is dedicated to teaching them how to perform these actions in an effective way. Results are difficult to check and different practices are carried out as control mechanisms (e.g. visual inspection of hand and teeth, touching toothbrush to check if it is wet, etc.). These practices inspired us to explore how IoT and interaction design can be applied to the field of children's personal hygiene, in order to reinforce the educational process and to teach them to be more autonomous, while at the same time reducing parents' burdening.

We decided to explore this problem space by designing dynamic products that focus on sensory and non-verbal communication. In interaction design, diverse forms of non-verbal communication have started to be investigated recently, which regard alternative—more physical and sensory—languages for the communication of digital information to the user. Ambient interfaces [1, 2] and dynamic products are at the core of this design area. In particular, dynamic products are objects that show sensory features (visual, tactile, auditory and olfactory) that change proactively and in a reversible way over time, providing information to users by transforming their own sensory appearances (i.e. shape, colour, smell, light, sound, temperature, etc.) [3].

Dynamic products provide the possibility to convey information in an implicit and sensory way, and highlight the emergence of a new semantics, which understands the changing and dynamic appearances of products as communication means. Design can apply different strategies to effectively shape and map information into dynamic sensory features, like abstract disruption, translation, reproduction and metaphor, according to the context where the product will be used and to the communication goals ([4], p. 96). Moreover, communicating by senses seems to be a more engaging way to provide information to users and has the ability to create meaningful experiences and to affect the users' activities and practices ([4], p. 92).

However, we could not find any study in this area investigating how product's dynamic sensory features can be used to convey information or to encourage certain behaviours, having children as users, with a product and interaction design perspective. As dynamic products seem to be powerful means to emotionally engage users and affect their behaviour, we explored their potential in the field of personal hygiene in children, through a real case study.

This work intends to explore how dynamic products can be used to influence users' behaviour in a practical project, and it wants to expand their application field, by testing this approach in the area of design for children.

2. Rationale

As stated by physiological and health studies, teaching personal hygiene practices in children is fundamental for a number of reasons. Referring to literature and dedicated websites [5–9] we summarized that:

- Personal hygiene is very important for wellbeing and for a healthy life.
- Habits and competences learnt in infancy are the deeply fixed and last longer in life.
- Incorrect habits and skills of personal hygiene are often learnt; this may lead to different problems during life and are difficult to be reversed.

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We took these considerations as the basis of our design activity. Indeed, we decided to design a set of objects that stimulate and improve the learning of the right hygienic habits during preschool age.

3. The design process

The design process followed the whole cycle of research, design, prototyping and testing solutions. Theories in the field of education, personal hygiene and health, and sensory communication were investigated, a benchmarking analysis was performed, consisting of a deep investigation of the current educational products, their strength and weakness, and the market. This research activity led to the definition of the design brief and to the concepts design and development. At the end, we built working prototypes and we performed pilot tests.

3.1. Research

3.1.1. The state of the art

The kickoff of this project was the perception of the lack of a fully dedicated and successful product for children hygiene, confirmed by a deep market analysis. The benchmarking highlighted that hygiene was encouraged either by making products more engaging thought an playful appearance, or by developing digital apps that gamify hygiene practices, mainly targeted to children in school age. The use of dynamic sensory features to engage and persuade was almost completely absent, with the exception of some toothbrushes, which light up while used.

3.1.2. Educational theories

To understand how to design something useful and specific for children, we investigated psychological and educational theories. We focused mainly on three approaches to education: the Montessori's pedagogy, focused on the principle of educating the child to independence and on the tactile experience [10–12]; the scaffolding theory, that is centred on how adults can help children to fill the gap between their abilities and the job required, to let them become better at those activities [5, 7, 13]; the Behavioural theory, which argues that all human habits and actions are pursued or abandoned depending on the reward or punishment that follows the action [5, 7]. Considering these knowledge, some guidelines emerged that guided the design process. The resulting interactive solutions should:

- lead the children to autonomy by monitoring and remembering the actions taught by their parents,
- allow the remote control from parents but, at the same time, let freedom and independence to children,
- support the acquisition of skills and automatic actions through the repetition and the application of 'positive reinforcement' [5, 7].

It is important to underline that the aim of this set of objects is not to teach the child the action to perform starting from scratch, but to lead them to the right hygiene habits and competences, always guided and overseen by their parents.

3.1.3. Hygiene rules

We focused on three hygiene practices that require learning and following specific rules, and that usually represent the focus of education in hygiene:

- brushing teeth [14–17]
- washing hands [14, 18]
- flushing the toilet [19]

A very important part of the research process was dedicated to identifying correct rules and hygienic practices; to this aim, literature research was performed and a dentist was interviewed, to collect information about the right practices. These rules have been implemented in the design of the final products and will be described concurrently with the presentation of the concepts.

3.2. Design brief

3.2.1. Goal

The brief emerged by research findings consisted in designing a set of three products for preschool children, each one related to a specific hygiene practice: oral hygiene, hand hygiene and use of the toilet. These products should be able to communicate information to the user by working alongside, or replacing, the existent items of the toilet. The set exploits the nonverbal communication and the positive reinforcement method.

3.2.2. Users

The products are addressed to two different users: the kid and the parents. The main user is the child, who should be reminded to perform the action, and should be guided during the activity. The second category of users is the parents, who should be supported in the control of their children's activities.

4. The Igeni set

Igeni is the result of the design activity. It consists of three products: Billy Brush, Fanny Flush and Wally Wash. It is a set of dynamic products meant to support children during everyday hygiene activities and habits thanks to dynamic sensory stimuli. Each of these little monsters, cute and colourful is related to a specific hygienic practice.

By using sensors, this set monitors children's actions and send messages both to parents and children through changes in their physical and sensory appearance (**Figure 1**).

Figure 1. The Igeni set.

4.1. Billy Brush

Billy Brush is a small green monster, a little devil or minotaur, which takes care of the oral hygiene and is made of a toothbrush and a toothbrush base (**Figure 2**).

The shape of Billy Brush's mouth is designed to host the toothbrush when unused. When the toothbrush starts to be used, its movement is detected and the monster's mouth starts to rotate. Also, a two-minute song is played, to signal the right duration of tooth brushing. When the brushing time is finished, the mouth returns to the initial position and the song stops. The monster's mouth flashes a white light when the activity is completed, to evoke a clean and healthy mouth. If the brushing is stopped earlier, Billy Brush's mouths stops in a wrong position that prevents the toothbrush storage; the music goes on and a blue flashing lights calls the child's attention. If the child does not finish his/her duty, the mouth becomes red to signal the error to him/her and to the parents. Moreover, the mouth becomes red also to signal if the toothbrush is unused for too long, this time pulsating, to encourage the child to brush his/her teeth (**Figure 3**).

4.2. Funny Flush

Fanny Flush is a small blue monster, a dinosaur or a dragon that reminds the child to flush the toilet. It consists of a body with a belly that can be pressed and of a balloon, a membrane button, connected with retractable wire. Fanny Flush should be fixed behind the WC in such a way that the WC cover lays on its belly when lifted. The balloon should be stuck to the flush button (**Figure 4**).

The aim of Funny Flush is to teach the right use of the WC. Indeed, it recognizes when the toilet is used thanks to a sensor in the belly and reminds the child to lay down the toilet cover and flush it after the use, by emitting a sound that reminds water. If the actions are done following the correct order, Funny Flush rewards the child with a "winning" sound. Otherwise, it makes a sad-loosing sound, like the ones used in videogames (**Figure 5**).

Figure 2. Billy Brush.

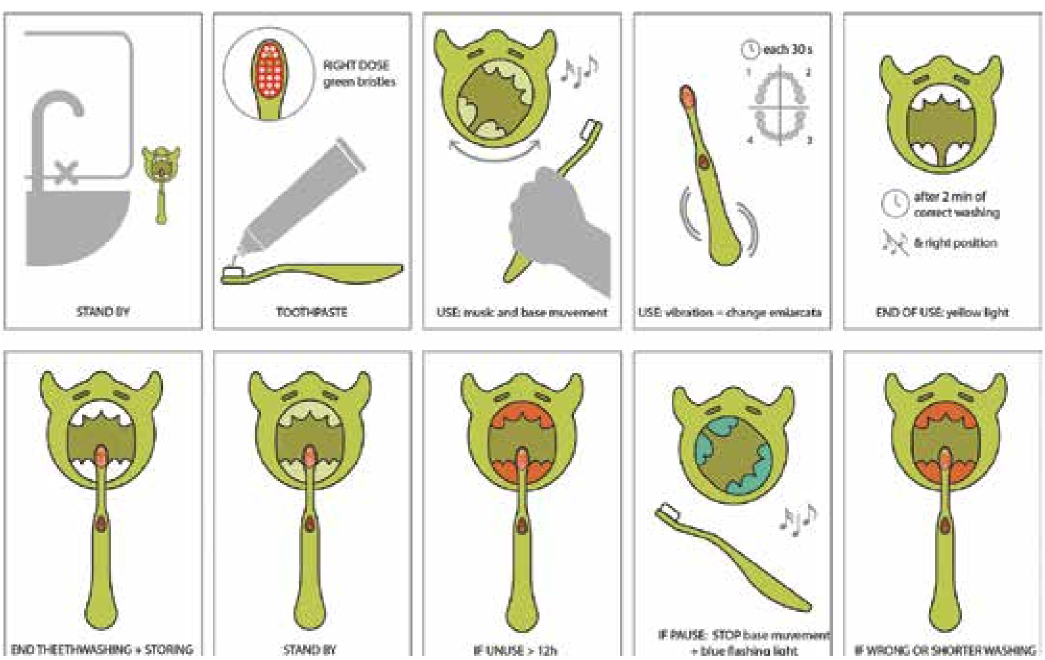

Figure 3. Billy Brush Storyboard.

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Figure 4. Funny Flush.

Figure 5. Funny Flush Storyboard.

Figure 6. Wally Wash.

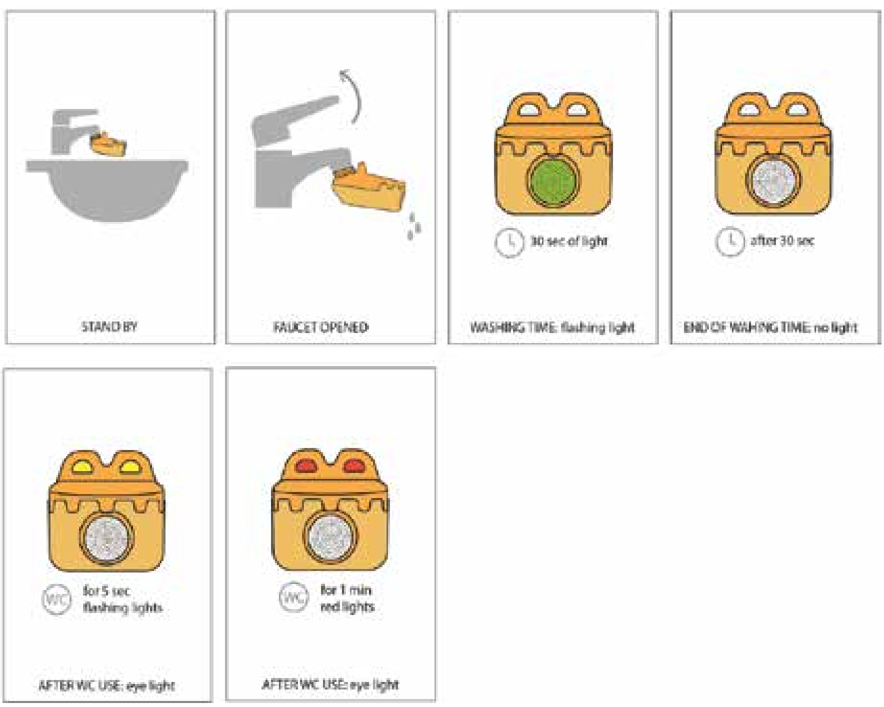

Figure 7. Wally Wash Storyboard.

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4.3. Wally Wash

Wally Wash is the last item of the Igeni set. It consists of a little orange monster resembling a crocodile, and a faucet adapter. This dynamic product promotes child's correct faucet use and hand hygiene in an engaging way, thanks to sensorial communication. Moreover, Wally Wash is designed to centre the water flow in the sink, making hand washing easier for children (**Figure 6**).

Wally Wash is connected to Fanny Flush and activates itself to remind the child to wash his/her hands after the toilet use. It calls the child's attention by flashing light through its eyes. If the child does not wash his/her hands the eyes become red. Furthermore, its mouth lights up for 30 seconds when the faucet is opened (an inner dynamo registers the water flow), to suggest the correct duration of hand washing, in order to avoid water waste (**Figure 7**).

The recall of the design in this paper is mostly focused on the products' dynamic features. Other important details should be considered in the final product design (e.g. anti-bacterial coating) but our intent was to discuss the relevance of the products in terms of how they change the experience and influence the user's behaviour thanks to dynamic elements.

5. User tests

A prototype of the Igeni set was built and tested with users in order to evaluate the efficacy of the sensory communication, the pleasantness of the experience and the overall effectiveness of the system (**Figures 8** and **9**).

The use of off-the-shelf components and available materials and technologies led to some small changes in the prototype, compared to the real design. In particular, the toothbrush prototype shows a split body, to host interchangeable heads and to improve safety during the tests. However, the main features, especially the dynamic ones, were kept identical to the design.

5.1. Tests deployment

Six pilot tests were performed. The Igeni set was installed in six homes and was tested by each family. Altogether, the trial was performed with six children (two male and four female), two fathers and four mothers (**Figure 10**).

The test was divided into four parts:

- a preliminary interview to investigate the child's habits and feelings about personal hygiene;
- an explanation of the products and their main features;
- an interaction with the set by the children and the parents;
- a final interview with both children and parents, performed separately. Children were questioned about their experience and comprehension of the products. Parents were asked to give feedback about the set.

Figure 8. Igeni prototypes outside.

Figure 9. Inside of Igeni prototypes.

http://dx.doi.org/10.5772/intechopen.71122

Figure 10. Children interacting with the Igeni prototypes during tests.

5.2. Preliminary results

The tests were mainly focused on evaluating the effectiveness of the communication by the products' dynamic sensory features and the children's overall experience. Results show that the communication by dynamic sensory features was very effective and all the messages were understood by children without difficulties. In particular, sounds and lights were appreciated as clear stimuli. The use of colours associated with meanings (white for a clean mouth as a reward, red for alert) and the use of metaphoric sound, like the water, were very easy to understand and recall. The careful choice of the dynamic sensory stimuli in the design process turned out to be successful. Children considered the experience very fun and engaging, they liked a lot interacting with "living" characters, they enjoyed performing hygiene practices thanks to the dynamic, simple and friendly communication between them and the monsters. Moreover, the mere presence of the objects in the bathroom caught the children's attention and reminded them of specific actions like flushing the toilet or brushing teeth.

The use of sensory features instead of screens or interfaces and the possibility to give contextual feedback was highly appreciated by parents that also found the sensory stimuli effective in communicating the messages addressed to them.

Experience was evaluated on a five-point Likert scale. Some of the results are shown in **Figure 11**.

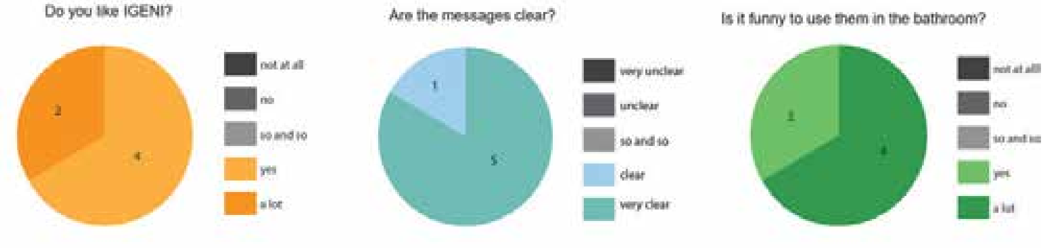

Figure 11. Test results.

6. Discussion and conclusion

A set of dynamic products was designed to reinforce hygiene practices in children from 3 to 5 years old. The design was focused on mapping messages into dynamic product features. The following sensory features were chosen to convey different kinds of messages:

- Encouragement: flashing light, sound or vibration were used to grab the child's attention in order to remind him/her to perform an action like flushing the toilet, washing hands or changing arch. Both abstract stimuli (flashing light) and metaphors (the sound of water to remind to flush the toilet) were employed. They both came out to be very effective, because also in the case of flashing lights in Billy Brush and Wally Wash, the stimulus was connected to the object, therefore easily associated to the suggested activity.

- Feedback: Still coloured light and sound were used to give feedback about the correctness of the activity. Red light was immediately associated to an error, and both high-pitch joyful sounds and low-pitch and sad sounds were instinctively connected with reward or "punishment". Sound came out to be stronger than light in conveying the idea of a right/wrong action.

The system is going to be tested for a longer period in households, in order to evaluate the impact of the use of such products on children's hygiene practices and to understand how to improve the design and the sensor application. The preliminary tests confirmed the ability of dynamic products to convey messages in an effective, engaging and contextualized way and their potential in encouraging positive and healthy habits in this context.

The preliminary findings reported in this paper can inform the design of dynamic features in other contexts, especially with children, where communication and encouragement are at the centre of the design activity.

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Section 6

Developing Sensitivity - Co-creating Experiences

On the Role of External Representations in Designing for Participatory Sensemaking

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Caroline Hummels

Additional information is available at the end of the chapter

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Abstract

Public issues demand highly complex collaborations in which different (public, private) stakeholders, each with their own complementary or conflicting interests, expertise and experiences, work toward public good. Typically, collaborative technological applications function to represent people's ideas and to enable the exchange of representational messages between people. By contrast, we designed [X]Changing Perspectives ([X]CP): an interactive table-system for multi-stakeholder collaboration around public issues. The system aims, not to *represent* views but rather, to *scaffold* the emergence of situated meaningful couplings in face-to-face interactions. It helps people to align their visual attention, materialises their input and provokes associations. However, [X]CP does contain representations, such as symbols, tangibles and an interactive visualisation. In reflecting on its design and use, we analyse what these representations *do*, as seen from the perspective of embodied, participatory sensemaking. We explain how representations are not the foundational building blocks of the system, and how they do not have fixed meanings. Rather, as scaffolds, our representations add a layer of artificial structure that guides the ongoing interactive couplings between people, contributing to *participatory sensemaking*. Applying this approach to the design of mediating technologies for multi-stakeholder collaborations can open up new ways of interacting and understanding between stakeholders without disrupting their collaboration.

Keywords: multi-stakeholder collaboration, participatory sensemaking, embodied sensemaking, representation, embodied cognition

1. Introduction

Public issues are complex as they cross borders of sectors and disciplines. Cross-disciplinary multi-stakeholder collaborations are needed to work on today's societal challenges [8, 9].

Researchers in the field of human-computer interaction (HCI) are increasingly working on sociotechnical systems for societal issues in the complex context of sociopolitical multi-stakeholder dynamics [6, 16, 21]. Buur and Larssen [3] even call for designers to design 'new formats of collaboration for large, complex contingents of stakeholders' ([3], p. 137), and, when facilitating such collaborations, to focus on the role of crossing intentions and conflict.

1.1. Tangible mediation of collaboration

In HCI, a vast body of work [17] is dedicated to mediating collaboration. The work focused on designing interactive systems, such as tangible interfaces and multi-touch tabletop interfaces. Such HCI systems indeed can contribute to collaboration [2], for example, multi-stakeholder brainstorms [1], the creation of narratives [12] or equitable participation [20]. In existing technological mediation (tabletops), tangibles tend to represent predefined meanings or functionality.

1.2. Representation

Within embodied approaches to HCI, and in the existing body of work, a core issue pertains to the role of *representation*. In tangible- and tabletop-interaction designs, physical objects, visual information on or around objects, as well as interactive behaviour of such objects (e.g., flashing led-light, sounds), are primarily used as re-presentations of digital information. Hereby, the digital information in itself is also a re-presentation: it often represents the insights and ideas generated by the participants: the 'results' [10]. Or, in other cases [17], it re-presents the prior knowledge given as 'input' to the collaborative process, as it is. Representing this information on a public workspace was expected to help people to associate further on the ideas of others, to combine ideas and knowledge into new ideas, to express one's own ideas and then communicate them, by means of its external representation, to others, and so on.

Such traditional interactive systems are representational through and through. The users of these systems are understood as cognisers: In the cognivist perspective on sensemaking, representation forms the basis of how insight is created and stored in the minds of individual users [11]. Likewise, representational messages (whether verbal, text or image) are the means by which insights get communicated between users. The task of reaching a shared understanding is regarded as an information processing task, and the system is assumed to have an information processing role: it functions to store, process and represent information to and from the user and to enable the exchange of messages between users.

1.3. Embodiment

We approach the design of interactive tools supporting multi-stakeholder collaboration from an embodied perspective. In our work, we build on embodied cognition theory, which takes an enactive view of cognition [4, 15, 25, 26]. Cognition does not happen solely in our brain, but is an emergent property of our active body as it is interacting with the world. We perceive and make sense of the world by interacting in and with it using our sensorimotor skills in active, ongoing and coupled processes of action and perception [26].

The social- and physical-*context* in which interaction takes place partakes in embodied processes of sensemaking, as socially situated practice theory investigates [24]. Suchman [24] argues that people's actions are not pre-planned in their minds, but rather actions are improvised achievements guided by the material and social circumstances: situated action. More specifically, Suchman argues that face-to-face communication and collaboration activities are fundamental for sensemaking. Suchman [24] explains how people inter-subjectively construct knowledge, in the physical world as well as in social situations, and how physical artefacts play a binding role in how people create shared insight together, in action. As every person has different bodies, experiences and skills, interpretations greatly vary amongst different people. Therefore, a rich respectful exchange of perspectives is necessary to reach participatory sensemaking; people influence each other's individual sensemaking and generate meaning in social interaction [15].

Based on the work of Suchman [24], De Jaegher and Di Paolo [15] and others [13], we regard technological artefacts first and foremost as a collection of publicly available objects that play a coupling role in skilled embodied manipulation and situated social coordination [7, 15, 19, 24].

1.4. Sensemaking

De Jaegher and Di Paolo [15] extend embodied cognition to the social domain: they take an enactive approach to social cognition. They explain that in social encounters meaning is generated in interaction between the actors. De Jaegher and Di Paolo [15] propose *participatory sensemaking*: 'the coordination of intentional activity in interaction, whereby individual sensemaking processes are affected and new domains of social sensemaking can be generated that were not available to each individual on her own' ([15], p. 497).

Joint meaning is generated between actors, in the *in-between*; it is not generated in each of their heads, as they cannot enter each other's heads. In the in-between, the interaction process itself becomes autonomous: it can change the actors [15]. In other words, when people interact in a social encounter, they generate meaning that could not have been generated by either person alone and cannot be attributed to either person; a truly new meaning emerges that can change them as persons.

1.5. Design challenge: Sensemaking and the role of representation

Our design challenge was to create a working system that would enable multi-stakeholders to constructively exchange their viewpoints on real-life public issues in their cities in multi-stakeholder consultation sessions. The topics for these sessions, public issues, would be contemporary, but not concrete: they would not be about public spaces, public services or city planning. Instead, the topics would be rather abstract: how should the municipality and citizens be able to make use of publicly available data or what is needed (from municipalities, citizens, housing corporations or SMEs) to support citizen initiatives?

With that question in mind, we embarked on a research-through-design (RtD) process that resulted in the design of [X]Changing Perspectives ([X]CP). It is an interactive system that enables up to 100 multi-stakeholders to discuss and exchange viewpoints on a public issue by (re)positioning tokens with symbols on top, on round high tables fitted that track the tokens' movements and visualise them on a screen in real-time.

As designers, we are inspired by embodied and participatory sensemaking theory. If the insight and ideas formed within a collaborative setting are not captured by and stored 'in representations', then the question rises whether we need any representational artefacts at all, in order to catalyse and sustain a participatory sensemaking process. Earlier work in embodied design [14, 23] shows that in design projects inspired by participatory and embodied sensemaking, representations do come into being in people's use of such designs. While iteratively exploring our design challenge, our design decisions were informed by the design context compromising theoretical principles for working principles. We found it was helpful to create some representational basic elements within the system, in order to support the sensemaking process and trigger interactions between the participants. Our intention is to address them as sensemakers rather than cognisers. In this chapter, we therefore raise the question: what *is* the role of representation in participatory sensemaking in collaborations?

We describe in what way the [X]CP system makes use of representations, tangibility and spatiality to stimulate participatory sensemaking in multi-stakeholder consultation settings.

We illustrate examples of participants' use of representation in our system and we use them to show (1) how the ground for these objects is non-representational in *what they do for* the participants in terms of participatory sensemaking and (2) how they are nonetheless representations. Through examples in our system, we elucidate what representations can actually do within an embodied, situated conception of participatory sensemaking in multi-stakeholder consultations.

2. Approach

Inspired by the theories outlined in the introduction, we designed [X]Changing Perspectives by taking a research-through-design (RtD) approach [18] . In an iterative design process, we developed low-fi and high-fi prototypes and deployed them in participant explorations in real-life multi-stakeholder settings. We gained insights through the materialising (prototyping) process: that forced us to make decisions: itself, but also through observations from participant explorations.

2.1. Research-through-design process

The concept of [X]CP arose in a cultural exchange of students in Sienna, informed by political history, cultural differences and the contemporary public issues in the city. A team of students and researchers designed Aesthetics of Politics [22], a tool that facilitates debate by writing down arguments on tokens and moving them around a central statement (**Figure 1**).

Inspired by the debating tool, the first prototype of [X]CP consisted of a Perspex board, flat writable circles and whiteboard markers. The concept remained similar, but this time, the participants wrote their challenge in the centre, not a statement, and the circles were meant to

Figure 1. RtD iterations of [X]changing perspectives: chronologically from left to right.

fulfil the challenge, or important milestones, or preconditions to fulfil it. The circles could be moved by dragging them with the markers, while simultaneously leaving a trace of the movement. In this way, the documentation of the discussion was made active (live) and analogue.

The exploration with users (multi-disciplinary neighbourhood professionals) showed that they used the traces of the pens to refer back to earlier moments in their conversation. Afterwards, however, the traces did not form a meaningful visual to them. The physical circles played a central role in sensemaking, as they invited participants to ask questions and to relate the different aspects (circles) to one another.

However, participants were hesitant to come up with new things to write down on the circles and the relative size of the board and circles did not allow for enough differentiation in positions of the circles.

These insights informed the third iteration of [X]CP, where we redesigned the circles into pillars (fitting better to the hand) with symbols (instead of blank canvasses) on top. Moreover, we scaled up from one Perspex board to 15 Perspex high tables, to be used by up to 100 participants in public consultation sessions. Participants could move the tokens on Perspex high tables, and the movements were tracked and visualised on a screen in real-time.

Participant explorations in nine real-life multi-stakeholder settings showed that the symbols triggered participants to share their primary associations and this started a lively exchange of viewpoints.

In the final iteration of [X]CP, we refined the prototypes and evaluated the system in a participant exploration with five tables.

In what follows, we describe the design's characteristics in relation to our theoretical frame as well as observations of the usage of the system in a real-life multi-stakeholder consultation session. We conclude with insights on the role of representation in designing for participatory sensemaking.

2.2. Design

Based on our theoretical frame, RtD iterations and earlier work [14], we designed the final version of [X]Changing Perspectives to invite embodied interactions in discussions between stakeholders with the aim of contributing to participatory sensemaking between them.

2.3. [X]changing perspectives system

[X]CP consists of a technological system, a moderation format and a service system. In this chapter, we focus on the usage of the technological system by multi-stakeholder participants, and do not describe the moderation or service around the system.

The technological system consists of 15 discussion tables with integrated camera tracking hardware and visual computing software, see **Figure 2**. On each table, there are six tokens that are identified by coloured LED light and a symbol on top (as in iteration 3), and are tracked by unique marker patterns on the bottom. The symbols, a bird, Euro sign, a gift box, a wound-up puppet, puzzle pieces and a clock with arrow, were inspired by literature on hurdles in citizen participation [5] but were not inscribed with specific meaning: on the contrary, they were intended to freely associate with.

Participants stand around the tables and discuss a central question, placed physically in the centre of the table. They do so by associating with the symbols on the tokens, and positioning the tokens in a meaningful place on the table, creating a shared *landscape* of meaning generated on the spot. Intentionally, neither symbols nor tokens or table surface positions have pre-defined meanings or terms of use: the participants at each table generate their own meaningful use of the objects. The symbols can be used to associate *content* with tokens and the table surface can be used as a *scale of importance*, where the most important tokens are placed in the middle and others in the periphery, or where the periphery can be used to place pre-conditions for the tokens placed in the inner ring.

While positioning and repositioning, stakeholders exchange different associations and together generate and reshape meanings of the tokens.

The tokens' (marker) positions are tracked by the tables and represented in real-time on a big projected data visualisation. The visualisation shows a helicopter view of the movements of all tokens at all tables and allows filtering between them, to discover patterns in movements, relative distances, centrality on the table or amount of touches. By showing alternative views

Figure 2. Elements of the [X]CP system, f.l.t.r.: real-time visualisation, table with tokens, symbols on tokens, tracking hardware and token hardware.

of—and relations between—all the table landscapes, the visualisation aims to support a collective reflection between participants of different tables. The visualisation alone does not represent the meaning generated at each table: the meaning forms in-between the participants and as such cannot be captured by the visualisation. Instead, the visualisation is intended to provide a mirror and trigger reflection between table groups.

The role of representational elements in our system is to invite interpretations and associations, rather than to express predefined, instilled meaning.

3. Participant exploration

The [X]CP system was developed in three research through design iterations in which we meticulously tested the technological functionality and evaluated the interaction and usage patterns in participant explorations in nine real-life multi-stakeholder sessions. Implementing insights from each iteration, it was recently prototyped as high-fidelity final design. At the time of writing, we have had the opportunity to implement the final system in one real-life context. In this section, we describe the context, set-up and findings of this first participant exploration with the latest prototype of [X]Changing Perspectives.

3.1. Context

The session was part of a congress about the increasing availability and usage of data for Dutch municipalities. The total of 30 attendees consisted of alderman, civil servants, policy makers, members of the city council and entrepreneurs. The central question was: 'what is needed in order for the data-driven municipality to work in a good way?'

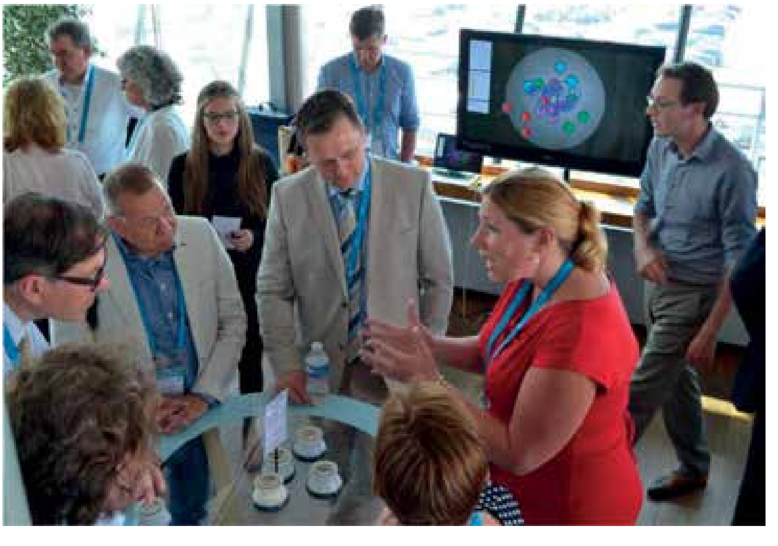

Figure 3. Partial overview of session set-up.

With the exception of entrepreneurs, all participants worked in municipal institutions. Even though they had different stakes in the discussion, this was an important limitation in participant composition.

3.2. Set-up

The session consisted of five tables and the participants were distributed over the tables so that there were six participants (unacquainted with each other) with different stakeholder roles at each table. The session lasted 50 min: two discussion rounds of 15 min separated by a collective reflection of 10 min. A wrap-up of 5 min concluded the session (**Figure 3**).

4. Observations

Substantiated by patterns in observations of earlier sessions, we use examples of the latest participant exploration to illustrate our observations on the role of representations of the [X] CP system in sensemaking processes between multi-stakeholder participants. We describe our observations in three categories: the interactions invited by the representational elements of symbols (1), tokens (2) and visualisation (3).

4.1. Symbols

In this section, we highlight some observations that elucidate the role of the symbols in participatory sensemaking during the use of the [X]CP system.

4.1.1. Symbols trigger primary associations and open inquiry into differences

It was easy for participants to associate with the symbols: they shared their primary associations with the symbols, which was often telling for their viewpoint or background. For example, participant A (entrepreneur) placed the bird-token in the centre for 'citizens' autonomy over own data, see **Figure 1**, and participant B (alderman) reacted 'oh, it's funny you said that because I would place it in the centre too, but to me it stands for overview: I think that we [municipality] should monitor the data that we have of the city'. Afterwards, another participant joined in by placing a new token on the table and relating it to the first two interpretations. As the tokens were repositioned, the conversation evolved and their meaning evolved (**Figures 4** and **5**).

In this example, the symbols were used for associating, and at first instance, represented something unique for each of the participants. One striking observation was that symbols functioned as social mediators offering a non-offensive motive to question each other without eliciting a defensive response: indeed, using the symbols as 'neutral' objects, people could attend to helped to catalyse an ongoing exchange of associative conversation in which different perspectives, personal experiences, anecdotes and ways of reasoning were shared, something that participants told us does not usually happen in such settings.

Figure 4. Participants discuss the firstplaced token.

Figure 5. Participant C pointing at the 'last' token.

4.1.2. Symbols carry dynamic attributed meaning, constantly altered through interactions

After the placement of a first token, the other participants joined in and shared their associations, sometimes adding other tokens to the table. The different associations with symbols were the beginning of a participatory sensemaking process wherein different *meanings and relations* were discussed and changed on-the-fly. For example, the symbols turned out to be used as on-the-fly generated representations of *values, bottlenecks or goals*. Meanings changed *while interacting* physically with other tokens (repositioning) and other symbols (pointing, *orienting other agents attention* [13]) to compare their meanings. In doing so, the participants generated new meaning together.

4.2. Tokens

In this section, we highlight some observations that elucidate the role of the symbols and token in participatory sensemaking during the use of the [X]CP system.

4.2.1. Tokens allow for intuitive expressions

For example, on one of the tables, five of the six tokens were positioned and one was left on the side. When the moderator announced that there was only 1 min left, the untouched token gained an interesting role. Participant A said to her table: 'OK we should add the puzzle piece!'. 'Why then?' asked participant B. Participant A, humorously: 'Because we do not want to leave it alone and exclude it, it would be sad… and-'. All laughed and then participant C stepped in: 'actually, for the puzzle piece, you know that when you put tech-guys together (…)' and he enriches their landscape with a new relevant meaning, that was only possible because the neglect of the token was physically visible—its physical distance to the other tokens bothered participant A. In other words, the physicality of the token invited to share a feeling, a line of thought that may have not been shared otherwise.

The physical presence of the tokens changes *the way of interacting* with each other. Intuitive expressions come to the fore, verbally, when moving them physically. Body language seems to be amplified, as the tokens afford different interactions that could communicate something to the other participations. Three examples of such communications were: (1) gesturing around tokens to indicate their preciousness or (2) tapping on the tokens to highlight their importance or to communicate that they should be related to the current conversation topic or (3) ticking or drumming around the token on the table surface to communicate one's interest to speak next (**Figures 6** and **7**).

4.2.2. Tokens lead to relations between discussed elements (multidimensional image)

The physicality of the tokens also means that they are physically positioned 'in space', on the table surface. Naturally, after symbols were given meaning, the connections between tokens were discussed: where should it be placed, closest to which other token, or how does one relate to the other?

The meanings were not limited to definitions of symbols; instead, they were narratives of arguments, anecdotes and interests that were brought to the table by all participants. The eclectic or even conflicting input was not brought to a 'safe middle way' or consensus; instead, the input was tied together as a story, supported by the physical token positions in space, the invisible *traces* on the table that the visualisation made visible through the digital representation of movements.

Figure 6. Pointing and repositioning a token to relate it to the others.

Figure 7. The visualisation is used to reflect across tables.

This was evident during the collective reflections, in which participants explained their landscape as a holistic story, of which the separate elements or symbol meanings *could not be attributed to any participant alone* anymore; they had emerged *in the interactions between* the participants. Moreover, the symbols functioned not only as external placeholders/representations of one (shared) meaning, but were continuously altered through ongoing interactions and in relation to other tokens.

4.3. Visualisation

In this section, we highlight some observations that elucidate the role of the visualisation in participatory sensemaking during the use of the [X]CP system.

4.3.1. Visualisation invites taking a new perspective

By showing the same view of all tables, the visualisation (**Figure 5**) enables the participants to relate their landscape to that of others. Initially in the collective reflection phase, participants were excited to see what the 'technology' would show them. Soon, however, they realised that without participant's explanations, the visualisation had no meaning at all. Together, the moderator and participants could discover patterns in movements of specific tokens but what could those movements mean? The moderator invited several tables to explain their landscapes, to give meaning to the visual representation on the screen. Participants were very curious to hear the stories and generated meanings of the other tables' landscapes. Moreover, they reacted to the explanations when a statement was made that connected to their discussion by giving a shout-out to share their views on it.

5. Reflections

Our observations of interactions with the [X]Changing Perspectives system shed light on several roles that the representations played in participatory sensemaking processes. Perhaps, somewhat contrary to our initial focus designing for the non-representational aspects of interaction, reflecting on the design case brings forward that representations have an important role to play in participatory sensemaking. However, observations show that representing information is not the *primary* function of the table—what we see is that representation forms an added 'scaffolding' layer that enhances the capacity of people to engage in a face-to-face, situated process of participatory sensemaking (see [11, 21] for related views). The representations we used mostly function to provide:

1. a layer of playfulness that breaks the ice;
2. a layer of associations that structures interactions while leaving open interpretations: 'social-embodied scaffolds'; and
3. (tactile as well as digital) visualisations of conflicting interests that make them discussable.

As our design was the vehicle that allowed us to observe the interactions, we are able to move beyond the description our intentions (as we did in the beginning of this chapter) toward pointing to the characteristics of the representations that supported the sensemaking processes in our design case. Our main reflection is that the [X]Changing Perspectives system provided a scaffolding structure for sensemaking, and to allow this we needed a careful balance between 'structuring' representations with open interpretations (point 2 in the list above). For example, the symbols triggered primary responses (*structuring* the interactions) from participants, disarming them, taking people out of their 'labelled' role and engaging them as whole person, with experiences, emotions and creativity next to expertise. The symbols, however, were *not pre-defined (open interpretations)*: they were asked to be interpreted by the participants. The same applies to the table surface: it provides structure in the sense that it frames a circular area, and it defines the proximity of participants standing around it, but it does not provide a structure for positioning tokens. At the same time, it does imply a structure due to the central question placement.

Reflecting on those examples, we regard the value of representations for participatory sensemaking processes to be in the balance of providing representational elements such as structure, while at the same time leaving open what they stand for and how they could be used.

The role of representations in collaborative sensemaking is especially interesting in the context of multi-stakeholder collaborations and consultations regarding public issues. Namely, in this context, the topics are often highly abstract, formal, and relate to different disciplinary expertise as well as corporate interests and different emotional or otherwise engaged interests. Structuring the dynamics between these interests in relation to an abstract topic is a complex task. The [X]Changing Perspectives system demonstrated that representations as social-embodied scaffolds can make (open-up) embodied, intuitive and personal interactions (leading to participatory sensemaking, to the shared generation of new understanding of the topic) approachable without resulting in discomfort, conflict or abstract meta-discussions.

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Design for the Next: Integration of Path to Sustained Usage Model into Design Process

Armağan Karahanoğlu and Yekta Bakırlıoğlu

Additional information is available at the end of the chapter

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Abstract

The aim of this chapter is to evaluate and further discuss the integration of the "Path to Sustained Usage" model into design process. To achieve this, this chapter explains the details and the outcomes of Engage! Workshop in which the model was tested with "backwards-designing" approach. The paper ends with further suggestions for application of the model into design process.

Keywords: path to sustained usage, long term user experience, user experience, technological products, workshop

1. Introduction

There are several models and perspectives in user experience literature that explore people's long-term experience of a particular system, product or technology [1–4]. In one of these models, Karapanos et al. [3] explored the temporality of experience by defining three phases of experience in which user (i) gets familiar with the product; (ii) explore the product more, and (iii) makes the product part of everyday life. In another framework, the "pre-interaction" phase also comes into prominence as users' perceptions and expectations also affect the way the product is experienced [5].

On the other hand, designing for experience is a challenge for designers. During this complicated, iterative and creative process [6–8], designers confront several user and product-related problems [9]. In the early stages of this process, several methods, such as personas and user journey maps, can be applied to comprehend the users' experience [10, 11]. However, other inspirational tools and methods are still required in this process [12]. While there are several tools and techniques suggested for designing for user experience [13], tools and techniques especially designing for long-term experience of users are limited [14]. Therefore, after exploring long-term experience of technological products, through user research we first developed a four-stage model [15]. This model (**Figure 1**) brings together affected human-related qualities and affecting product qualities at every use phase (i.e., before acquiring, learning, mastery and post-mastery). The purpose of the model is to develop technological design solutions which will end up in sustained usage that people will keep using for a long period.

In this model, *path dependency* refers to feeling dependent to previously used products. This dependency affects the experience of new products as users expect the new product to have several qualities of previously used products. *Learning phase* of the product is about exploring and understanding the qualities and capabilities of the new product. At this phase, users get *familiar* with the new product and *adapt* to the qualities of it. In *mastery phase*, users make a decision on whether they want to continue using the product or quit using it. For technological products, this decision is made through the abilities of the product (1) to *change* existing *habits*, (2) to be used in *different contexts*, and (3) to become a routine part of everyday practices (i.e., *habitualization*). Finally, at the *post-mastery* phase, product becomes indispensable to the user (i.e., *sustained usage*) until the user finds a new product that satisfies emerging needs and preferences. The end of this phase intrinsically becomes the *path dependency* of the next product. For more information, see [15].

With the definition of these phases and by considering the current debate in design community, we conducted a design workshop study in which we investigated the usage of "backwards designing" approach to integrate "Path to Sustained Usage" model into design process. Thus, the aim of this chapter is to first discuss the outcomes of the ENGAGE! Workshop, and further discuss the possibilities of integrating our model into design process.

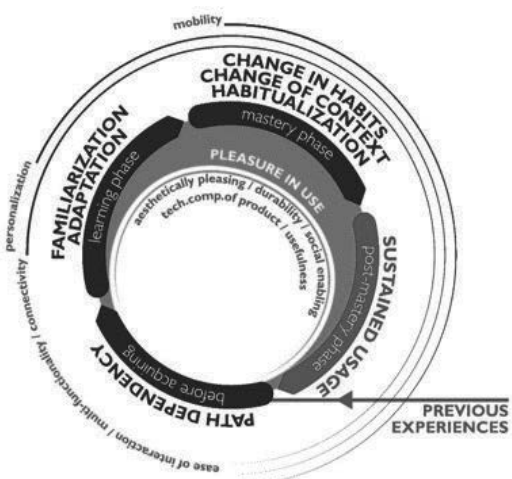

Figure 1. Path to Sustained Usage Model (retrieved from Bogazpınar et al. [15]).

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2. Engage workshop

We undertook an investigation into how the Path to Sustained Usage model can be employed as an idea generation method in design process. To achieve this, we defined a set of criteria to go through the phases of the model. Naming the workshop "ENGAGE!", we structured the idea generation workshop with 19 industrial design bachelor students. One month prior to the workshop, we published an online invitation for the 3rd and 4th year industrial design students to participate in the workshop. In total, we have selected 20 participants out of 27 applications, one of which had dropped out before the workshop. One week prior to the workshop, we sent an email to the participants to inform them about the workshop process with detailed instructions of the user study that we expected them to conduct before coming to the workshop.

On the day of the workshop, after 30-minutes briefing about the workshop process, the students were introduced the details of the Path to Sustained Usage model. Following that, the students were formed into the groups of 4 in relation to the technological products to be designed. With these groups, the Engage workshop took about 6 hours in total with a final presentation and discussion of the workshop outcomes.

During the workshop, we applied the "backwards-designing" process in which we asked students to start designing the final product without thinking of the applicability of technology. Within this process, participants started the design process from the "post-mastery" phase and then, continued their design process backwards by considering the product features that we listed in our model, from post-mastery to before acquiring. The aim of applying "backwards-designing" process was to help the participants break free from the current technology and develop possible future design solutions (i.e., the next product/experience). By following the backwards design process, the participants made associations with the currently available products and designed the path towards the new experience and its sustained usage.

We spared 1 hour for each phase (i.e., post-mastery, mastery, learning and before acquiring) during the workshop. At the beginning of each hour, the groups were informed about the aim and focus of designing for the phase. Through discussions, group members first decided how to implement the human-related and product-related qualities defined for each phase to the product they are designing. For instance, when designing for path-dependency phase, participants considered the qualities that could be adopted from similar products that could break the users' dependency to previous products. Following this discussion, participants made visualizations and mock-ups for further developing the product. The discussions and brainstorming followed on until the end of final visualization of the product.

3. Results

Five groups of participants developed five different design solutions during the workshop. The solutions were smart (i) sports watch, (ii) cam, (iii) screen, (iv) children's watch and

(v) earphones (**Figure 2**). All these initial design ideas were extremely detailed as the participants dwelled upon all the aspects of our model and developed usage paths to adopt and to use for a long period of time. Hence, in this chapter, we will follow upon the backwards designing process of one of the outcomes (i.e., SmartScreen) to present the kind of outcomes to be expected from ENGAGE-Path to Sustained Usage Workshop. Here, it should be stated that the participants were free to define what the next product would be. Also they were allowed to make iterations of visual and interactive qualities of the products throughout the design process in relation to the human-related and product-related qualities listed for each phase.

3.1. Stage 4: designing the post-mastery phase

In this stage, the participants were expected to come up with a design idea for the "next" product and the way it is going to be used after a potential user learns and masters its features. This is the stage where designers sketch out the intended use for their technological product, and how it will have been integrated into users' lives. At this stage, the groups utilized the knowledge they gathered from the initial field work (i.e., interviews with users) to understand users' needs, expectations and desires.

For the SmartScreen design solution, the participants preferred to develop a Persona to map out potential users of their products and decided upon the necessary features for the next home entertainment system. The persona they developed was someone working in a creative work, who values his/her independence, rather nomadic and enthusiastic about trying new things. Through the utilization of this persona and the knowledge they gained from the field work, the participants interrogated possible features of such a home entertainment system and tried to foresee the context it will be used in. The sketches drawn on large post-it notepapers in **Figure 3** show the initial interaction details between the user and the product which helped to develop the spherical form as well.

It should be noted that, although participants were generating an idea for the final stage of our experience model, it was only the first step of the ENGAGE workshop. At this point, the ideas were initial and the details developed were vague. The final design solution and other elements of the long-term experience are detailed in the coming steps of the workshop.

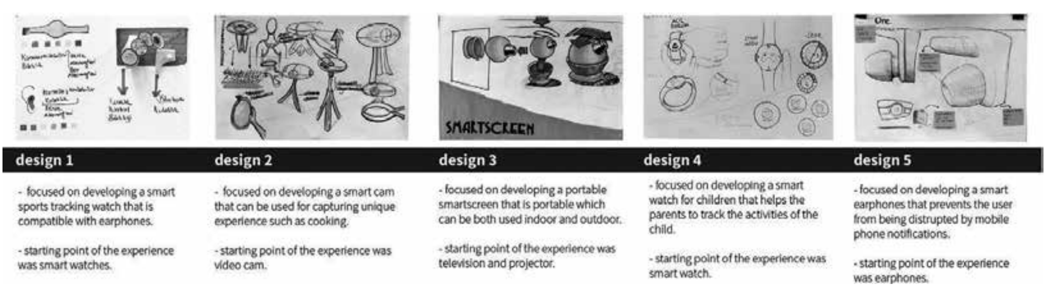

Figure 2. Summary of workshop outcomes.

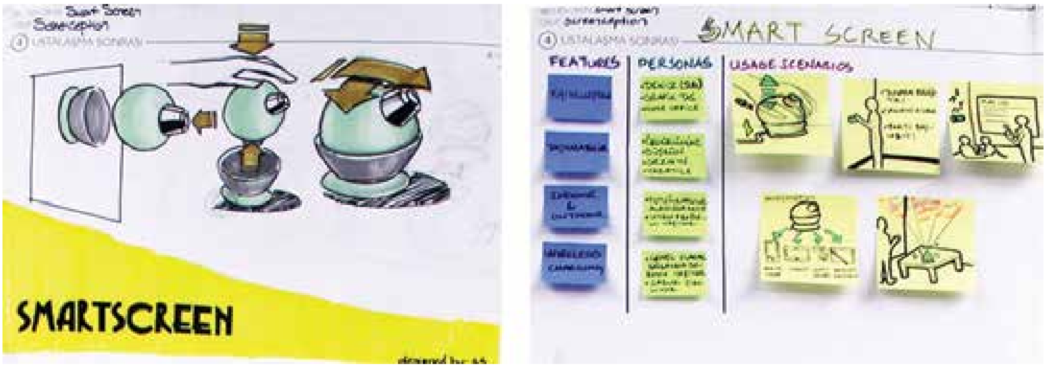

Figure 3. Sketches for the post-mastery stage (developed by Groups 2).

3.2. Stage 3: designing the mastery phase

In the second stage of the workshop, groups were expected to extend the product idea by considering the product and human-related qualities of "mastery phase." At this stage, students both did sketches (**Figure 4**) and early mock-ups (**Figure 5**) to improve the *interaction* between the user and the product. With the mock-ups, participants elaborated on how the product will be interacted. At this stage, they also searched for the product qualities that would help the user to understand the interaction of the product better and achieve the integration of product into users' lives (i.e., *habitualization*) through *ease of interaction.*

At this stage, participants were informed that mastery phase is the one that users make a decision to accept or reject the product to be a part of their life. The product features such as *personalization* and *mobility* are listed as the important factors of product acceptance. Therefore, the groups pursued for additional product features facilitate the user to personalize and mobilize the product. They also put extra effort to understand how the product will *change users' habits* with new product features (left end side of **Figure 6**). Developing upon the assessment of possible *changes in habits* and figuring out how it is related to *changing*

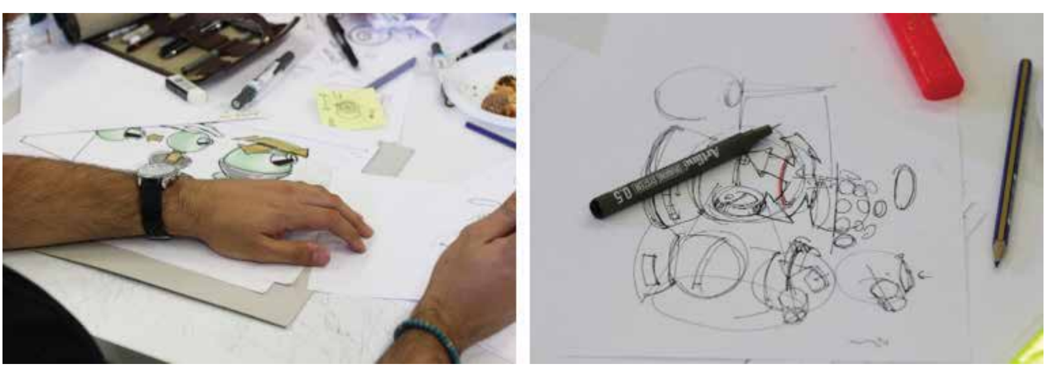

Figure 4. Sketches for the mastery phase for SmartScreen (developed by Group 2).

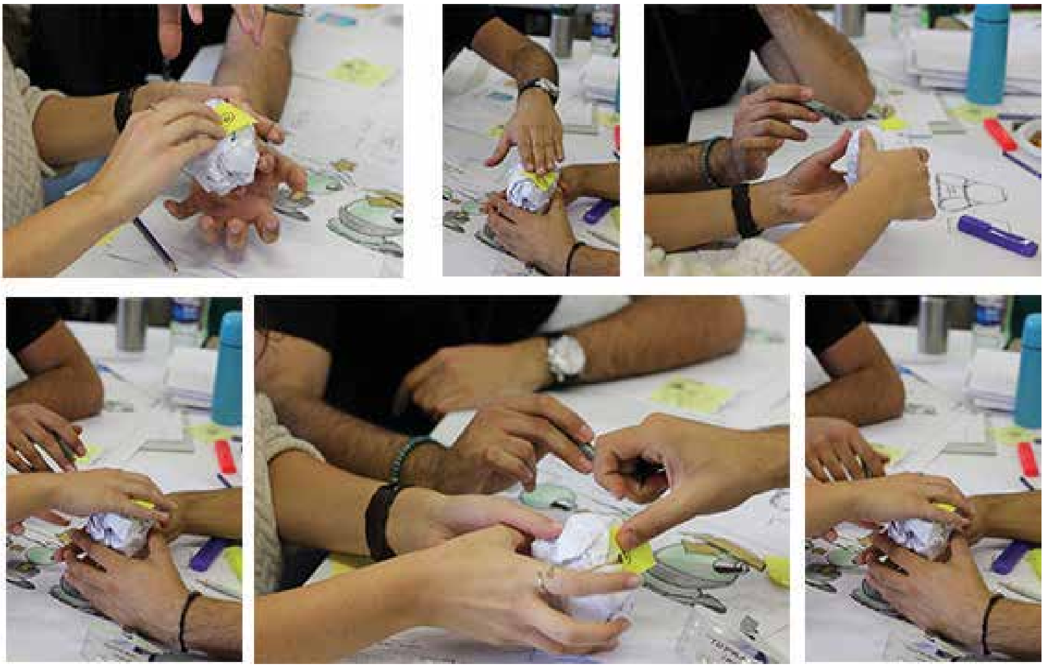

Figure 5. Mock-ups for the mastery phase for SmartScreen (developed by Group 2).

contexts, also considering that the persona they have created is enthusiastic about creating new things, participants added "customized kit" idea to the product to facilitate the user with the ability of buying extra kits in relation to their changing personal interests. They have selected three key functionalities to develop specialized parts, namely a projector, a high-power speaker and a motion sensor. These specialized parts are offered in various combinations to respond to people's needs and expectations, as illustrated on the right end side of **Figure 6**. Furthermore, the spherical parts were designed to be taken out of their stands and placed in different rooms or outdoor settings to provide their functionality in various contexts.

At this stage, the participants also inquired into advanced interactions by considering the change in the context and habits of the user. These included products giving haptic and audio feedback to inform the user about the interactions (e.g., buzzing, clicking sounds and even playing recorded information). The interaction ideas that the participants came up with at this stage were also additionally explored in designing the learning phase.

3.3. Stage 2: designing the learning phase

The interactions that the participants explored in this stage aimed to help users understand how the product works through *familiarization* and *adaptation*. As affecting product qualities, *connectivity*, *multi-functionality* and *ease of interaction* comes to fore. For the SmartScreen, participants focused on four interactions as turning on and off the device,

Figure 6. Visualization of mastery phase for SmartScreen (developed by Group 2).

initiating the functions, making the adjustments and charging (**Figure 7**). These interactions were actually considered by the participants as the "initial interactions" with the product after the purchase.

The participants also reviewed the product-product interactions that affect the users' interaction through using the product for different purposes (i.e., multi-functionality). On the right end side of **Figure 7**, the other products are depicted as laptops, smartphones and tablets, which connect with the SmartScreen to provide content. *Connectivity* and *ease of interaction* are crucial for the learning phase, as the new product is introduced into a context of other products the user owns, and the connectivity is essential to create a "fitting" product experience. And, if such *connectivity* is established, the user can use the product for various purposes. For this purpose, participants thought of an auto-on function, in which case the projector turns on as soon as a smartphone or a tablet is in its vicinity, and an app to control the SmartScreen is launched automatically.

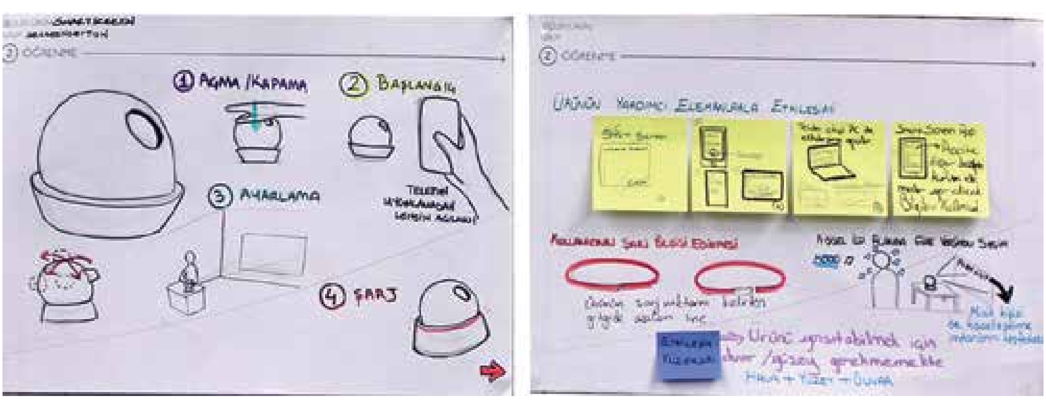

Figure 7. Visualization of learning phase for SmartScreen (developed by Group 2).

3.4. Stage 1: designing the before acquiring phase

Before acquiring is the initial stage of user experience, which is heavily influenced by *path dependency*: a kind of loyalty to their previous experience with similar products. Hence, this stage requires an understanding of the previous products and use experiences, which—if any—of the product qualities should be transferred and how. Only through such an assessment, the "next" product (in this case, SmartScreen) can be adopted by users.

Figure 8 presents an analysis of products by participants that are defined as predecessors of the SmartScreen (i.e., television, Apple TV, Smart TVs and projectors). During this assessment, they highly used the knowledge they gained from the field research. Through this assessment, they have defined *connectivity*, *being stand-alone* and *personalization* as key product qualities, which are also transferred to the SmartScreen. They referred to the results of their field research and their personas, and defined *mobility* as an important product quality. It was because, the users of this new system will like to travel a lot and would like to carry this multifunctional product wherever they go. This was stated as an essential way to break *path dependency* to previous products.

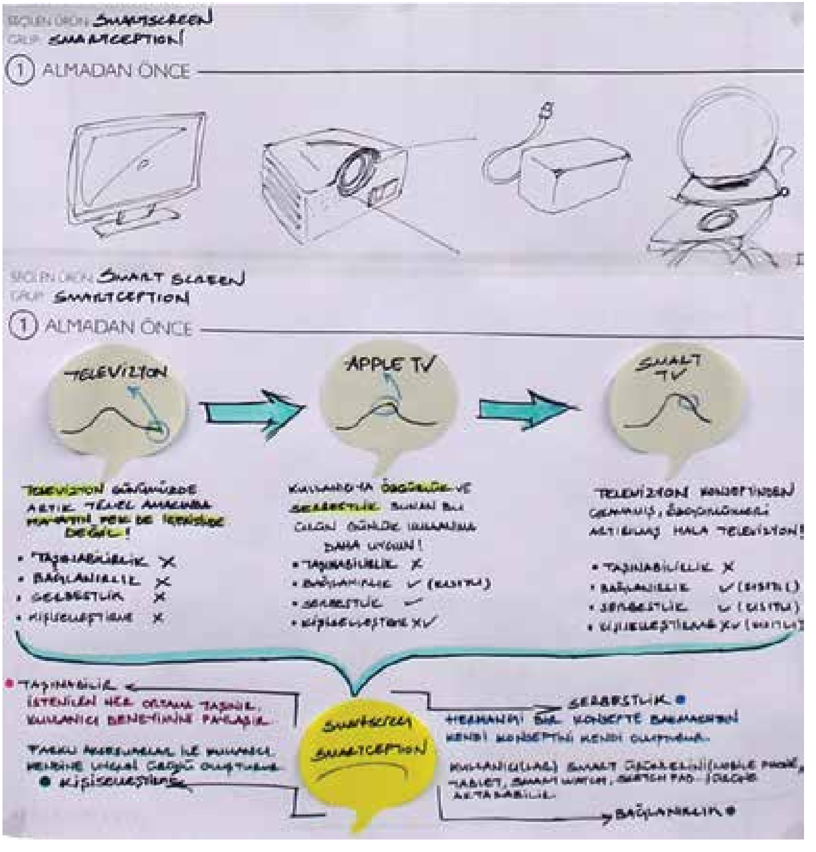

Figure 8. Visualization of before acquiring phase for SmartScreen (developed by Group 2).

4. Discussions

As stated, designing for experience is a complex task and requires tools and techniques to support the designers in this process and [10, 11]. With this vision, we designed the ENGAGE! Workshop with an aim of integrating the Path to Sustained Usage model into the idea generation phase of the design process. The results were two-fold: on one hand, we were able to assess if the model could be integrated into the design process, and on the other hand, we were able to try out a new tool (i.e., backwards designing) to help designers imagine the next product. The outcomes of the workshop showed that both the human-related and product-related qualities we listed in the model and "backwards-designing" method were complementary and guided the participants in this task. We observed that with the guidelines we provided, the participants were able to develop very detailed product ideas in a short time. It was because the workshop we designed for the effective usage of the model associated the participants with a systematic approach at every stage.

There can also be drawbacks of designing a model. For instance, as seen in **Figure 8**, participants used the before acquiring phase as a phase for self-assessment rather than further development of the product. The participants conferred to the products that can be the predecessors of their design just to check whether it can break path dependency through the product qualities they employed. In addition, we were expecting the participants to come up with more advanced interaction suggestions than the participants listed at the learning phase.

However, starting the design process from the "post-mastery" phase and designing "backwards," prevented the participants from setting personal mental blocks that might restrict them from thinking "out of the box." On the other hand, the qualities that are listed at every phase of the model helped the participants to focus on the design process better. By trying to cover all the product qualities, in the end, the participants were able to associate the outcomes of the design process with the technological products that users currently use.

5. Conclusions

In this chapter, we have explained and discussed the outcomes of the first design workshop that we conducted to integrate "Path to Sustained Usage" model into the idea generation phase of the design process of technological products. We applied the "backwards-designing" method in which we asked the participants to start designing the "next" technological product without taking the boundaries of current technology into account. The participants were asked to further develop their products—to design the path to the sustained usage of their solutions—by considering the human and product-related qualities we provided for each phase of the long-term experience of technological products.

Our study revealed that the participants of the workshop were confident with design of the model we developed, especially with the backwards-designing method. This process assisted the participants in the sense that they did not have to consider the feasibility of the product. As the participants were totally free in defining the next product, design criteria were created by the participants themselves. Our model and backwards design process were just a guidance for them throughout this process. We believe that this process can better help the companies to design and develop products to be produced in the following 5 years.

With the learnings from the participants of this workshop, we will further develop the backwards designing process. For further studies, we plan to further investigate this process in detail by researching upon how designers can benefit from it for specific consumer products with futuristic scenarios.

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Chapter 23

Unveiling the Expressivity of Complexity: Drifting in Design Research

Jeroen Peeters, Stoffel Kuenen and Ambra Trotto

Additional information is available at the end of the chapter

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Abstract

Design research is regarded to be a mode of inquiry particularly suited to engage with complex topics. In our work, we are interested in unpacking the complexity at the heart of an embodied aesthetic experience. In this article, through our digital and physical artefacts and a methodological reflection, we illustrate an ongoing design research project that a multi-disciplinary team of interaction designers, professional dancers, software developers, artists and 3D modelling experts are carrying out to develop insights on how to understand this complexity and how to use such insights as inspiration for interaction design-related projects. By embracing combinations of design, new technologies and simple visualisation tools, the project investigates the complex and hidden expressivity embedded in the skills of dancers in a programmatic design research approach. This investigation leads to insights on different levels. Firstly, cycles of formulation, realisation and reflection on design programs express parts of this complexity and this lets new research interests emerge. Secondly, as a body of work, reflecting on these cycles exposes how our "drifting" within this programmatic approach has started to unveil the complexities inherent in our research program. In this article we aim at contributing to the growing understanding of what designerly ways of knowing might be and how a practice aimed at expanding and contributing such knowledge unfolds.

Keywords: constructive design research, drifting, embodiment, aesthetics, complexity

1. Introduction

Our approach is based on constructive design research [1]: research based on design action that builds things, with some form of reflection or evaluation on that action that generates knowledge. In previous work [2, 3], we employed this approach to design and build prototypes aimed at articulating how certain qualities may elicit an engaging aesthetic experience in interaction. In the project presented in this publication, we employ a similar designerly approach in a different way. Instead of developing and implementing our understanding of qualities in designing *for* an aesthetic experience, our intention here could be considered the opposite. Here, we aim to use our skills, interests and technologies to design *from* an experience—defined by the whole of its aesthetic qualities—in order to gain access to its complexity by expressing and amplifying the qualities we find in it.

The qualities of the dancers' experience are revealed in this process through cycles of reflection-on-action, where the action is constituted by different ways of making elements of the dance explicit and the reflection happen as a joint dialogue between designers and dancers. Such qualities are subsequently explored through several individual design research projects, in which we transpose them into other instances, where design becomes a tool to better understand them. These design projects follow several different avenues of exploration, with different design teams, within different contexts, and they exist in varying states of completion. We ask the reader to bear with us, since we will explain in detail and with clear examples, what we just mentioned in a generalised way.

We report on intermediate results of the project here because we believe they are valuable to the Interaction Design Research community on two levels: firstly, the various avenues of exploration that have emerged form a palette of different opportunities in which an embodied perspective on the aesthetic experience can become relevant in other design projects. In this sense, what has emerged from these different individual projects so far is not a knowledge contribution per se. It rather constitutes emergent design programs that are being further developed in parallel. This palette of opportunities is illustrated in the fourth section of this paper.

Our focus, in this publication, is thus less directed towards the knowledge of aesthetic or movement qualities that these individual projects have generated (or are generating) as isolated studies. Our main intention is to present a wider view, to frame and place these projects from a methodological perspective: as a body of work that explores the complexity of experience in dance through design. As a body of work, this brings about new design programs. The overarching project, in its current state, offers an opportunity to be used as a research vehicle to expose and reflect on our programmatic design research approach, that is, investigating the complexity of experiences. The work provides different perspectives on this complexity when framed as a programmatic design research approach. In reflecting on the program/experiment dialectics [4] that guided this research project, we aim to contribute to the growing understanding of what designerly ways of knowing [5, 6] might be. Or, more particularly, what ways of *drifting* there might be in design research [7, 8] and how a practice aimed at expanding and contributing such knowledge unfolds.

2. Related work and scope

Building on an embodied perspective [9] the importance of movement for interaction design is clear and the community has produced a variety of different approaches, methods and tools to develop this importance. In particular, many approaches and methods have been developed to use dance, as a way of moving that is expressive and has aesthetic qualities, in embodied interaction design research (e.g. [10–13]). Instances of work more directly related to our research program here are projects by Silang Maranan et al. [14] and Alaoui et al. [15] that also aimed at visualising and understanding the qualities of movement in dance using interactive technologies. Other related works that capture, translate and transpose qualities from movement into visualisations or materialisations, include both artistic (e.g. [16–18]) and academic (e.g. [19]) projects. Similar to this work, our intention in this research program is to use our design skills to create prototypes that emphasise and amplify the qualities hidden within the complexity of dance.

Similar to our other design research work, this program builds on theoretical foundations that include ecological perception [20], phenomenology [21] and embodied cognition [22]. These foundations share a notion of embodiment: we experience and make sense of the world subjectively, through our bodies, by acting in the world. Meaning is released in dialogue and so our experiences become ungraspable, ephemeral and dynamic. A phenomenological and embodied perspective on our experiences with the world thus stresses the inherent complexity of such experiences. In this publication we aim at exposing how our *drifting* has started to unveil the complexities inherent in this research program.

3. Methodological framing

Since Frayling [23] coined the term *Research through Design*, many scholarly efforts have been made to articulate methodologies, strategies and approaches as to how this form of research can generate knowledge. Koskinen et al. [1] aimed at specifying such ideas further, proposing the notion of *constructive design research*, where the construction of artefacts or interventions takes centre stage as the source of new knowledge.

A particular approach to articulating how knowledge may be generated within such a research endeavour is *programmatic design research* [24]. The program in this case is a provisional knowledge regime, a statement that acts as a lens through which to view the research interest. This statement proposes handles on how and where to start designing. An experiment then can be a designed artefact, intervention or even proposal, that brings (parts of) the program to expression. In a dialectic process, the researcher repositions herself between program and experiment: both program and experiment mutually influence and sharpen one another [4].

3.1. Research cycles

When we cast our own research work in a programmatic approach, we can make a distinction between the research program and the design program. The research program formulates an intention and area for an overarching research interest. Design programs are particular instances of that research program more directly related to the design experiments within a project. The research program for the projects presented in this publication is to use the forming language of design to amplify and express the (hidden) qualities and intentionality embedded in the skills of dancers. The research program is grounded in theory and practice: it builds on a embodied and phenomenological understanding of experience and points to a design space: expressing the qualities in dance. This design space is always in flux, as it is impossible to fully grasp. Yet, it can be seen as an encapsulation of complexity on a certain level of abstraction (see **Figure 1**).

From the research program, we can formulate a design program: the starting point of a design research project (see **Figure 2**). The design program provides a particular perspective on the design space providing handles on where and how to start designing. The design program is realised through design experiments (see **Figure 2**). The design experiment is engaging directly with the complexities of the design space. They extend outwards, towards abstraction, as they gain value in relation to the design program through reflections. Individual reflections exist on a certain level of abstraction but stay connected to particular experiments. Reflecting on these results in relation to the design and research program, allows for the formulation of a new

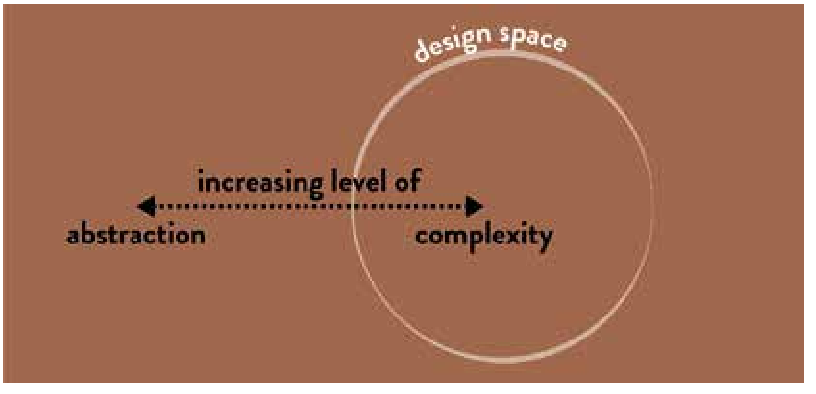

Figure 1. The design space as existing between increasing levels of abstraction and complexity: as a metaphor for the potential of possible designs, it is infinitely complex, as the subject of a research investigation it is limited by the particular design domain that is of interest.

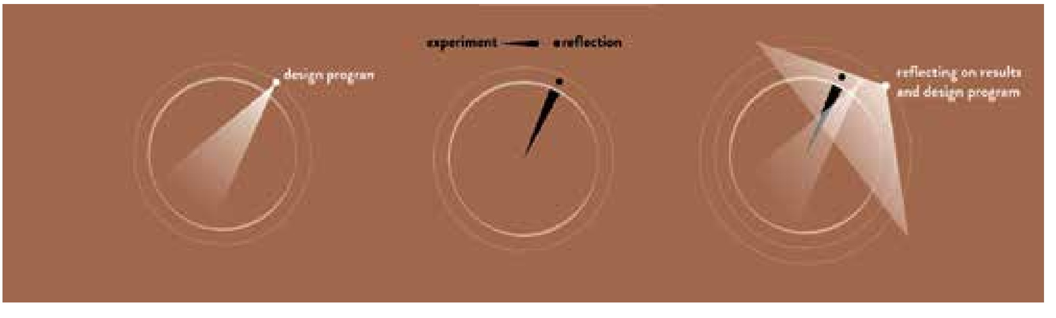

Figure 2. The three stages of a cycle: formulating a design program (left), realising the program through individual design experiments and reflecting on individual results (middle) and reflecting on the results and program (right) to gain a new perspective.

program. Cycles of formulation, realisation and reflection on design programs express parts of the complexity of the research topic and suggest where further expression can be found [25].

In this publication, we present and reflect on what we have learned about our research program using this approach. Our focus here is not on describing in detail the lessons learned from each individual cycle, nor on presenting a highly precise theoretical model describing all the complexities inherent to design research practice. Rather, our focus is on describing how each cycle influences the following cycles, thereby articulating how the body of work as a whole engages with the overarching research program in a complementary way. It is therefore important to note that the three-stage model of a cycle, introduced earlier in this section and presented in **Figure 2**, is intended merely to illustrate the dynamics of a constructive design research process. The position, size and form of the elements in the model should thus not be considered as formally accurate individually, but rather as relative to one another. For example, the design program (**Figure 2**, left) is a perspective on the design space and thus exists on the outside, looking in. However, the shape of this perspective (angle, width) in the illustration is arbitrary: the design space is an infinite domain of possible designs and the limits of a design program are inherently unknown before realisations are created. Similarly, it is difficult to accurately draw the shape and position of the new perspective one gains from reflecting on a cycle in the third stage (**Figure 2**, right). How this new perspective relates to the infinite possibilities of the design space, or the potential of a design program, is impossible to describe accurately. What we do know, is something about how this new perspective exists in relation to the graphical elements that describe stages 1 and 2. First, its position in relation to the design space is more abstract than that of the original design program, because it is a reflection on this program. Second, it casts a wider perspective on the design space as new insights of the possibilities inherent to this design space have emerged. And finally, that it is formed by, and thus overlaps with, the design program and experiment generated in stages 1 and 2.

3.2. Drift and stabilisation

This process is characterised by *drift* [4, 24]: as understanding of the research interest develop, one's perspective often shifts from its original position to a new one. It is what such drift exposes that we aim to address in this publication. In particular the work we present exemplifies a kind of mechanics—between research program and its series of heterogenous design explorations—that reveals while leaving complexity intact.

Several other scholarly efforts [7, 8] have been made that attempt to describe what this *drifting* is, how it may be controlled or steered and what its relation is to knowledge production. To describe drift in a design research process if fundamentally difficult, because it is often used as a general term to describe the many elements that form the ephemeral activity of designing. This includes the tacit and explicit knowledge that steer decisions [6, 26], intuition and skill of the designer [27], the personal agendas present in multi-disciplinary design teams [4], serendipity or even more banal issues such available resources. Nonetheless, we agree with others (see e.g. [8, 28]) that it is important for design researchers to attempt and articulate the process

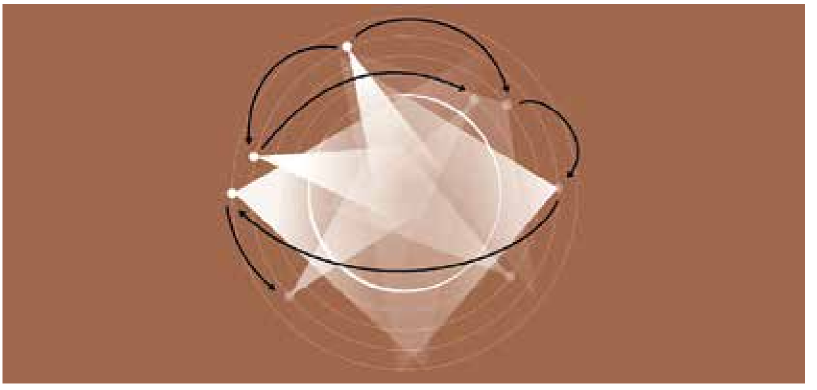

Figure 3. By articulating start and end stages of different cycles that explore the same topic, we can sketch how we drift from one perspective to another, and how these perspectives together express the complexity of the research topic.

of drifting, in order to better understand how design as an activity functions in generating knowledge.

What is easier to describe than the process of drifting and the factors and forces that influence it, are the moments of stabilisation: points where we are not synthesising different concerns through designing, but take a step back to relate what we have done to our research interest. Although these points are also certainly not accurate: they are to a certain extent post-rationalisations of a dynamic process. They serve as anchor points: moments where we state an intention (in the formulation of a design program) and moments of reflection (on realisations of that program). In describing and exposing our considerations, we can describe vectors that connect these perspectives on the design space and that allow us to sketch what happens as we drift between these perspectives (see **Figure 3**).

On the following pages, we first introduce the initial design project that formed the start of our investigation through describing the formulation, realisation and reflection of its design program. The pages thereafter sketch different avenues of exploration, that is, new design programs that have emerged from reflections on previous design programs. We conclude with a methodological reflection on how the continuous repositioning between program and experiment in this approach is a valuable way to give expression to complexities inherent in the research interest.

4. Design research cycles

The following pages briefly discuss several of the different avenues of exploration, framed within the programmatic approach through their presentation: as full cycles of formulating, realising and reflecting on a design program. These three stages of each cycle are illustrated on the left-hand side of each subsection image. These cycles are intended to illustrate how knowledge generated in one cycle, influences the actions and reflections in following cycles. The reflections on the design program and its realisation highlight insights that steer further drift

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Figure 4. Still image from the MoCap tango performance with the dancers in the middle, and a real time visualisation of their movements projected behind them. Photo courtesy of Murat Erdemsel.

after a moment of stabilisation in the completion of the design program. Salient points of these reflections form the basis for the formulation of new design program(s).

4.1. MoCap tango performance

A performance with world class tango dancers Murat Erdemsel and Sigrid Van Tilbeurgh took place during the Midnight Light Tango Festival in Umeå, Sweden in June 2015 (see **Figure 4**). For more information on this project, please refer to [29].

Design program: use novel technologies to create the possibility for an audience to appreciate dimensions of the dance that are normally unperceivable for the audience, but clearly present for the dancers.

Realisation: the dancers' movements were tracked through a motion capturing system and custom designed wearables. The movements were visualised in real time through a projection behind the dancers. By building on the embodied experience of the dancers, we visualised particular aspects of the dance, that is, accelerations and traces of movement through space. The visualisations emphasise elements of the dynamics and makes them linger in time, to enhance their perceivability.

Reflection: the overall sophistication of the visualisation was not at the same level of the dancers' performance. However the design case has operationalised the research program, by creating a common vocabulary (both verbally and visually) between dancers and designers, enabling a mutual understanding of aesthetic qualities that we aimed at exposing. Another reflection relates to the method of visualisation: the projection reduced an embodied experience to a two-dimensional representation of parts of that experience, leading to interest as to how the movements might acquire a physical, embodied presence in its representation that resonates more strongly with its original (see Section 4.2). Shared reflections with the dancers revealed another quality: in discussing their bodily, felt experience in relation to the visualisation, the dancers were able to show how glimpses of their intentionality, the play of forces between partners to indicate future movement that is normally hidden for an audience, were visible in the visualisation (see Section 4.3).

4.2. Materialising movement qualities

The enormous amounts of data gathered in the MoCap tango performance provided the basis for a wide area of explorations with the intention of exploring ways to materialise the qualities of movement embedded in the dance.

Design program: find an expression of the captured data that is as rich, beautiful, dense as the dance.

Realisation (see **Figure 5**): data from dancing tango dancers were gathered with a motion capture system, allowing specific steps and figures to be isolated. Both 3D models and animations of the data in those intervals were generated. Renderings were done both by using particle systems and ray-tracing techniques and we investigated the visual effect obtained through assigning different kinds of materials. Sculptures were realised with FDM techniques and visualisations of the data were projected onto fabric sculptures to examine ways in which the visualisations could acquire a physical presence in the same space as the dancers.

Figure 5. Experiments in materialising movement qualities with data captured during the MoCap tango performance. Clockwise from top left: animation experiments, rendering experiments, 3D printing movements, and materialising projections. Bottom left photograph courtesy of Murat Erdemsel.

Reflection: there are qualities about the aesthetics of the material that is being produced along this project, that is simply, irresistibly, sensually beautiful and is demanding us to keep on exploring: the grace, sensuality, viscerality of the visual material that we realised so far; the combination between live dance and visualisation or the materialisation of dance (yes, we can touch a dance now!); all these elements, make this design research project irresistible and push us to go further and dig deeper. Leaps from one medium, one materiality to another, starts unveiling hidden elements, even to the dancers. At that point, we started noticing ephemeral leads: in materialising movement qualities, different models and prototypes provided new perspectives on the dance. The dancers themselves were able to see and discuss things they were unable to perceive before. This brought us to elaborate, later on, educational material, meant for the dancers, in their pedagogical work (see Section 3.4). The physical materialisation of the movement, especially in forms of 3D printed sculptures, showed how the dance may inspire spatial explorations, further explained in Section 3.5.

4.3. Intentionality

Together with the same tango dancers that we have collaborated for the performance design program, we started working on how to expose the dialogue among the two dancers, by digging into how the initiative that is taken by one dancer, is communicated to the other. Together with the dancers, we have chosen to isolate the element of transmitting pressure on the floor, as one way to visualise how the intention of undertaking a specific step can be studied, exposed and made more apparent (see **Figure 6**).

Design program: to explore ways in which the intentionality, the hidden forces with which partners sense each others' movements before they happen, may be expressed and become perceivable.

Realisation: we initially defined 'pressure transmitted on the floor' as the element to visualise, in order to further explore ways to transmit intentions in the dance dialogue; we did some

Figure 6. Exploring intentionality in tango: pressure sensors embedded in the shoes of the dancers are used to gather data and visualise pressure, force and points of contact. Photos courtesy of Murat Erdemsel.

photoshop work to simulate how we could visualise such pressure (see **Figure 6**). We then recorded the pressure, by implementing a pressure sensor under the dancers' shoe soles and gathered data while motion capturing movements. The pressure sensor data is currently being integrated with the motion capture data, in order to add the dimension of intentionality to the visualisations.

Reflection: the first trials in visualising downward pressure from the feet of the dancers are promising, in the sense that it shows activity. However, as our investigation is a design-oriented one, and not an analytical inquiry into objective, measurable elements of tango, this also highlights a difficulty: in itself, the sensor data in this project is meaningless, unless integrated with other elements of the dance, like the whole movements. Shared reflections with the dancers, in which they explain their intentions and felt experience in relation to the data, are one way in which these missing dimensions might be exposed. Moreover, reflecting on this design program also made clearer that our real interest regarding intentionality is in the direct dialogue between dancers: for example, the physical dialogue at points of contact between the dancers' bodies that elicit or guide successive movements. This latter reflection is the driving force between a new design program, that explicitly aims to use the laid by this project, into interaction design: produce material to inspire a reflection intentionality in intelligent products and systems, in relation to how such products and systems can detect and respond to human cues and intentions.

4.4. Educational material

The first and second design programs and their realisations informed us about the possibilities of creating visualisations to be used for educational purposes, in teaching Argentine tango. The suggestion came from the dancers: through the materialisations, renderings and animations of the captured data, they were able to compare and articulate their felt experience and reflect on it. In some cases, their felt experience was completely different from what happened in reality (e.g. feeling like make a circular movement pattern, but in reality making a distinctly different shape, see **Figure 7**).

Design program: develop material that supports the teaching of dance, exposing elements of complexity that are difficult to verbally explain to others. Such tacit elements are, for instance, the physical dialogue between dancers, complex movements that require coordination of several body parts or better visualisation of movements' characteristics, such as place and space.

Realisation: in tight collaboration with the dancers, we have developed a visual language that has specific aesthetic characteristics, such as how long the trace of movements lingers, how acceleration and speed are represented (the thicker the line, the faster the movement), how the position of the feet is represented (light dots), or what interval of dance is visualised (see **Figure 6**). We have elaborated a series of visualisations that show separately movements of feet, movements of hips and movements of shoulders.

Reflection: this design program constitutes a very practical application of the first, more abstract and artistic case, that is, the *MoCap tango* performance. In proposing a specific representation of the movement (with defined aesthetic qualities), we make a decision concerning

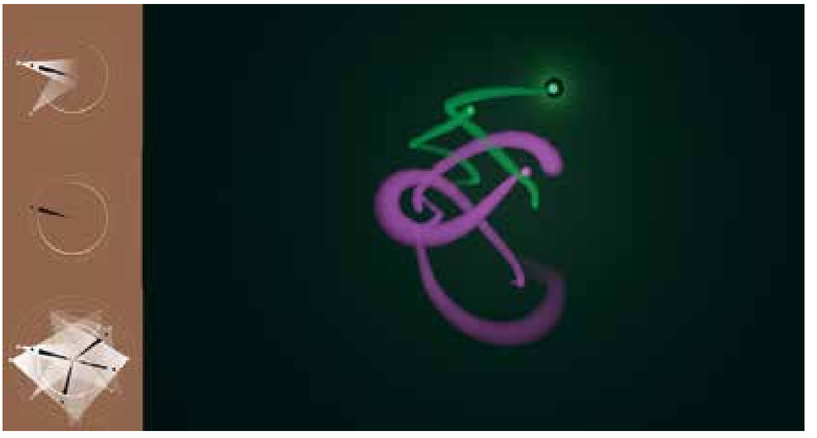

Figure 7. Renderings of the data can be used to provide a new perspective on the movements (in time and space), or to isolate particular body parts. In the above still image, only the feet of the man and woman dancing are shown (green and pink, respectively) from a bird's eye view. This visualisation showed a professional tango dancer that the patterns of movement he thinks he makes are in fact very different from what he does in reality.

the exposure of certain movement's features. The material that has been produced so far, is currently used for educational purposes and will produce a feedback by its impact on students, which will inform the next iterations. From a design perspective, this design program also highlights an interesting tension: to isolate certain elements of the movement reduces its complexity to a more handleable form, however, at the same time, this process reveals elements that were obscured by its complexity.

4.5. Tools for spatial design

The design program aimed at materialising movement qualities (Section 3.2) drew attention to the sculptural and spatial qualities of the dance. This led to a new design program, in which we explored specifically how the technologies that we were using to understand dance, might become functional as ways to directly design spaces. Within a research project called *+Plus* on sustainable production methods for residential buildings, we carried out a series of explorations with the contemporary dance collective *Nomodaco*. The movement sessions had specific assignments for the dancers, who were sketching with their bodies in a virtual reality space, using the *HTC Vive* technology, a motion capture system, and a mixture of custom and commercially available softwares.

Design program: inspire new ways and create new (digital) tools that support the design for spaces, by using one's body movement as a means of sketching.

Realisation: the explorations were designed in order for the dancer to express the interactive qualities of an everyday activity (making and drinking tea), using different obstructions, such as being physically connected with each other with a rigid joint or with a flexible joint. The movement was traced with brushes connected to their hands in a virtual reality space and later, with sensors on all of their body, tracked by a motion capture system. The sketches were visualised and materialised using different methods of representation.

Figure 8. Designing spaces from movement, annotating movements using motion capture (left) and carving spaces with dance virtual reality (right).

Reflection: each representation highlights different elements of the session and caters for a different purpose. The most relevant are: firstly, sculpturally annotating movements to give expression to specific interactive qualities that can be abstracted and turned into spacial qualities to inspire the design of a space. Secondly, by moving carving out space from a solid volume, to directly shape a space and be able to experience the qualities of that space to inspire further design steps. Further iterations will be carried out on the basis of this first exploration: in particular to explore how the tools and techniques used in this workshop, may be used by architects, as experts in the design of spaces (**Figure 8**).

5. Perpetual perspectives

To conclude this article we reflect on our cycles of formulating, realising and reflecting on design program, to expose how the drifting this process causes allows for expressions of the complex research topic. Reflecting on a design program and its realisation, affords a shift in perspective on the design space (see **Figure 9**). We drift from one position to a new one: a vantage point where our point of view on the design space is guided by reflections on the work and the knowledge it generated. This new perspective highlights new opportunities within the design space: it can show us something that is interesting to pursue further from the particular realisation in this design program. For example, the ephemeral intentionality that is part of the embodied dialogue between dancers: glimpses of it were visible in the first visualisation experiments for the performance. This suggested we could further expose them and leading to the design program explained in Section 3.3. This reflection at the end of a cycle might also highlight or emphasis qualities we have neglected to address in the current design. For example, the richness that is lost in creating a two-dimensional

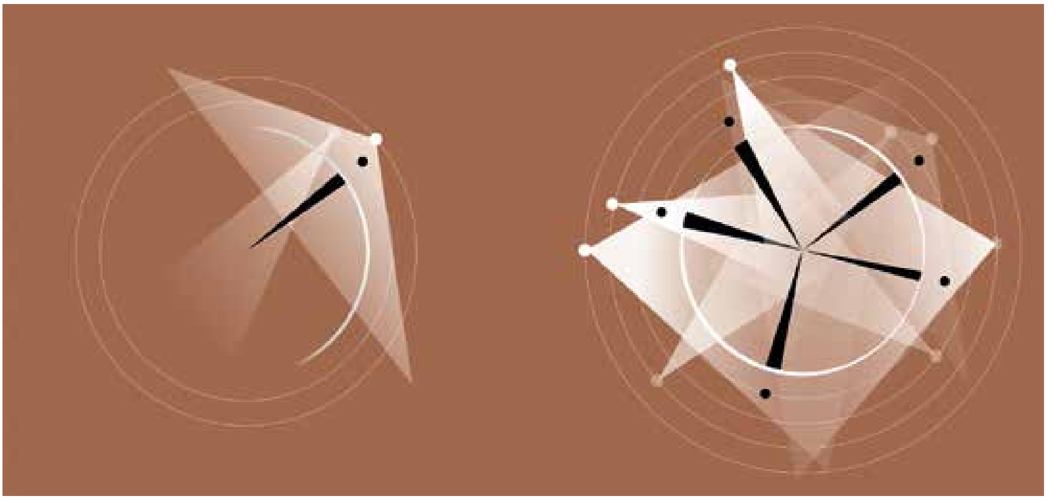

Figure 9. The conclusion of the first cycle (left) and the conclusion of the fifth cycle (right).

representation of a three-dimensional movement (leading to the design program explained in Section 3.2).

We find the distinction between the research program as a whole, and the individual design programs that substantiate parts of this whole, useful. The research program is concerned with expressing the (hidden) qualities embedded in the experience of dancers. It is difficult for individual design programs, and the design experiments they bring forward, to address of all the complexity that constitutes this experience. However, in casting the design programs as a certain systematic way to address new elements found in this complexity, and to build upon earlier work in order to expose it, aids us in viewing separate design projects as part of a bigger whole (see **Figure 9**). To develop new cycles based on earlier cycles, balances what has been discovered, with what is missing and latent. This way in which past experiments and design programs stay relevant for subsequent cycles, and thus for the research program as a whole is crucial. Design experiments typically focus on parts of the complexity of the design space and express certain parts of this complexity. To unveil and understand this complexity, these individual expressions as need to be considered as a whole, mutually influential and relevant, to respect and embrace the complexity.

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Why Healthcare and Well-being Researchers should Become Developers: A Case Study Using Co-Creation Methodology

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Peter Peters and Loe Feijs

Additional information is available at the end of the chapter

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Abstract

Wearable technologies increase the ability to track different parameters related to health and well-being. As the variety and amount of data sources grow, a better understanding of health-related data can be obtained through research on data fusion. Outcomes can either be validated by end users when results are finalized or throughout the design and development process of mobile health applications. This chapter addresses the co-creation methodology applied for the creation of a mobile health application, called *Vire*, and the backend, called *Synergy*, to serve personal data to the mobile health application. *Synergy* provides an interface for the research team to interact with participants and visualizes parameters relevant to the study. Modern frameworks and platforms, such as React Native and Meteor, are used to facilitate the adaptiveness and functionality required for the co-creation of *Vire*. The chapter concludes by addressing the findings from the study with 26 participants.

Keywords: mobile health application, mobile application, research team, back office, react native, minimum viable product, experiential design landscape

1. Introduction

Wearable technologies increase the ability to track different parameters related to health and well-being. Mobile applications such as Gyroscope [1], Apple Health [2], and Google Fit [3] aggregate health data to provide a better personal insight or a collected overview of data. Individual vendors of wearable trackers, such as Fitbit and Beddit, provide mobile applications specific to their devices. These vendors often provide Application Programming Interfaces (APIs) to collect data for analysis or visualization. The objective of *Vire* and *Synergy* is to design a mobile health application that applies data fusion and data visualization techniques to create additional value for the users besides the vendor-specific applications. Existing research and design methodologies to evaluate the value of these visualizations for potential users are limited. Questionnaires can provide insights into specific topics such as the comfort of using trackers [4]. Text messaging can be used to test the efficacy of a system intended to improve blood pressure control and treatment adherence compared with usual care [5]. The co-creation method described combines these methods (questionnaires/text) and uses the infrastructure. The infrastructure developed (*Vire* and *Synergy*) enables to use these methods real-time for continuous observation and responsiveness to events within the scope of the research objectives.

2. Methodology

The methodology, being developed through this case study, is based on the *Experiential Design Landscapes* (EDL). EDL follow a research-through-design approach where the design process is positioned in the social context by creating infrastructures that enable designers and other stakeholders to develop *Experiential Probes* that evolve over time [6]. The EDL methodology solves the dilemma of ecological validity versus control, by enabling measurements to be taken in the actual context previously only possible in a controlled environment. Also, the EDL methodology solves the complication in generalizing the findings from a controlled environment to a real-life setting. The real-life setting, in case of an EDL, is an open environment accessible to the general public. Our methodology is applied to the individual participant's context instead of the open environment, so it extends the probes to *Personal Experiential Probes* (PEPs). As visualized in **Figure 1**, each participant independently interacts with the mobile application and related devices. Feedbacks from participants are collected throughout the study, and changes to the mobile health application are pushed to the participants in an iterative fashion. The advantage of this approach is that suggestions for new features, or other changes, are evaluated independently by other participants. In comparison with the EDL methodology, our methodology is restricted to software possibly extended with connected devices.

2.1. Minimum viable product

Prior to the inclusion of participants, a period of 1–2 months is reserved for the definition and building of the minimum viable product (MVP). For this study, no prior cases provided experiences to substantiate features to be included in the MVP; thus, existing mobile health applications were investigated to define features. Features were categorized between *essentials* and *optionals*. *Essentials* are required to be ready before the launch of the mobile application whereas *optionals* can be built during the study. See **Table 1** for examples of features defined for this case study.

2.2. Participants

The size of the study population is limited from 20 to 30 participants between the ages of 18 and 75. The lower limit (20) prevents over-fitting and generalization of feedback on design decisions. The upper limit (30) is dependent on the number of available devices, but a larger sample would require additional members in the research team. Participants without an iOS- or

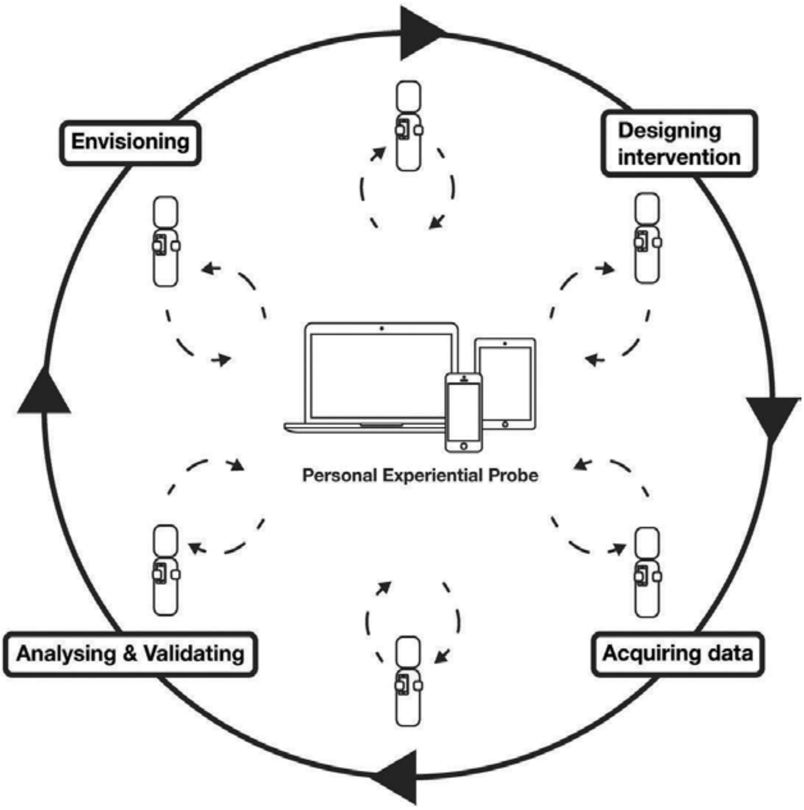

Figure 1. Visualization of methodology based on EDL.

	Essentials	Optionals
MVP	Communication through a messenger service Data integration mechanism with Meteor Authentication with user accounts Profile page with settings	Push notifications for new messages Bluetooth integration for other external devices GPS tracking Localization (multilanguage support)
Vire and *Synergy*	List of DOs Integration of Fitbit, Beddit, and Moves Textual representation of data	Visual representation of data Personalized representation based on correlations

Table 1. Essentials and optional features for MVP.

Android-based mobile phone operation system are excluded due to the current limitation for Windows Mobile development in React Native. Each participant received a Fitbit Charge HR [7] and Beddit 2 [8] and was asked to install the corresponding mobile applications, Moves [9], *Vire*. Also, all research team members used the same devices.

2.3. Environment

Figure 2 depicts the ecosystem utilized in the study. Specific for the aggregation of Fitbit, Beddit, and Moves data, the services preceding *Synergy* are used to facilitate the availability of

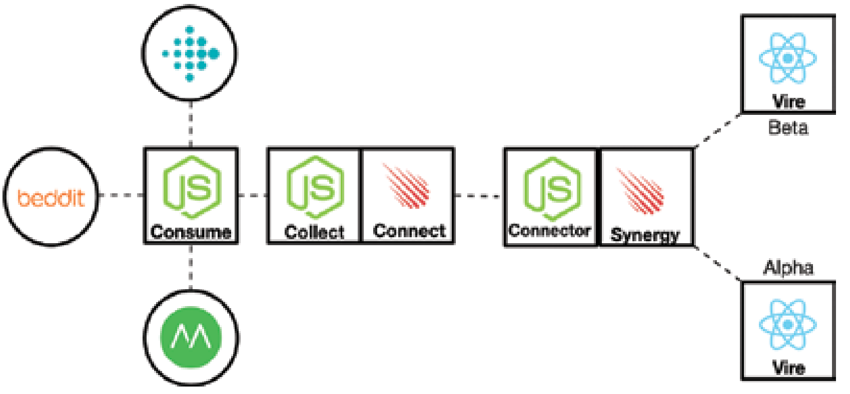

Figure 2. Visualization of ecosystem used in study.

personal data in *Vire*. **Figure 2** also shows two versions, alpha and beta, of *Vire* that are used to evaluate a new *Vire* version within the research team before deploying to the participants. The illustrations used in **Figure 2** are the logos of the platform or framework used by the services.

Synergy is built using the Meteor (open-source) platform, developed by the Meteor Development Group (MDG). *Synergy* functions as the backend for *Vire* and serves the back office for the research team. Meteor was chosen for its use of the distributed data protocol (DDP)—a publication/subscription mechanism through websockets—that enables "real-time" applications. *Vire* is built using the React Native framework, developed by Facebook [10]. React Native enables the development of native, iOS and Android mobile applications using JavaScript and React. React Native was chosen for its crossplatform compatibility and performance in comparison with its alternatives. The uses of Meteor and React Native require researchers to only have experience in JavaScript for the development of the backend, back office, and mobile applications. The use of one programming language throughout enables a lower threshold for new researchers to become skilled in the tools used.

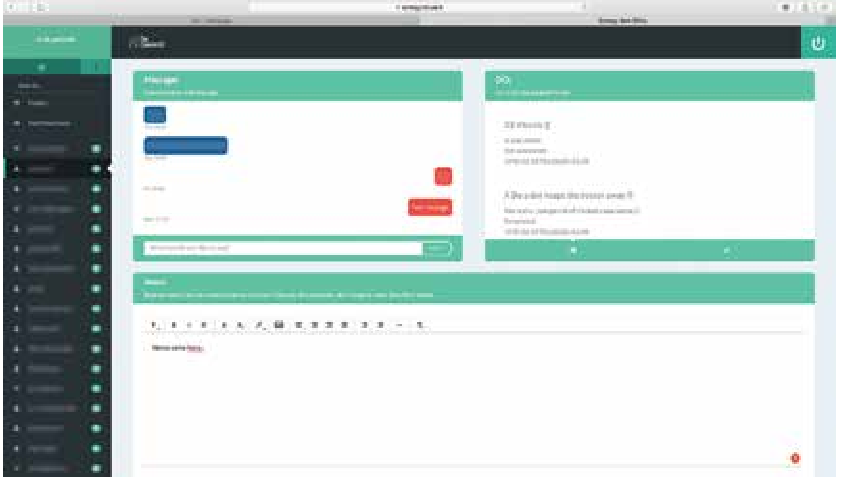

Figure 3. Screenshot of back-office participant view.

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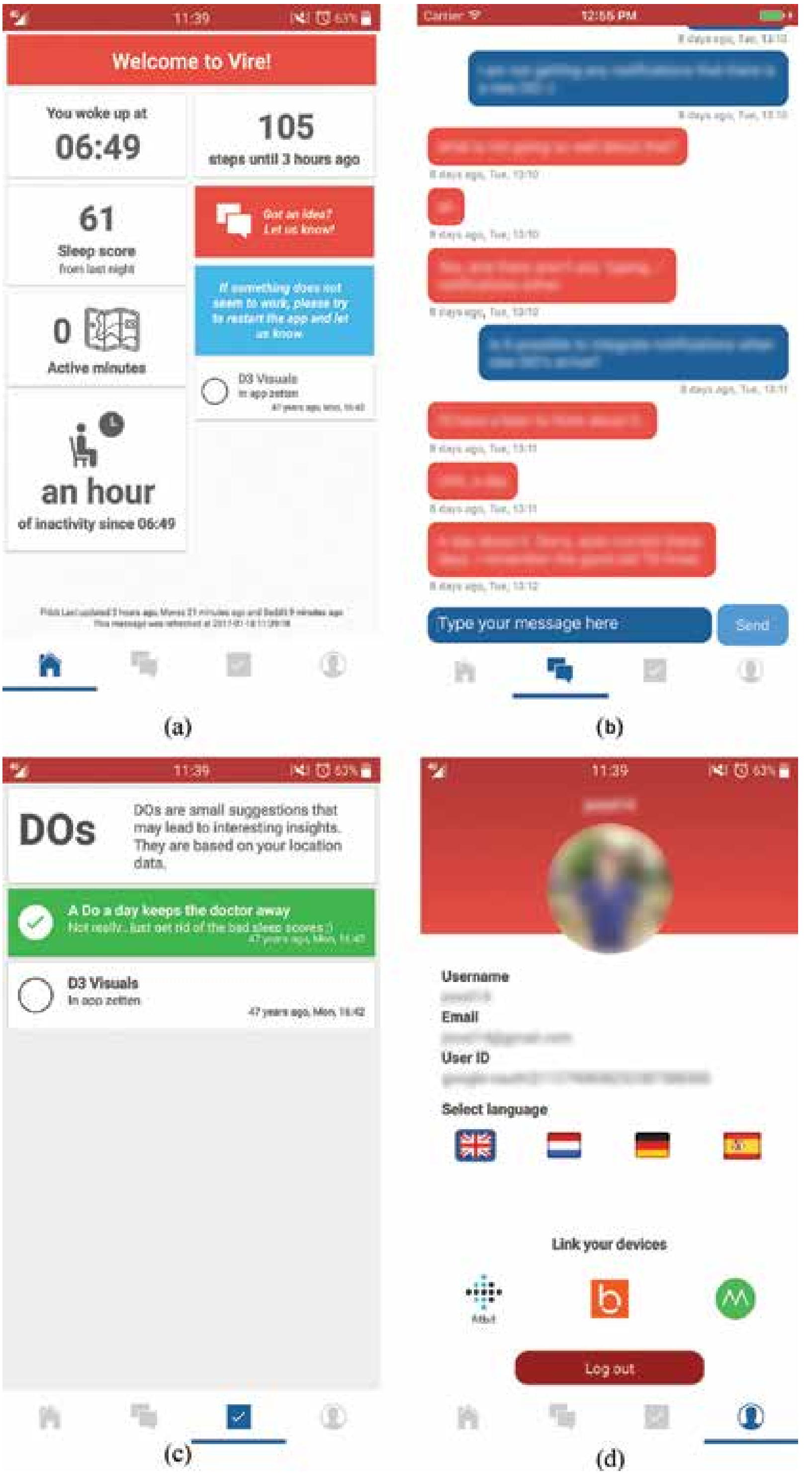

Figure 4. (a) Vire daily, (b) chat with researchers, (c) list of DOs, and (d) profile information and settings.

2.4. Interfaces

The interfaces presented in **Figures 3** and **4** are specific to the implementation of *Vire* and *Synergy* but can be stripped to be reused for other researches. Throughout the design of these interfaces, the intent of creating a boilerplate for future research is kept in mind.

Figure 3 shows the interface for the members of the research team. On the left pane is a list of all users with a notification label that shows a counter of unread messages sent by the participants. In the center pane, top left is the chat module to communicate with the participants. Participants do not know to which researchers they are talking to. On the top right, a list of current DOs for the participants and the completion state is listed. New DOs can be added there as well. On the bottom pane, there is room for notes from the researchers about the participants. Researchers share notes on the homepage and have a single page for notifications.

Figure 4 shows four screenshots of the MVP of *Vire* containing the homepage, where the visualization work will be done; the messenger, where participants can communicate with the research team; the list of DOs, where participants can see and mark their DOs complete; and the profile page where participants can link their devices and change language. The primary focus is on the development of the homepage.

3. Results

After six months of running the study, the results on user requirements can be categorized as macro- and microfeatures concerning the MVP or for the implementation of *Vire* and *Synergy*.

Table 2 shows the division between MVP and *Vire*- and *Synergy*-specific requirements found during the study. For *Vire* and *Synergy*, the new MVP requirements are built in during the study. Future studies will include these before the involvement of participants. The requirements for *Vire* and *Synergy* are meant to be obtained while performing the research and are planned to be implemented and evaluated during the duration of the study. The outcome of this methodology is a back-office and crossplatform mobile application, ready for further research. The final results provide new requirements for the definition of the MVP. Future studies can reuse the boilerplate—template code for the MVP—with the improvements from previous experiences. Also, as stated in **Table 2**, the structure of the methodology can be redefined to clarify expectations from participants and increase efficiency in the iterative process.

	Macro	**Micro**
MVP	Communication of current activities to participants Overview of activity/engagement of participants in back office	Integration of push notifications Display connectivity status for internet and server connection
Vire and Synergy	Back-office interface mimicking participant's views Defining value *Vire* over the existing mobile applications	Data availability when offline Localization features and limited use of text Descriptions of calculated values

Table 2. Overview on user requirements.

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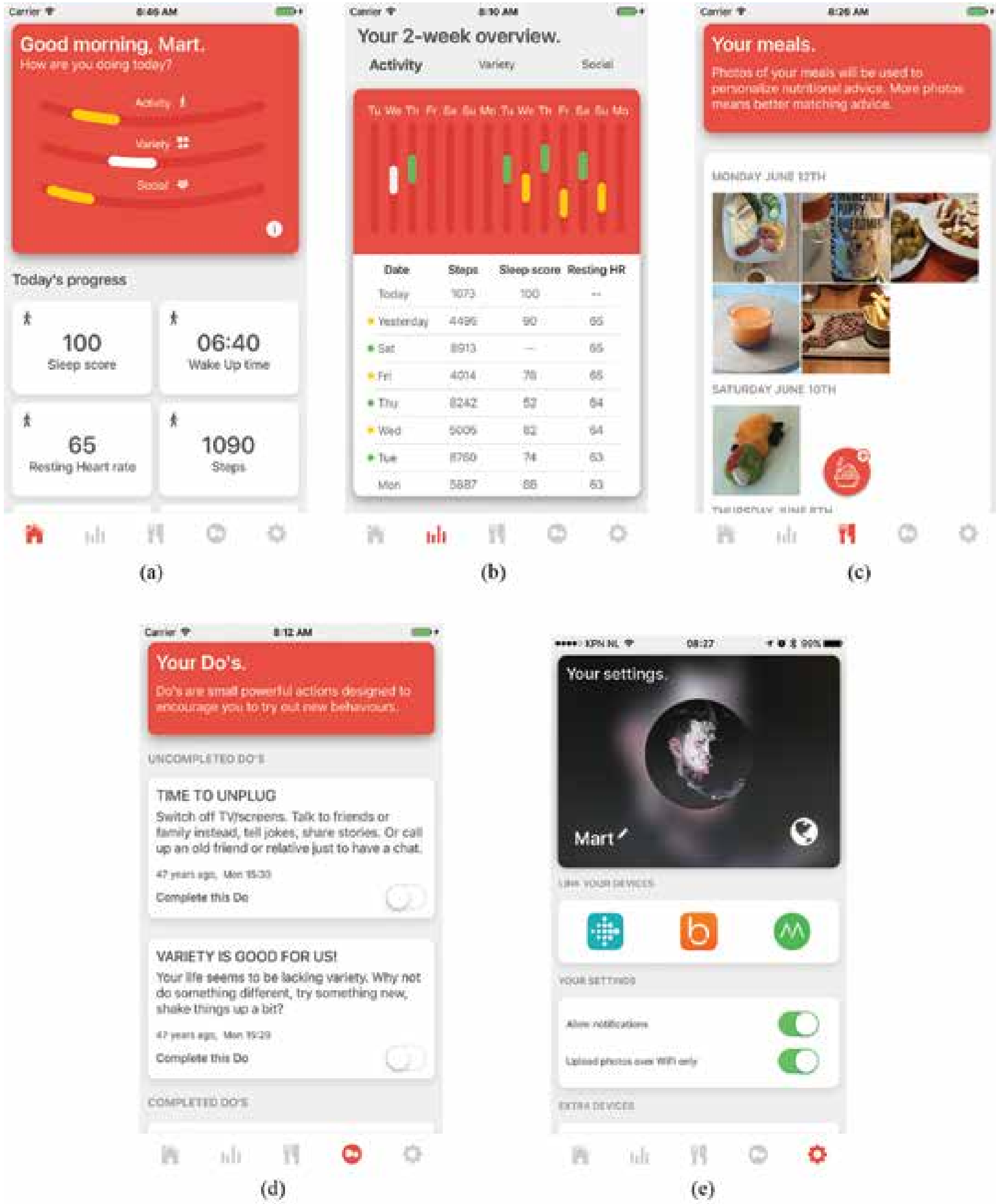

Figure 5. (a) Daily overview, (b) two-weekly overview, (c) dietary pictures, (d) list of DOs, and (e) profile and settings.

Figure 5 depicts the final version of *Vire*. In relation to **Figure 4**, a two-weekly overview and food record is added to provide better information to the users. Other notable differences include the refinement of general styling and markup. Throughout the study, the focus lies on the definition and development of core functionalities of the app and test that the app works both on low- and high-end mobile phones. To the end of the study, the requirements become saturated and more concrete; this enables to focus on improving the visual experiences.

Vire, for Android and iOS, will be used for a clinical trial of 150 cardiac rehabilitation patients in the Netherlands, Spain, and Taiwan. The methodology and study itself have contributed to the clinical trial by evaluating the functionality and usability of *Vire* outside the scope of the trial within an open environment. Without this process, issues or additional requirements not considered on forehand could affect the experience of the clinical trial.

4. Discussion

The methodology described in this chapter provides a rich feedback mechanism for the design and development of a research-based mobile application and accompanying back office. The reasons *why well-being researchers should become developers* are evident. The ability to define the MVP and the flexibility to implement features based on user feedback on the spot are the two main reasons we have found. By being involved in the development of a mobile health application as a researcher, the quality of the research increases. The effectivity of an intended interaction can be compromised by an esthetic mistake or incompatibility on certain devices. Using our methodology, the design and development artifacts that influence the user experience are already tackled. The experience, or the ability to gain experience, in defining prerequisites for the development of a mobile health application is gained through the hands-on approach. Within this process, the researchers are confronted with real-life development issues that give insight into the feasibility of a proposed or requested feature from participants or from within the research team itself. These learnings will provide the experience to prevent working on over-ambitious features and trigger creativity by discovering the limitations of used software and hardware. The use of JavaScript-based frameworks (React-Native) or platforms (Meteor) eases the learning curve for researchers, without in-depth programming experience, to tackle issues and develop iteratively by responding to feedback from participants. This approach enforces careful consideration of design and development decisions to (re)define the chosen direction of the study and offers a method to strengthen the qualities of the mobile health application and thereby the research itself.

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Section 7

Developing Sensitivity - Dynamic Aesthetics

Designing Biologically Inspired Movements into the Esthetics of Interactive Artifacts

Neda Fayazi and Lois Frankel

Additional information is available at the end of the chapter

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Abstract

Biological creatures have a variety of qualities that inspire design esthetics such as form, color, texture, structure, mechanics, and dynamics. This paper presents a biology-to-design approach as a design research method for adapting biological movements into the design of the kinetic and interactive esthetics of jewelry artifacts. It describes a preliminary study in which prototypes were developed by identifying and classifying the biophilic movements of small creatures, in consultation and collaboration with a biologist. It details how the biological insights were adapted into ideation concepts: beginning with a brainstorming workshop followed by further iterative sketching and prototyping. It adds to the literature on methods for taking design inspiration from nature, in particular, in the area of kinetic product esthetics.

Keywords: kinetic interaction esthetics, biology-to-design, kinetic design, biophilic movements, wearable computing

1. Introduction

Product esthetics are important in product design, where designers have traditionally paid considerable attention to the visual appearance of products. Although visual esthetics are important in design, designers are also becoming more aware of other aspects of product esthetics that contribute to pleasure such as interactions that engage multi-sensory modalities [1–5].

Incorporating physical movements into product esthetics can also enhance the emotional value of the objects [6]. Nam et al. noted, "One of the ways to enhance emotional interaction is to use dynamic attributes as a way of expressing functional or emotional states of products" ([7], p. 1). Nevertheless, incorporating the element of movement into the design of products has been somewhat overlooked in the realm of industrial design. According to kinetic designer Ben Hopson (oral communication, December 2013), "Movement has not historically been the designer's territory. It's really been the engineer's territory". He believes there is a need for tools and guidelines for designers working in this area [8].

Moreover, interdisciplinary approaches to the design of kinetic and interactive devices may involve various disciplines including science, design, fashion, computer, and technology [9–11]. This interdisciplinary study draws from the disciplines of biology and kinetic design to explore the esthetics of movement in the design of interactive artifacts. It adds to the literature on methods for taking design inspiration from nature, in particular, in the area of kinetic product esthetics.

1.1. Interactive wearable artifacts and kinetic design

Today, wearable objects are becoming increasingly interactive by engaging a range of sensory experiences through various types of sensory inputs and outputs. Garments with embedded sensors are employed for interactive entertainment, sport, military, medicine, exercising, connecting people to others, and to other networked activities [9–11]. The technology inputs and outputs may depend on embedded sensors that could result in dynamically lighting up, moving, and/or changing shape. Shape changing interfaces may be functional, exploratory, or hedonic. Hedonic interfaces that evoke human emotion may be used to stimulate, to identify, to esthetically enhance, or to increase the experience of fun [12]. The examples that follow demonstrate different kinetic dynamics that may evoke hedonic responses in the design of wearable artifacts.

In Joanna Berzowska's behavioral dresses, named "Kukkia and Vilkas", kinetic components frame the wearer's face, opening and closing slowly over time [13] and Fusakul's work, "Aliform", responds to the wearer's heartbeat by changing shape [14]. Wallace's neckpiece, "Journeys Between Ourselves" provides kinetic tactile feedback when a mother interacts remotely with her daughter through it [15]. Ross and Wensveen note, "designing such products and systems requires an aesthetic that goes beyond traditional aspects of static forms. It requires a new language of form that incorporates the dynamics of behaviour" [16]. Young et al. recommend that in designing movement for a product, the form of the object, and the capabilities of performing its designed movements should be considered first [17]. Furthermore, Hopson emphasizes the importance of choreographing product movements as follows:

Designers are not just form-givers, they are whole object creators and experience designers. By incorporating the creative and experiential notions of kinetic design into their vocabulary, designers will produce more exciting, more unified products, which will, in turn, lead to greater commercial success [8].

This study explores the kinds of biologically inspired movement that could contribute to different interactive outputs and kinetic product esthetics for wearables. It builds on other studies that indicate that shape-changing interfaces and organic, life-like movements can contribute to emotional or hedonic responses to the product [12–17].

In addition, the literature describes the qualities of movement: such as direction, volume (change in size), path (the line the object movement creates), speed, rhythm, continuity, and beat (cited by [18, 19]). For expediency, this research concentrates only on the kinetic qualities of direction, volume, and path. Other qualities of speed, rhythm, continuity, and beat are considered as stable variables in this study.

1.2. Intersection of biology and design: bio-inspired movements

Humans have a historical and emotional attachment to nature. Contact with nature can provide positive impacts for human beings [20–22]. Even a minimum amount of interaction with nature: in the form of representations and reminders such as images, statues, and jewelry with a nature focus: can act as a medium for satisfying people's biophilic desire for nature [23]. It improves the physical, emotional, and intellectual well-being of humans [24]. As a result, natural biological elements-referred to in this paper as biophilic elements- can provide a familiar and even comforting source of inspiration for design.

Natural features have long-inspired science and engineering as well as art and design disciplines [20, 24, 25]. In the design literature, discussions about biology and design may refer to copying, adapting, or deriving from nature, or in some way integrating nature or natural elements into everyday objects, and environments. These discussions cross disciplines, but are related thematically, with names such as, 'biologically inspired design', 'biomimicry', 'bionics', 'biomimetics', 'biophilic design', and other similar terminologies [24, 26]. There are also numerous examples of biologically inspired kinetic approaches in the literature, however, few are focused on the hedonic aspects of kinetic esthetics as this study is. For example, Oxman's 2013 sophisticated robotic arm that uses figure-eight movements, similar to those of a silkworm, to create cocoonlike structures [27] and Festo's robotic octopus gripper, based on the octopus' tentacles, provide functional alternatives for the design of mechanical products, but not for addressing emotional experiences [28].

This study takes a biologically inspired design and 'biophilic design' approach. The latter is derived from Wilson's concept of the 'biophilia hypothesis'; that people have "an innate human urge to have contact with other species, to spend time in natural environments, surrounded by animals and other living things"(cited by [25], p. 34). Kellert further adds to the meaning of biophilic design as having a positive environmental impact, due to the bonding between people and nature within the built environment [24]. It would seem that biophilic design creates environments and products that incorporate naturally agreeable and appealingly positive emotional experiences [20, 29]. For that reason, bios forms are often applied in design to improve the value of the products for the consumer market [30].

Benyus and Baumeister, co-founders of the Biomimicry Institute, proposed two approaches for developing nature-based things: they are biology-to-design and challenge-to-biology [31]. Volstad and Boks refer to these as biology-to-design and design-to-biology. In the biology-to-design approach, the design could be inspired by form (what it looks like), material (what it is made out of), structure (how it is made), mechanics (how it works), or function (what it is able to do) [32]. Challenge-to-biology and design-to-biology are outside the scope of this study.

Therefore, this paper presents part of a biology-to-design preliminary study in which a step-by-step approach for adapting biological movements was developed and applied to prototype design of kinetic jewelry. This is a process for generating bio-inspired designs for wearable products with kinetic esthetics. It presents an approach for designing movements that were inspired by natural creatures, especially those that people seem to experience positively. While positive impacts may enhance the value of a design, impacts from dangers in the natural environment, like snakes or height could create fears, stress, and "biophobic" responses [33]. Given that jewelry is typically an accessory to fashionable clothing, this study is part of a larger project to explore positive emotional responses to biophilic design elements. Its main contribution is a design approach for taking inspiration from biological movements and generating new ideation concepts in the design development stages of practice. It adds to the literature on methods for biology-to-design inspirations for ideation and early design development stages [32, 34, 35].

It describes the steps taken to identify, classify, and adapt biological movements into the design concept development process in order to create esthetically pleasant interactive products. This paper proposes a set of steps for applying biophilic movements in the ideation stage of designing interactive/kinetic esthetics for artifacts that may also convey emotion and elicit biophilic responses. The methods may be useful for artists, fashion designers, and form creators who aim to evoke various emotions in users through biophilic movements.

2. Methods

This biology-to-design study includes the stages of: identifying, classifying, and adapting biological movements [**Figure 1**].

2.1. Stage 1: identifying

The first Identifying stage started with investigating and gathering information from the field of biology. Different methods were employed to collect the information about movements found in biological systems. While movements could have a positive or negative impact on viewers, this study attempted to identify the type of movements in nature that could possibly bring about a positive emotional impact on human beings. They were considered to be 'biophilic movements'. It was important to have a biologist to consult with when designing and taking inspiration from nature in order to benefit from his knowledge and expertise [36]. This interdisciplinary study included on-going consultations with a biologist, Dr. Jeff Dawson, as a method for gaining more insight about the movements of living creatures. Dr. Jeff Dawson is a biologist and professor at Carleton University who is an expert in the biomechanics of insect flight and animal locomotion.

2.1.1. Internet survey of videos and exhibition visits

The study also included observation of plants and animals in natural settings, videos, museums, and exhibitions. Regarding the importance of observation in research, Martin and Hanington note, "A fundamental research skill, observation requires attentive looking and systematic recording of phenomena-including people, artifacts, environments, events,

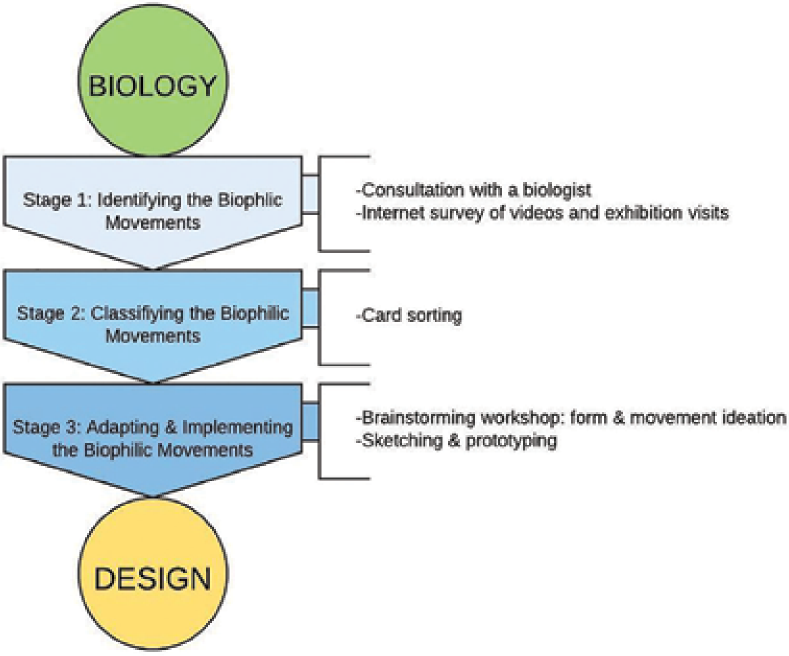


Figure 1. Biology-to-design process.

behaviours and interactions" ([37], p. 120). Initially, butterflies were observed at Carleton University's weeklong 'Annual Butterfly Show' in the department of biology. In addition, the behaviors of insects were carefully observed while attending the Insectarium, a Botanical Garden in Montreal. Lastly, a visit to the American Museum of Natural History and a special exhibition on marine animals provided more observation opportunities to study the life of sea creatures and different types of marine creature movements. This step involved careful observation as well as gathering visual materials such as videos and images (Appendix A). The visual materials collected were samples of the movements that might create a positive emotional impact on viewers. The choice of visual materials was based on ease of access to videos depicting motion details, as well as direction from the biologist.

2.2. Stage 2: classifying

The aim of this step was to categorize similar types of movements and explore if the concepts could be related to one another. Classification of the creature's movements began after observing different types of movements and participating in on-going consultations with the biologist. This phase of the research was accomplished by using a card sorting technique.

2.2.1. Card sorting

Card sorting is a design technique for meaningful categorization [37]. In this phase of the research, card sorting was conducted to generate options for structuring the information collected. The participants in this session were the biologist and design researchers. The crucial aspect at this stage was the interdisciplinary collaboration between the biologist with a background in biomechanics and locomotion and the design researchers with kinetic design interests. The biologist's knowledge assisted in better analyzing the patterns of movements in this step. Images of each of the creatures and their movements were printed onto a specific card for each one. During the session videos related to each image were also viewed to better clarify the movement pattern. The goal in this stage was to group the similar patterns of movements based on the formal qualities of direction, volume, and path.

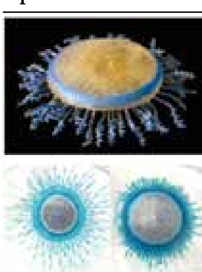
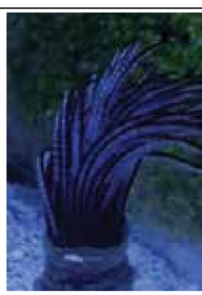
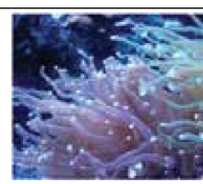
In the card sorting session, 12 cards were used with the following creatures' images: Blue-button, Feather Duster Worm, Anemone, Orange Cup Coral, Long-spined Sea Urchin, Fire Urchin, Green-and-orange Nudibranch, Christmas Tree Worms, Dragonfly, Morpho Butterfly, Sun Coral, and Ladybird. These were the creatures whose movements were identified in the previous step. They were chosen because their movements were different enough from each other and still basic enough to observe and reinterpret, and were perceived as pleasant, as opposed to dangerous. They were also simple enough to consider that the movements might contribute to generating a wider range of bio-inspired kinetic product esthetics combinations from simple to complex.

For each card, plenty of time was dedicated to watching the video, discussing, and analyzing each creature's movement. At the end of the session, biophilic movements, based on the direction and shape they formed in space, were classified into four different types: open-close, flapping, translational, and tentacle-like [**Table 1**]. At this point the classifications were primarily esthetic and not based on the kinds of mechanisms enabling the movements, however the organ that moves is indicated (e.g. Butterfly-wings).

The different categories are explained below:

In the *Change of size* category:

- **Open-close** movement occurs when an object moves outwards from a center and goes back to the center again, like the movement of strands in *Porpita porpita* (blue button).
- **Translational** movement refers to the movement of the object from one point to the other point in a direct path like the direct movement of the tentacles in feather duster worm from one point inside the tube to the other point in the same path outside the tube.

Change in size (variable volume)		Not change in size (fixed volume)	
Open-close	**Translational**	**Flapping**	**Tentacular (tentacle-like)**
 ***Porpita porpita*** **(Blue-button)-strands**	 **Sabellidae (Feather Duster Worm)-tentacles**	 **Dragonfly-wings**	 **Sea Anemone-tentacles**

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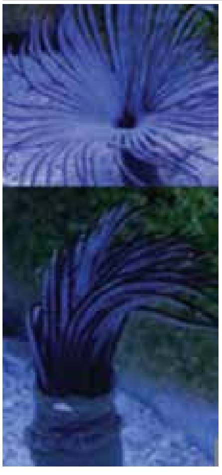
Change in size (variable volume)		**Not change in size (fixed volume)**	
Open-close	**Translational**	**Flapping**	**Tentacular (tentacle-like)**
 **Sabellidae (Feather Duster Worm)-tentacles**	 ***Spirobranchus giganteus*** **(Christmas Tree Worm)-tentacles**	 **Butterfly-wings**	 **Tubastraea (Orange Cup Coral)-tentacles**
			 **Long-spined Sea Urchin-tentacles**
			 **Fire Urchin-tentacles**
 **Ladybirds-elytra**			 **Feather Duster Worm-tentacles**
 **Tubastraea (Sun Coral)-tentacles**			 **Green-and-Orange Nudibranch-tentacles**

Table 1. Classification of biophilic movements.

In the *No* change *in size* category:

- **Flapping** movement refers to symmetrical wing shapes that come together and apart in unison as in a flying butterfly's wings.
- **Tentacle-like** movement is the wavy movement of an object, which does not have the same continuity or rhythm such as the movement of Sea Anemone's tentacles in the water.

Overall, while translational and open-close movements result in a change of size, flapping, and tentacle-like movements do not.

2.3. Stage 3: adapting from classification to inspiration for ideation concepts

In this stage of the study, the research aimed to translate the knowledge and insight gathered through collaborating with the science of biology into the design of interactive kinetic wearable objects. This phase of the study employed: a Brainstorming workshop, Sketching, and Rough Prototyping.

2.3.1. Brainstorming workshop: form and movement ideation

The objective of the workshop was to understand how participants might create three-dimensional kinetic models using simple materials such as paper, beads, wire, colored paper, cardboard, and foam to model their ideas. These materials were chosen since they were familiar, easy to work with and did not require sophisticated technical knowledge. This was important because the workshop participants were drawn from a convenience sample of one professor and five university students from different fields, since the participants' backgrounds were not a controlling factor. The six individuals provided their consent according to the approved ethics protocol. Four participants had design backgrounds and the others had IT backgrounds.

This workshop lasted for 2 h: it had three sections: an introduction (15 min), a working session (1:15 h), and a sharing session (30 min). In the introduction, participants were asked to design different movements with the materials provided. They were not aware of the natural movements classified in the previous stage and were not constrained to specific movements or forms. In the working section, all six participants created different forms incorporating a range of movements. In the final section, participants discussed their model/models, how it/they moved, and the source of inspiration for that type of movement [**Figure 2**].

Even though the participants were sitting beside each other, they did not copy each other's ideas. Each participant explored different forms and three-dimensional kinetic models. Some workshop participants developed similar movements through various forms. **Figure 3A** shows two different models from the workshop. Both have the same pattern of movement, but the movement is represented through different formal compositions. The final rough concepts show that, based on the models' direction of movement, some participants represented the movement through a circular or a direct path while others showed movement through a change in shape [**Figure 3**, Panels A–C]. In short, the workshop results indicated that similar movements could inspire a wide range of formal esthetics, even without inspiration from nature. Some of these movements were similar to those observed in the natural creatures in the previous stages.

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Figure 2. Models developed in the brainstorming workshop.

2.3.2. *Sketching and prototyping*

This phase synthesized the kinetic outcomes of the two previous stages: the classification of biophilic movements (different types of movements) and the insights from the brainstorming workshop (form and movement ideation). The researcher undertook sketching and "looks-like" prototyping explorations to select and translate insights into rough, but tangible "works-like" prototypes.

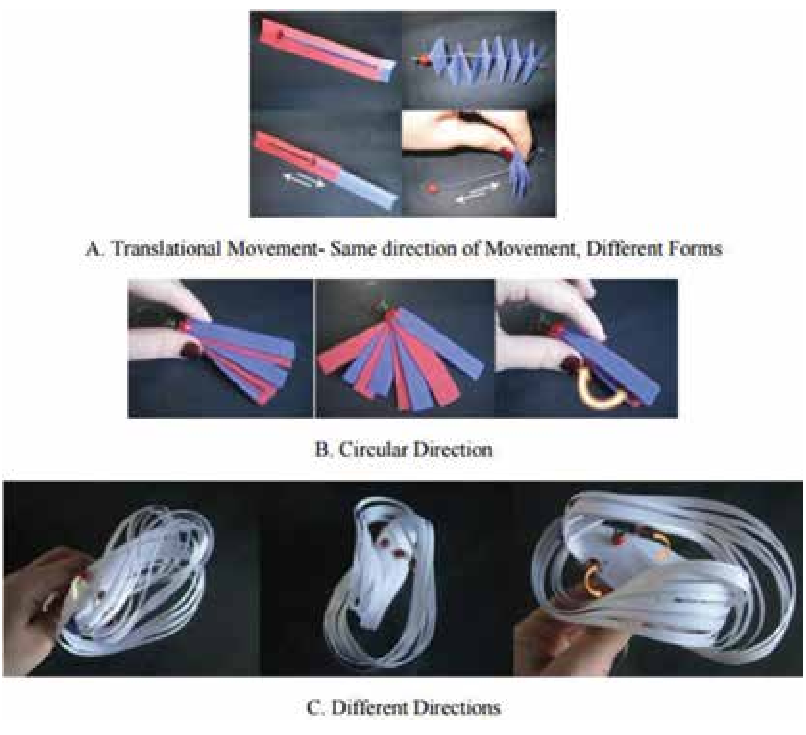

Figure 3. Different directions of movement presented through various forms.

The results of the previous phase of this research revealed the importance of form in representing movement. For example, **Figure 4** compares the same movement pattern with non-organic forms and organic forms [**Figure 4**]. Both of them have a translational type of movement. This means that the object moves in a direct path from one point to the other point. In the three-dimensional model shown on the left side, the arrows show the direction of the movement. In the image of the feather duster worm on the right side, the same type of movement occurs when it moves from one point inside the tube to the other point in the same path outside of the tube.

Based on this comparison, it seems that the form of the object has a significant impact on how the same type of movement is perceived in different objects.

Thus, concepts from the brainstorming session with an organic esthetic were selected and combined with the related types of biophilic movements taken from **Table 1**: classification of biophilic movements. The different forms and movements that were generated through two-dimensional and three-dimensional sketches are illustrated in **Figure 5**. At this point only the design researcher generated the sketches.

After the phase of sketching and initial rough model making, four different kinetic forms were selected in order to reflect the biophilic movements of **Table 1**. Each form was selected because it would best mimic its inspirational biological creature and better reveal the type of movement that specific creature embraced. This study then applied prototyping as a creative method for translating research and ideation into slightly more esthetically pleasing tangible and "works-like" physical forms for the development and testing of ideas [37]. In the more refined prototyping phase, this study aimed to integrate all four types of biophilic movements resulting from stage 2 (classification) into the design of wearable artifacts. The four types of movements are: open-close, flapping, translational, and tentacle-like.

Four different prototypes (wearable objects-brooches), with a range of different movements, were developed as testing prototypes. The creatures—butterfly, feather duster worm, anemone, and blue button—were the main inspiration for the forms and movements of the prototypes. Provisional and simple mechanisms were designed and added to the objects to make each one move in a certain direction, mimicking its inspirational biological creature. For these early experimental prototypes, the movements were activated by a hand-controlled mechanism. This is often the case in early prototypes to minimize the cost, effort, and time involved in creating working models before finalizing the design concept [38]. Mechanisms were designed and built in the biology lab, at Carleton University with the assistance of the biology professor Dr. Jeff Dawson. The prototypes were all in the form of brooches. The brooch

Figure 4. Similar movement in non-organic and organic forms.

Figure 5. Two-dimensional and three-dimensional sketches.

format was selected because it has the least formal human factors' limitations; for example, it does not have to conform to a wrist, a finger or a neck. The premise was that it would be much easier to experiment with size and shape as well as represent different types of movements. Moreover, it could be gender neutral—an important consideration for future testing.

As shown in **Table 1**, each of these creatures exhibited specific types of movements. These four prototypes also have the same distinct movement types as described below:

2.3.2.1. Prototype A

The movement and form of this brooch were primarily inspired by the feather duster worm [**Figure 6**, Panel 2]. This brooch includes 'translational', 'open-close', and 'changing size'

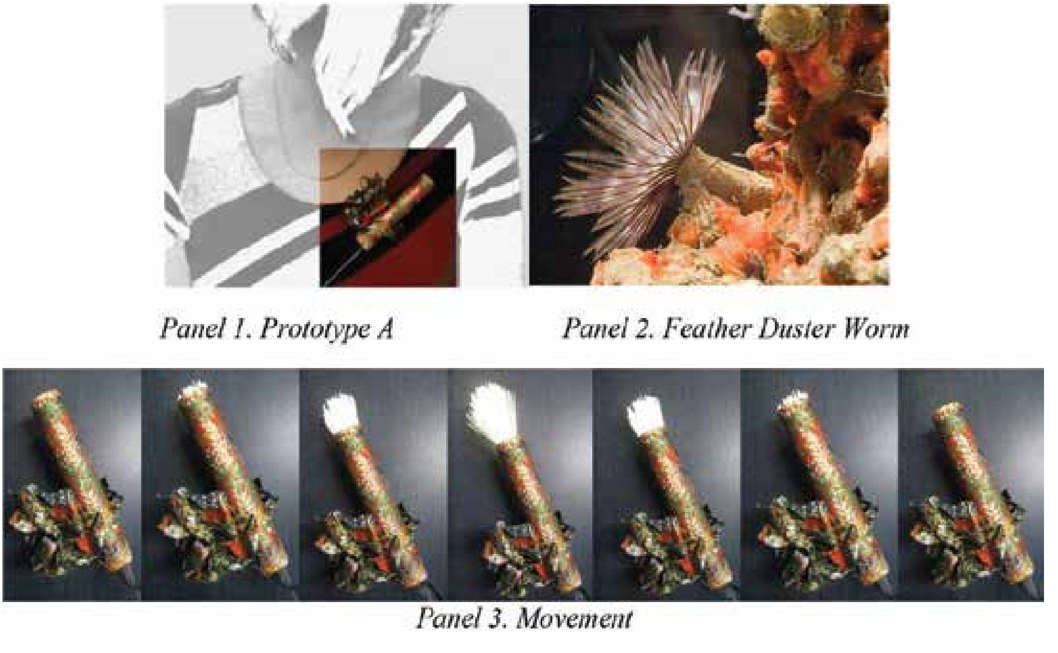

Figure 6. Prototype A.

types of movements [**Table 1**]. In this brooch, the fibers come out of the tube along one plane (translational movement), open in another direction and then close (open-close movement), and go back inside the tube again (translational movement) [**Figure 6**, Panels 1 and 3].

2.3.2.2. Prototype B

The movement and form of this brooch were primarily inspired by the movement and the form of a butterfly [**Figure 7**, Panel 2]. In this brooch, the wings have a bi-lateral symmetrical up and down movement (flapping motion) [**Figure 7**, Panels 1 and 3].

2.3.2.3. Prototype C

The movements and form of this brooch were inspired by a blue button [**Figure 8**, Panel 2]. The movements of this creature are open-close and tentacular [**Table 1**]. This marine animal has many strands, each having multiple branchlets that radiate outwards and go back inward to their previous position. In this brooch, the five attachments come out of the blue dome shape, move outward (which enlarges the overall size), and return inward again. Therefore, this brooch includes 'tentacular', 'open-close', and 'changing size' types of movements [**Figure 8**, Panels 1 and 3].

2.3.2.4. Prototype D

The form and tentacle-like movements of this brooch were primarily inspired by an anemone [**Figure 9**, Panel 2]. The organic form of the brooch consists of curvilinear strips that curl to make its shape. The prototype includes three strands filled with red beads that can be seen from inside the shape. These strands come out of the whole shape and go inside again (open-close movement). When the strands move outward, they also vibrate in a tentacle-like movement form. This prototype includes an 'open-close' and a 'tentacular' movement which also results in a change in size [**Figure 9**, Panels 1 and 3].

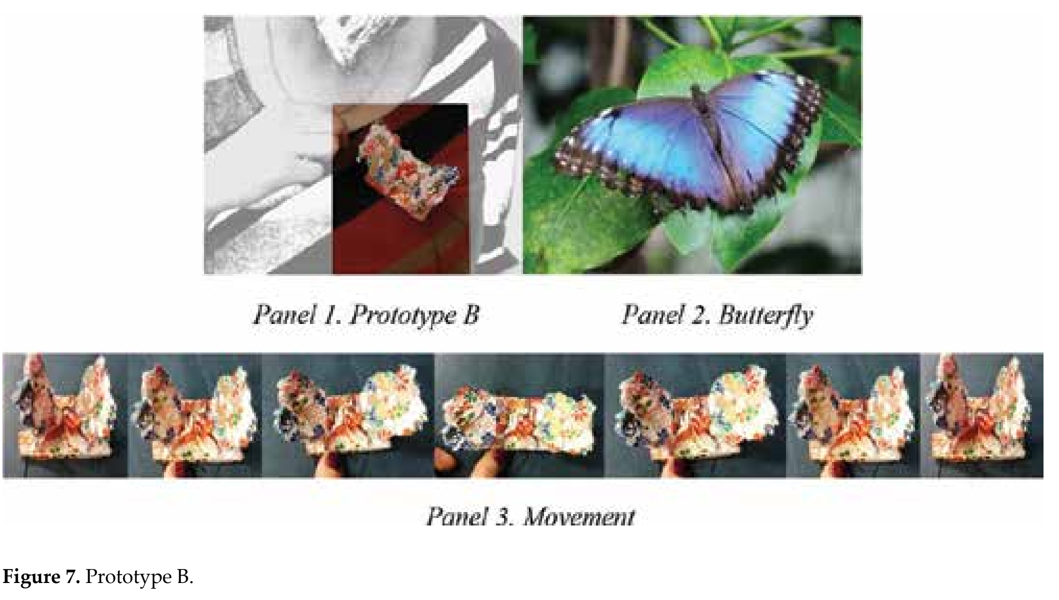

Figure 7. Prototype B.

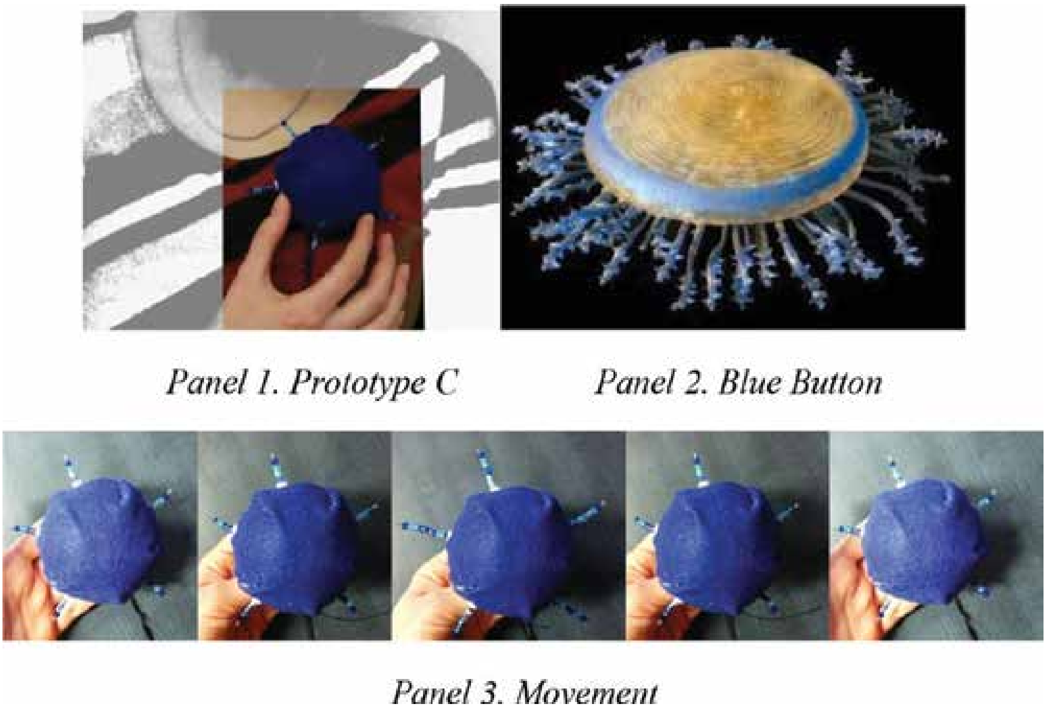

Figure 8. Prototype C.

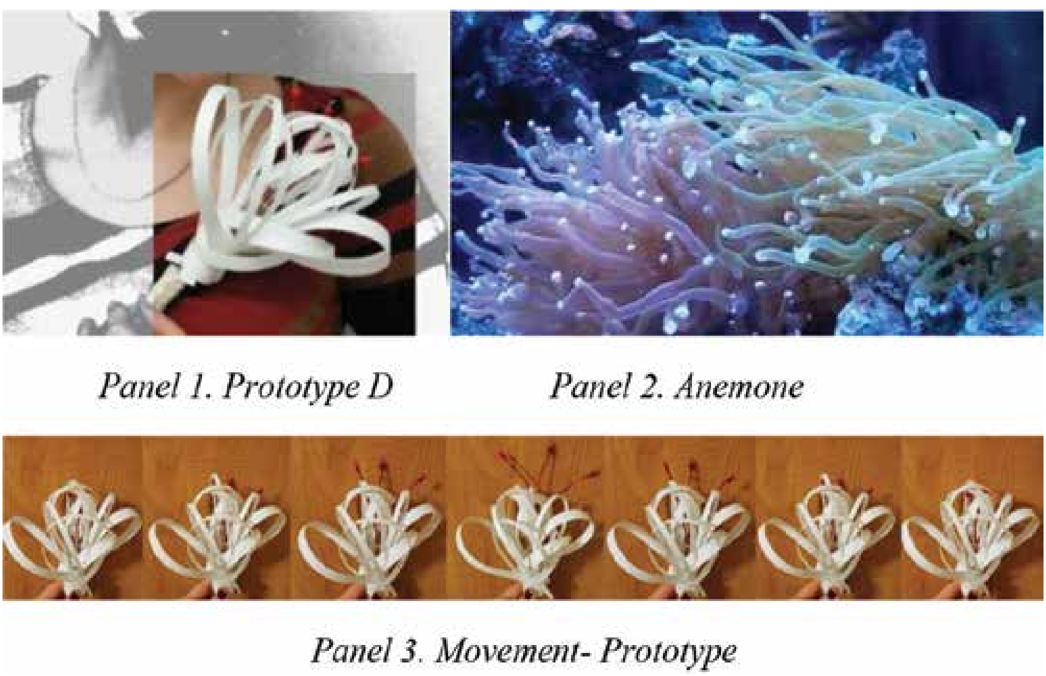

Figure 9. Prototype D.

3. Discussion

This exploratory study introduced a step-by-step process for applying a biology-to-design approach to early stages of ideation and concept generation.

3.1. Step-by-step biology-to-design approach for kinetic ideation

Each stage of this exploratory study provided useful outcomes for developing the next stage [**Table 2**]. The steps taken for adapting inspiration from biology and applying it to design esthetics followed this path:

- **Observing and identifying** natural movements with a biologist and designers/design researchers.
- **Classifying** the kinds of movements based on direction, volume, and path [**Table 1**]. These classifications were based on observations of nature and conducted in consultation with a biologist.
- **Sketching and iterative prototyping**. This stage involves synthesizing the ideas inspired from observation of movements in nature (creatures, in this case) and ideas generated by considering movement on its own.

3.2. Biophilic form and movement

This study contributes the term "biophilic movement" to the area of biophilic design. In this research, the initial focus was to take inspiration from the 'biophilic movements' found in nature. However, the findings that emerged from the brainstorming workshop indicated the importance of creating 'bio-inspired forms' as well while designing 'movement'. Therefore, it was not possible to define 'biophilic movements' without related 'forms' that represent their behaviors and movements. Ben Hopson and Young et al. indicated that form and movement are tightly correlated [8, 17]. In addition, Ross and Wensveen refer to this as a "new language of form that incorporates the dynamics of behaviour" [16].

3.3. Collaborating with a biologist

This interdisciplinary study benefitted from collaboration with a biologist at different research stages. As illustrated in **Figure 1** and described in **Table 2**, working with and consulting the biologist throughout stages one and two was important for generating innovative and creative outcomes. In stage one, the biologist provided expert insights related to the science of biology as well as more exposure to this discipline. In stage two, the collaborative card sorting provided a scientific approach to categorizing the types of biological movements. This indicates that biologists who study the movements of specific species may be able to recommend suitable sources of inspiration and provide designers with examples of organisms that may be of interest as design inspiration.

	Stages	Method	Explanation	People involved	Purpose	Result
Biology	Stage 1. Observing and identifying the biophilic movements	Internet survey of videos and exhibition visits	On-going consultation with a biologist Observation of: plants and animals (marine animals, butterflies, and other insects) in natural settings, videos, and exhibitions	Design Researchers and a biologist	Gathering visual materials and information on samples of movements in nature that might create a positive impact and emotional responses on viewers	Identifying examples of creatures' movements that might create positive emotional responses in people
	Stage 2. Classification of biophilic movements	Card sorting	Grouping the similar patterns of movements based on the formal qualities of direction, volume, and path	Design Researchers and a biologist	Categorizing similar types of biophilic movements gathered from previous stage	Classification table (types of biophilic movements: open-close, translational, tentacular, and flapping)
Design	Stage 3. Ideation	Brainstorming workshop: form and movement ideation	Practicing creating three-dimensional kinetic models (this step was conducted apart from the previous section)	Convenience sample of one professor and five university students from different fields	This workshop was conducted to understand types of movements participants create without paying attention to the biological inspiration	Describing the importance of form in representing movement. It is not possible to define 'biophilic movements' without related 'forms' that represent their behaviors and movements
		Sketching and prototyping (adapting the biophilic movements)	Sketching organic forms and synthesizing the forms with the biophilic movements derived from classification table	Sketching: researcher only Prototyping: researcher and a biologist	Creating ideation and initial "looks-like" prototypes that represent biophilic movements	Creating "works-like" design prototypes of interactive brooches with kinetic esthetics

Table 2. Step-by-step biology-to-design approach for kinetic ideation.

3.4. Observation

In stage one, the Internet survey of videos and exhibition visits, and the deep observation in the science of biology was an exciting technique for a researcher with a design background. This kind of observation is valuable in 'bio-inspiration' for becoming familiar with the behaviors and interactions of creatures in their natural environments (a sort of animal ethnography). Part of this observation was done with real creatures in museums and exhibits, and part was done virtually through videos and images. Closely observing the behaviors of creatures helped in better analyzing the patterns of movements. While observing different species and creatures, it was important to keep a record of the creature movements that seemed to evoke positive feelings in viewers since the focus of the study was on 'biophilic movements'.

3.5. Limitations and further research

This study was part of a larger qualitative research project focused on identifying terms for and emotional responses to biophilic inspirations. As a result, the prototypes from this study were later evaluated by another set of participants. Testing different prototypes with various biophilic movements could provide more complete knowledge about this topic.

Given that the study focused on a narrow set of sea animals and insects due to time constraints, there is potential for studying a wider range of animal and plant movements and expand the **Table 1**. The initial step of identifying and observing biophilic movements could also be applied to different kinds of biological sources of inspiration and used as a guideline for kinetic designers in the area of biology-to-design.

This preliminary study focuses on biologically based movements and the qualities of direction, volume, and path, not on the mechanisms that generated the movements. Further study would benefit from investigation into the mechanisms of the movement in order to develop the technical requirements for implementing the concept.

In addition, the Brainstorming workshop participants were not exposed to the results of the earlier creature studies. If future participants could be exposed to the natural movements previously classified, the participants might generate more bio-inspired concepts. Moreover, the materials for the workshop were primarily two-dimensional. A more advanced workshop could use more sophisticated materials and/or parts with Arduino programming of kinetic movements.

In this study, biophilic movements were designed for "looks-like" and "works-like" prototypes of jewelry pieces and activated by the researcher manually. In further studies, prototypes could be made using Arduino and sensor technologies to replicate nature more accurately. This would also provide the opportunity for different movement variables, such as speed, time or beat, continuity, direction, volume, and rhythm.

4. Conclusion

This study is preliminary research into inspiring idea generation for biophilic movements for kinetic and interactive artifacts. It contributes a step-by-step biology-to-design approach for kinetic ideation. In particular, it highlights the importance of collaborating with a biologist when collecting, observing, and classifying natural movements.

Appendix A: Internet survey of videos and exhibition visits

Exhibition: Carleton University's 'Annual Butterfly Show', Ottawa, Canada.

Museums: Canadian Museum of Nature, Ottawa, Canada | American Museum of Natural History, New York, USA | Insectarium, Botanical Garden, Montreal, Canada.

Web sources:

www.nationalgeographic.com | www.bbc.co.uk/nature/wildlife | http://www.amnh.org/ | http://nature.ca/

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[Tim M]. (2013, Feb 20). Anemone is on the move. Wild saltwater REEF tank [Video File]. Retrieved from http://www.youtube.com/watch?v=A7nMWjnrelQ.

[Mark Heckman]. (2012, Feb 10). Feather Duster Worm Retracts and Expands [Video File]. Retrieved https://www.youtube.com/watch?v=9QUFmX5aaaY.

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Chapter 26

The Experience of Dynamic Lighting

Kjell Yngve Petersen and Ole Kristensen

Additional information is available at the end of the chapter

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Abstract

The experience of the dynamic flux in daylighting is a complex relation between experiential and perceptual modalities, spatial presence of lighting qualities, and the architectural situation for the experience. In architectural practice, the understanding of daylight influx is key to the design of daylight openings and the experience of spatial form. However, current developments in light-emitting diodes (LED) light sources and adaptive software control systems allow for an enhanced correlation between daylight and artificial lighting, where the variations of the daylight are dynamically supplemented by variations in the artificial lighting. It is recommended that a particular type of Observational Instrument is developed, which situates detailed experiential investigations into the design potentials of integration of natural and artificial lighting and thereby enables differentiated dynamic lighting design in architecture.

Keywords: architecture, adaptive lighting, perception, perceptual training, perceptual reasoning

1. Observing the spatial distribution of light

The experience of spatial distribution of the daylight influx is complex. The experienced light formations are a result of a series of operations. The influx has its origin in an advanced composite of direct light, diffuse light, and reflected light from the environment, which is then formed by the daylight openings such as windows. Entering the architectural space, the light influx is then redistributed by shapes and surfaces and refracted and reflected in complex routes and operations. Further, the composition of the daylight influx is highly dynamic and transforms its composition and distribution throughout the day, often in speeds and changing patterns that make the dynamic variations the dominant form factor of the experience of daylight. The research leading to the design of the Observational Instrument (**Figure 1**) has been concerned with how to enable observations of the experiential qualities of the spatial distribution of dynamic daylight.

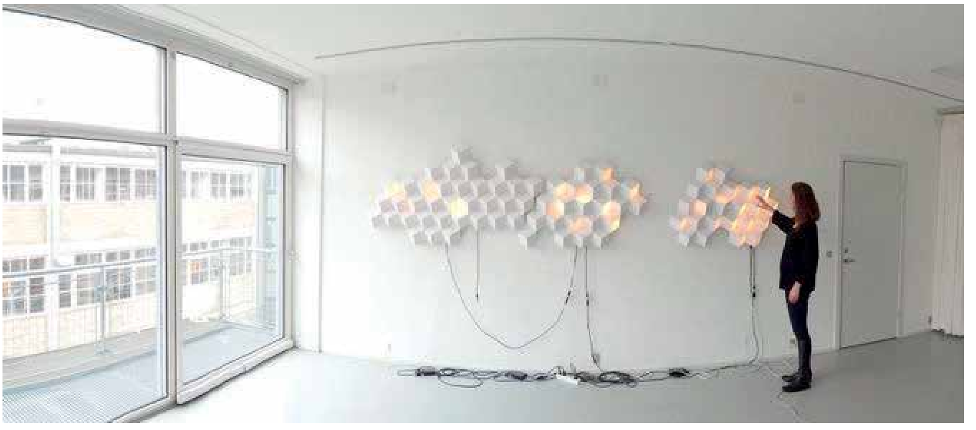

Figure 1. The Observational Instrument installed at the daylighting lab at KADK in Copenhagen. Window facing east; overcast day at noon.

The Observational Instrument is in the current version, an artefact composed of a tessellated pattern of square cubes, organised in an overall form that seeks to make the instrument neither a part of the wall nor a separate object in itself, but situated in-between these experiential categories. The Observational Instrument is slightly detached from the wall, and composed in a slightly fragmented way, in an attempt to enable focus on the light formations rather than the wall or the object. The size of the Observational Instrument, reaching from the light influx of the window to the darkest end of the space, allows for observations across and in depth of the space. The single cube elements hold the analytic form that enables a simplified observation of the light distribution in space. These cube objects divide the incoming light at that particular point in space into three main directions: one up, one towards the incoming light, and one away from the incoming light. An otherwise diffuse composite light formation at that particular point is by the cube separated into a clear division of direction, enabling an analysis of how the local light is composed of light from these three directions.

The tessellated design of the analytic cubes in the Observational Instrument allows for enhanced experiential observations. The pattern and size of the cube elements allows for perceptual comparison across the instruments, comparing lighting appearances on similarly shaped objects across space. The systematic view of lighting conditions serialised by the cube object also to some extend reveille the observations slightly from the very significant perceptual processes of 'perceptual constancies' [1], which seek to interpret the light formations along a surface, such as this wall in **Figure 1**, as one uniform spatial presence with almost even colour and light distribution. Having separated the spatial distribution of light into a series of identical triplet occurrences, the instrument opens for clearer observations on the dynamics of changes across the pattern.

The cube elements in the Observational Instruments are constructed with tuneable white light-emitting diodes (LED) behind each surface, as separate luminaires with each of their separate controlled dynamic of colour and intensity. The design enhances the subtle integration of the light reflected in the surface and the light emitted through the surface, and in this way, enables experimentation with the nuances of integration of daylight influx and artificial light emitted from the instrument.

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2. The experience of light as perceptual engagement

The architectural lighting designer Lam [2] introduced similar concerns and approach to lighting design in his seminal work 'Perception and Lighting as Formgivers for Architecture' in 1977. The basic assumption is that, given the perceptual dynamics of the human, and a perspective on architecture as form emerging out of perceptual activities, there is an interest in how architectural form appears as visual impression of form. In Lam's view, the experiential processes of perception of lighting and architectural form is not a passive process, but an integrated part of our activities, sense of place, orientation, and history of inhabitation, which is negotiated relative to what we do, what we see, and how our perceptual processes operate. These experiential perspectives are similarly argued as essential to architectural form and design of lighting by Rasmussen in his book 'Experiencing Architecture' [3] and seen from a philosophical perspective in Nöe's 'Action in Perception' [4]. Rasmussen presents a set of form factors as a suggestion for an experimental approach to architecture, and Nöe investigates the consequences of how, for instance, light and environmental form appears if we understand perception as something we do rather than something that happens to us. In her PhD thesis [5], Karin Søndergaard further offers the design considerations that emerge when designing for participatory experiences, a perspective that further involves the social and relational aspects of perceptual engagement as framing agencies for the particular experience of place, environment, and event. For a more general introduction to the field of daylighting design and integration with artificial lighting, please consult Cuttle, Mathiasen, Madsen, and Tregenza [6–9].

The goal of the Observational Instrument is deliberately spatial, in the sense that the observers move and relocate across space while observing, and that the actual architectural forms and the relations to fellow inhabitants is a crucial part of the analytic activities. Analysis and considerations on lighting dynamics is an active performance of observational activities. The situation surrounding the Observational Instrument involves the experience and perception of the light and visual adaptation as part of the analytical context [10, 11]. The interrogation of the light in the space is based on the perception and experience of light as a relational experience rather than on measurements of light. Moreover, there is a focus on how the experience of lighting formations can be understood as spatial parameters. The Observational Instrument stages an architectural situation, a full-scale installation in any space of interest, where the influx of daylight can be observed, and the potential integration with artificial lighting dynamics can be investigated. The instrument enables a situation, where perceptual processes are actively incorporated in the event, through perceptual training and perceptual reasoning, while adjusting on incidents of lighting dynamics.

3. The composite of light from outside weather conditions

The fluctuation of daylight is an everyday experience of almost endless variation, observed as a direct consequence of the weather conditions and the composite of reflections from the environment. Components of sunlight and the luminous sky are modulated by dynamically changing cloud formations. Variations with larger duration are formed by the cycles of day and night, time of the year, and geographical position. These repeated operations form recognisable and predictable patterns that inform interpretations of orientation, shape shadows, and light distribution and change composition of colour temperature and luminous intensity. The variations during the day create a range of differently tinted colours, different angles of light, and different luminous intensities (**Figure 2**).

The morning light often starts in blue colours and shifts through a palette of variations into the whiter daylight. During evenings, the variation follows similar transformations, continuously and repeatedly unfolding the full range of dynamics, colours, and intensities possible.

Figure 2. The dynamic and complex daylighting flux. These images are from the same location photographed only 20 minutes apart.

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Clear sunlight produces sharper light zones, distinct shadows, and bright glare. Overcast days produce blurred light zones, diffuse shadows, and more evenly distributed colours and luminous intensities. The composite of the daylight influx is projected through the openings of the building, literally as project images of the outside, appearing upside down and reversed due to the camera obscura lens effect of the daylight openings, such as windows. The daylight in the building is a direct effect of the outside illumination and includes every reflective and shadowing element present, such as reflection of light from grass, trees, traffic, houses, etc. All these elements contribute to the complex composite of daylight influx and offer nuances to the visual experience of the indoor space.

The images in **Figures 3–5** depict two instances with very different lighting condition, **Figure 3** with diffuse light reflected from the opposite wall, **Figure 4** with direct sunlight on the Observational Instrument, and **Figure 5** in early morning light, resulting in very different colour tone and luminous intensities on the floor, the ceiling, and the wall. In **Figure 3**, the floor reflects the bluish sky, the wall the reflected sunlight, and the ceiling the combination of the green grass and the light reflected by the yellow brick building outside the window. In **Figure 4**, all internal reflections are dominated by the direct sunlight influx. In this way, every element in the surrounding environment is a component in the composition of the daylight influx in constant recomposition driven by time of day, weather, and environmental reflections.

Figure 3. The Observational Instrument with diffuse light from sunlight reflection at 11:40, April 30, 2014.

Figure 4. The Observational Instrument with direct sunlight influx at 9:20, April 30, 2014.

Figure 5. The Observational Instrument early morning at 7:30, April 30, 2014.

4. The digital weather

Taking the offset in the dynamic rather than the static lighting qualities, the design of the Observational Instrument is based on the concept of an artificial weather system. The digital weather software is in constant flux with dynamic parameters of adjustment, to be able to integrate with the complex of the natural weather variations through compositions of changes, dynamics, scales, and specialisation. The animated artificial light is projected from inside each surface of the cubical elements in the instrument, which enables separate adjustments in every direction of a cube and across the tessellated cube elements. The digital weather can be set to produce a dynamic composition that is reminiscent of the pattern similar to the effect of cloud variation in the sky, simulating dynamics that sometimes is composed with larger contrast and faster flow, and sometimes with delicate variations and almost imperceptible dynamics. The intent is to be able to develop complex compositions of dynamic flux in the artificial light that allows for integration with daylight flux as an ambient experiential material. The suggestion is that with the composite and dynamic weaving of light variations reminiscent of daylight fluctuations, the Observational Instrument gives access to investigations into dynamic relations and dynamic developments of integrated daylight and artificial lighting that otherwise is difficult to approach as material for architectural lighting design.

The software is built around the Perlin Noise algorithm, which is actually not a 'noise' in the sense of introducing uncontrolled variations, but a procedural generator [12] that is designed specifically 'to produce natural appearing textures on computer generated surfaces' [13]. The software is designed to perform two separate operations: one for generating kelvin variations and the other for generating luminous intensities. These two are layered and the combined expression makes the output for the light qualities at any particular point in space. The Perlin Noise algorithm is spatialised and negotiated as a two-dimensional space with fluctuations appearing across the space as waves, rhythms, speeds, and progressions, organised into larger formations of collective patterns and individual agencies (**Figure 6**).

The access to the generative parameters in the Digital Weather software is organised in scales and termed as Range, Speed, and Spread. The Range parameter sets the scale within which the colour or luminous intensity can change, with a minimum and maximum level. This adjustment could, for instance, determine, in the case of direct sunlight, that the variation in luminous intensities are only within the highest levels, but the change in colour spans the whole range possible. The Speed parameter determines how fast the dynamics unfold: from the slowest and almost imperceptible changes, through rhythms of waves, into rapid flickering. The Spread parameter determines the spatial composition of the light variations, in a scale where the extremes allow for totally individual behaviour of each LED, through to collective behaviours across the Observational Instrument as patterns and flows (**Figure 7**).

The Observational Instrument produces continuous fluctuating light compositions, which can be adjusted in how the dynamics unfold. Adjusting the settings allows for experimentation with how range, speed, and spread of artificial lighting dynamics are experienced to relate fluctuations in daylight. The effort of the adjustments can be difficult to eliminate the difference and thereby simulate dynamics similar to the daylight dynamics, which produces a digital formula on that particular dynamics in the settings of the instrument. There can be

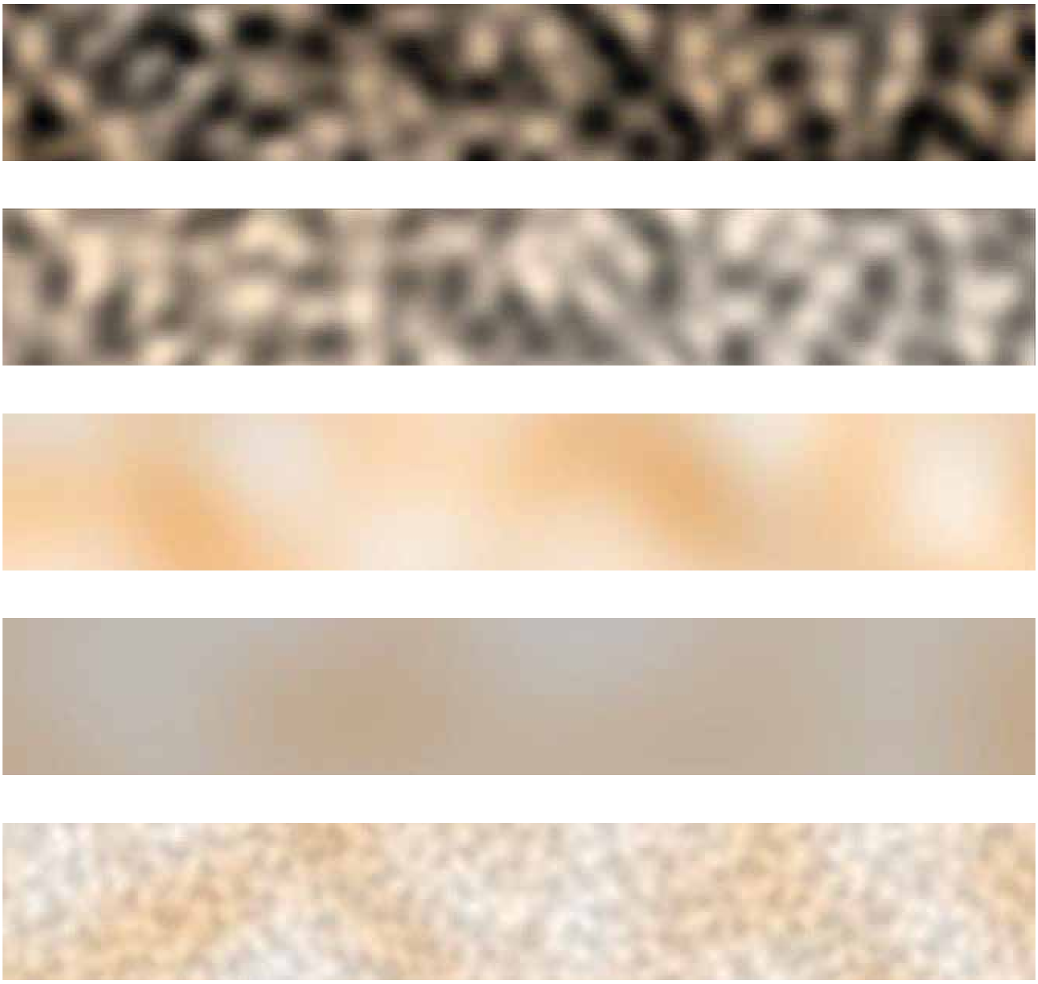

Figure 6. Instances of the digital weather procedural generator. The sliders through iterative tests have been adjusted to output dynamic imagery within a scope relevant for the Observational Instrument to produce lighting variations and dynamics similar to the influx of daylight.

investigation of subtle relationships of difference, which produce experiences of couplings between the two light domains as to which is foregrounded or backgrounded as organising texture. The design of the procedural software generator in digital weather delivers the exact same output, the exact same lighting formation given the same input on the sliders. The particular output is linked to the absolute time the software runs, so when the time of the particular moment is replayed, the software produces an exact duplicate lighting dynamics. This absolute time dependence allows the replay of events, reverse replay of events, and replay in any scaling of time as well as range, speed, and spread of the output. The organisation of the procedural software generator, which enables asynchronous and adjusted parameters, produces a design opportunity for detailed adjustments on scenarios recoded through experiential investigations. Further, an opportunity is created to delicately design lighting scenarios for aesthetic preferences or organised according to practical needs.

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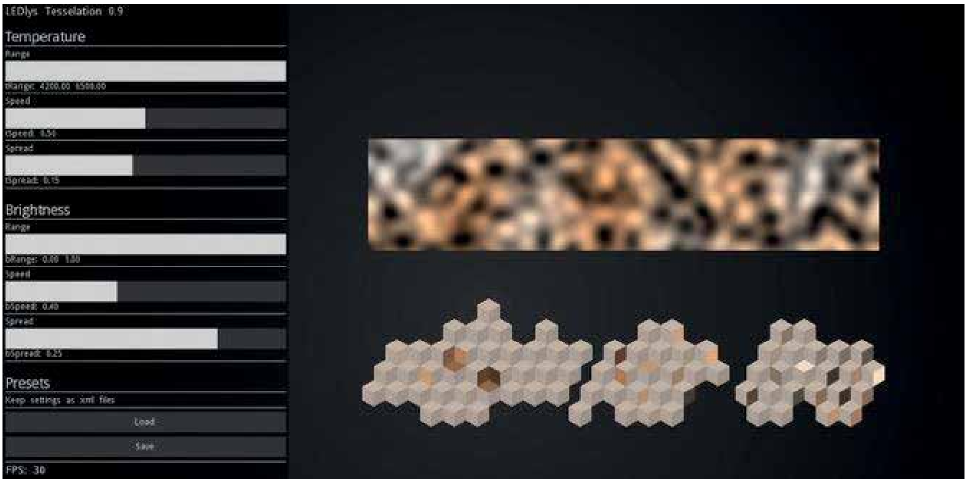

Figure 7. The control interface of the digital weather system shows exactly how the generative software produces a dynamic cloud texture, which then is mapped upon an image of the instrument. The back-lit surfaces of the instrument are adjusted accordingly. The sliders on the left help in adjusting the software parameters. The texture generation occurs in two separate layers: temperature and brightness, which control the colour temperature and the luminous intensities, respectively. Pre-sets can be saved and reloaded to allow for comparison across time and enable the development of sets of reference setting. One of the most interesting aspect of the Observational Instrument is to observe the most minute variations between artificial and natural light, an almost seamless integration, and thus enable a deeper and expanded experience of ambient relations, which then becomes possible to observe. Through the delicacy of the interweaving of fluctuations, the integrated lighting appearances become a separate quality in architectural lighting design, in ways that possibly enhances the material ambient qualities of architectural space.

Figure 8. Integrated daylighting and artificial lighting. A close look at a section of the instrument where some surfaces are lit by daylight and some by the embedded LED. The surfaces appear in a range of lit, reflected, and shadowed showing the range of local light variations. **Figure 9** shows the same section with the curtains drawn for the window, excluding the daylight.

5. The design of the Observational Instrument

The physical setup of quadratic surfaces is constructed to reflect incoming daylight, has a clear readability of shadows and light, and enables compositions of artificial light from a subset of surfaces with integrated LEDs. The surfaces are made of semi-transparent acrylic with frosted surfaces, and they are in this way able to merge light from the LEDs emitting from the inside with daylight reflected on the surface from the outside. The aim is to have a structure for experiencing compositions of fluctuating artificial light integrated with natural variations of daylight. Each light-emitting surface is outfitted with a reflector and a piece of LED strip with high colour rendering indices (CRI) warm white and cold white LEDs. The embedded LED strips are driven from LED drivers that are capable of operating with a bit depth of 16, giving a fine-grained control of intensities with more than 65,000 digital steps, effectively making fine and slow intensity shifts almost imperceptible. With the usual bit depth of 8, we would have experienced discrete digital quantisation in slow intensity fluctuations, especially in the lower 10% range, where a range of 256 steps becomes very visible. Dimming curves are adjusted to perceptual dynamics, with much higher resolution in the darker range than in the brighter one and further adjusted to enable smooth transition through the Kelvin scale.

5.1. Intensity and colour temperature

The built-in luminaires have two variables, luminous intensity and colour temperature. These two variables can fluctuate completely independently, as our LED lights decouple the relationship between colour temperature and luminous intensity that was interlocked in incandescent bulbs. The variables form a two-dimensional space of possible light outputs. Any point in this space can describe the current state of a single light emitter. The lightness could be experienced as bright, dim, off, blinding, etc. The colour temperature could be warm, cold, etc.

5.2. Time and durational composition

Fluctuations occur over time, and we are interested how fluctuations affect our experience of artificial light. The fluctuations are our path through intensity and colour temperature. How does the experience of the fluctuations change with their speed and what is the relationship between speed of light fluctuations to its integration and adaption as artificial light to the daylight influx?

If colour temperature and intensity describes the ‘what’ of our light emitter, the fluctuations describe the ‘how’. Fluctuations can have temporal qualities such as repetition, rhythm, syncopation, flicker, etc. We would like our light compositions to potentially exhibit all of these complex qualities, without having to expose a plethora of parameters and options in the software interface.

With LED lighting, any change in intensity or colour temperature can occur discretely or continuously, that is, at an instant or gradually over time. However, we are mostly interested in exploring artificial lighting fluctuations that are reminiscent of natural phenomena. As nothing moves physically in zero time, we want the fluctuations to appear continuous. We look for

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a simple function that allows us to generate fluctuations that are continuous at low frequencies and appear unpredictable yet subtle. The function should have sets of time variables, and the user should be able to control the speed of this time. The core driver of fluctuations over time is the Perlin Noise animations, which generate a form of pseudo-random coherent noise that has proven useful for procedural generation of seemingly natural structures. When interpreted as light fluctuations over time, the Perlin Noise exhibits qualities ranging from imperceptible, alive, over syncopated to noisy.

5.3. Spatial composition of light fluctuations

A major visual component of LED lighting is the possibility to individually control light emitters. Let us now look at a collective of lights. When more lights are arranged together, their fluctuations collectively assume relative spatial qualities such as dense, sparse, coarse, uniform, and individual. When taking part in such an arrangement, a light emitter can be interpreted as a pixel.

If the coherence takes the form of figurative representation, it is reminiscent of the effect of mapping the spatial relationships of the lights to a video input. However, our focus is on the experience on spatial and temporal qualities that lies beneath concretely representational uses of lights as pixels, towards signals that give our lights a spatial relationship. For this abstract spatial reference, we use Perlin Noise in two dimensions, which could look like the one in **Figure 9**:

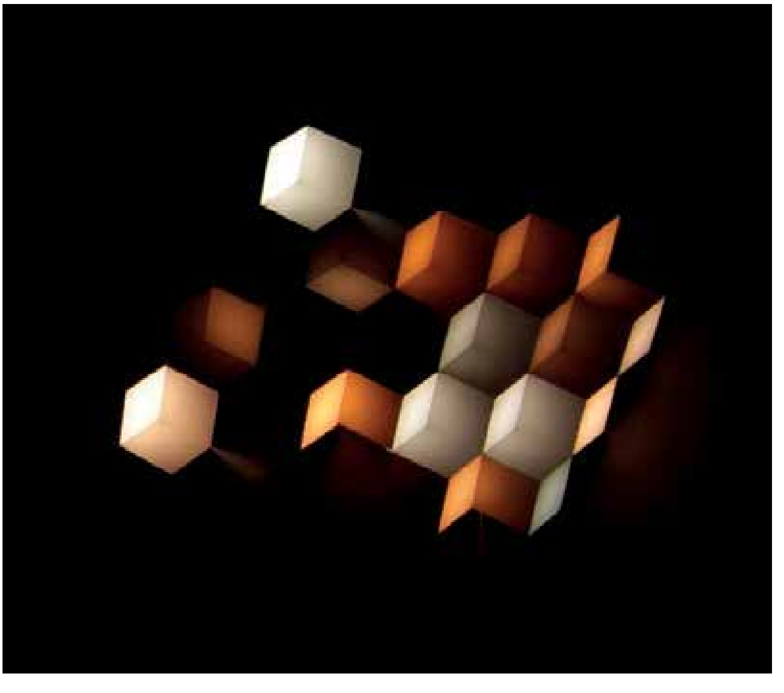

Figure 9. The artificial lighting as it looks when the curtains are drawn excluding the daylight influx. **Figure 8** presents the instrument with both daylight and embedded artificial light.

5.4. The control of adaptive lighting dynamics

With an outset in the principles of using generatively animated two-dimensional Perlin Noise as a source for colour temperature and luminous intensity, a control software has been developed that enables the designers to generatively synthesise, study, and describe temporal and spatial qualities of fluctuating light compositions. This cloud of Perlin Noise would be animated over time, at a user-defined speed. The image at the top of the screen is a composite of the two animated Perlin clouds. This animation is sampled and mapped onto the individual light-emitting surfaces that are shown in the visualisation of the Observational Instrument. The mapping retains the spatial relationship from the image to the arrangement of lights. (**Figure 10**).

There are two similar-looking sections for 'Temperature' and 'Brightness' and a bottom section for loading and saving pre-sets. The two sections for Temperature and Brightness each have three parameters that control how their Perlin Noise animation behaves. The first parameter is manipulated with a Range slider that sets two values: the minimum and maximum for the fluctuation. This means the white portion of the slider can be dragged sideways at both ends, effectively contracting or expanding the possible range of intensities of temperatures. The range slider is linear.

The middle slider sets the Speed of the fluctuation. This slider is cubic, prioritising high resolution in the lower (slow) end of the scale. A cubic slider allows for finely tuning extreme slowness, an important prerequisite for composing fluctuations that are changing at an almost imperceptible pace. On the other hand, the slider will still allow extremely fast fluctuations at the higher end of the scale, allowing comparative experiential research of the extremes. When at zero, the animation is stopped.

The last slider sets the so-called Spread of the cloud. This is effectively a 'zoom' slider allowing scaling of the Perlin Noise. This can be understood as 'how far the lights are from each other' or 'a scale between uniformity and individuality'. When at zero, the Spread parameter generates an animation that is 1x1 pixel, rendering a uniform value across the noise field, in effect letting the lights behave in unison. When dialled all the way up, the Spread parameter generates an animation that is very fine-grained, in effect letting the lights behave totally individual without any apparent coherence (**Figure 12**).

Figure 10. A two-dimensional Perlin Noise field at a given frequency: spread or zoom-level.

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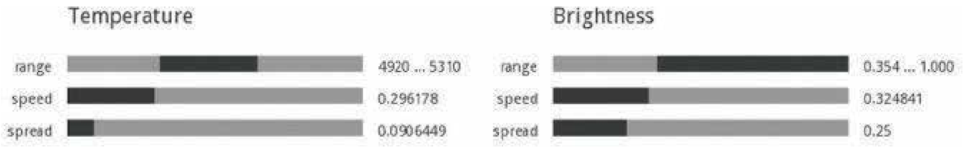

Figure 11. Digital weather animation controls.

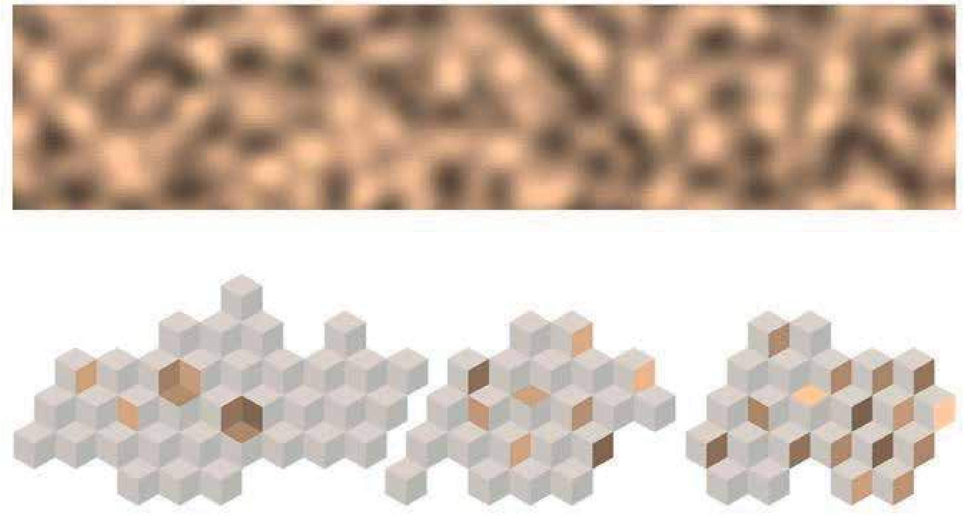

Figure 12. The digital weather animation and the mapping onto the Observational Instrument.

Remember that this is an animated noise: generative and continuous. When formatted as light output in the Observational Instrument, it is possible to synthesise abstract lighting fluctuations that are reminiscent of the fluctuations in natural daylight as weather fluctuations, reflected light from water surfaces, filtered light from the movement of leaves in trees, or modulated light variations by the passing of clouds (**Figure 11**). Other more extreme or 'unnatural' compositions are also possible, and allow for comparatively studying and qualifying the temporal aesthetics of dynamic artificial light interplaying with the always-dynamic daylight.

Engaging with the Observational Instrument and tuning between daylight and artificial lighting enables the development of enhanced sensibilities to minute nuances in the light fluctuation. The Observational Instrument stages an experiential situation where experience of delicate adaptive lighting dynamics can be rehearsed and tested, progressively building a refined capacity to understand and design with lighting dynamics.

6. Engagement with lighting design experts

The integrated weather systems focus on change and variation and promote an expanded field of dynamic flux in the artificial lighting. The appearance of adaptive dynamics as ambient flux might also allow a new form of entanglement of user experience, which involves a dynamic overlap between the dynamics of visual impressions and perceptual processes that emerge out of actions [9]. Ambience in this thinking is the experience of light fluctuations integrated as context, as an emergent material quality in-between several environmental influences [14, 15].

Fourteen architectural lighting design professionals have visited the installation in 2014 during the development phase and first iteration of the Observational Instrument, advising in the parameterisation and dynamics of the instrument. Each visitor spent 60 minutes closely observing the installation (**Figure 1**) guided through a pre-defined schedule of activities and engaged in continuous discussion as a semi-structured interview. The investigation followed three phases, where the visitors focused on: (1) the experience of lighting dynamics, (2) the integration with daylight dynamics, and (3) the perceptual experience of moving through the space themselves [16, 17]. The responses were rich and contextualised with in-depth expert knowledge on the challenges in the field, but a few significant positions can be extracted and synthesised.

The dual dynamics of the integrated daylighting and artificial lighting enables movement and changes the designers' focus from light as designed objects in space towards a form of ambient composition, which could be rehearsed in a range of variations through engagement with the instrument. The visitors noted the obvious capacity to enhance the daylight dynamics further into space, maintaining the textual and ambient qualities often missed in current system designs. The embedded Digital Weather algorithms seemed to show the ability to deliver daylighting qualities in spaces with no daylight access, enabling a relevant lighting design service in IoT infrastructures. The strategic move from lighting design as a configuration of luminaires that each contribute to the light in space, towards lighting as an embedded feature in the reflective materials of walls and objects, possibly with no primary light sources at all, would prioritise the architectural shapes as primary light givers rather than luminaires, and thus change the basic assumption on the elements that compose a lighting design.

The implications of the enhanced design capacities rehearsed by experiential engagement with the Observational Instrument have relevance in several contexts of lighting design. The possibility of adaptive lighting enables heightened focus on the need for daylight exposure when indoor facilitates enhanced relation between dynamic outdoor condition in the indoor environment and promotes energy saving by using more daylight and less artificial lighting. The delicate adaptive artificial lighting allows architectural designs beyond the current constraints, where the design solution facilitates a common average of daylight influx, often leading to measures of shading to keep the daylighting dynamics in control. With a dynamic integration of daylight and artificial lighting, more daylight can be allowed to enter indoor, delicately controlled by adaption of lighting conditions across the day, and weather conditions.

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design and descriptions of the software functions and interface design were done by Ole Kristensen, ITU. The project is described in detail in the published report: An Exploration into Integrating Daylight and Artificial Light via an Observational Instrument [18].

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Designed for Delight: Surprising Visual-Tactile Experiences Using 3D Printing in Lighting Design

Edgar R. Rodríguez Ramírez,
Sebastien Voerman and Helen Andreae

Additional information is available at the end of the chapter

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Abstract

Designing for surprise is a useful tool for designers and can elevate a product from mundane to memorable, drawing attention and inviting engagement. Existing strategies have explored surprise in product design through the exploration of sensory incongruities, most notably visual-tactile incongruities: when an object looks different to what it feels like to touch. There are two digital technologies that offer new opportunities to investigate surprise in tangible-embedded interactive systems: 3D printing and tangible interaction through sensor controls. Research is yet to investigate how visually tactually incongruous 3D printing can offer new strategies for eliciting surprise in lighting design through tangible-embedded interactive systems. This research addresses this identified gap by assessing the applicability of the Ludden's strategies to surprise through 3D printing. This was performed through the design of a series of experimental 3D printed objects and lights that sought to surprise by using visual-tactile incongruities. We suggest new approaches expressed through the final designs of four interactive lights; objects designed to inspire delight through their unique interactions and surprising qualities. We report on new strategies to surprise by using an experiential gap between vision and touch through 3D printing and we report the findings from user-testing sessions.

Keywords: surprise, visual-tactile incongruity, 3D printing, interaction design, lighting design

1. Introduction

Surprise represents a useful and powerful tool for product designers looking to inject more dynamism and intrigue into people's relationships with their objects [1–5]. It has the potential to draw people in; inviting touch and encouraging interaction. One technique for exploring surprise in the design of objects is by manipulating the user's visual perception of the tactile experience they expect to have. This is known as a visual-tactile incongruity (VTI). The use of this was identified by Ludden [2] as a technique employed by designers to elicit surprise in their products. Ludden developed a collection of strategies that addressed and identified the various ways in which VTIs had been employed in a collection of products. Most of these products did not explore multimaterial 3D printing, which is an advanced additive manufacturing technology and offers capabilities and qualities outside the possibilities of other manufacturing techniques [6].

This chapter explores how the unique qualities that multimaterial 3D printing offers can be coupled with the capabilities of electronic sensors to generate surprising interactive technologies that create a perceptual and experiential gap, seeking to ascertain whether there is the potential for developing new specific approaches for generating surprise.

Fox-Derwin [7] identified that surprise generated through a VTI in existing products is often marred by a lack of longevity, a property that she called a "one-liner" (p. 2), also referred to as a "one-time experience" [2, 8]. Since surprise can be perceived as value-adding, this loss of surprise could be translated to a loss of perceived value in the product. Fox-Derwin [7] suggests the use of layering surprise into the interaction as a way of extending the experience and encouraging a rich reflection and relationship with the object. This research explores this in combination with VTIs and interactive systems in lighting design, seeking to extend and expand the user's' experience and sense of surprise. Lighting design acts as a focal point, offering direction and a specific outcome for both the interaction and the surprise. This directed focus and expectation of illumination offer a specific field of design opportunities to experiment with the use of VTIs in combination with interactive systems and 3D printing.

2. Background

The key existing explorations that underpinned the research included the Ludden's strategies for surprise that she developed by assessing existing product designs. These strategies were conceived and analyzed in the context of traditional manufacturing technologies and were limited to the prevailing manufacturing technologies that the designers had access to. Rapid prototyping technologies, particularly 3D printing, were not as widely used by designers in 2008 as they are today. Strategies proposed by Ludden explored how VTIs had been used in the studied designed objects but did not systematically explore how new and emerging technologies could have an impact on the way these strategies could be applied. Therefore, there was an opportunity to assess the applicability of these strategies to 3D printing as well as suggesting new approaches to generating surprise in product design. Polyjet photopolymerization (PPP), a multimaterial printing technology where ultraviolet light cures incremental layers of photopolymers laid down by an extrusion head, was chosen as the primary printing technology due to its capabilities for hard and soft material blending (gradients, interlocking sections, and materials within other materials) and high-resolution finishing, potentially lending itself well to setting up visual-tactile incongruities.

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Ludden [2] identified six strategies for eliciting surprise in the design of a product: "new material with unknown characteristics; new material that looks like familiar material; new appearance for known product or material; combination with transparent material; hidden material characteristics; and visual illusion" (p. 31). These six strategies are all framed within two categories: Hidden and Visible Novelty. These categories illustrate an overarching difference between the strategies and whether the user can discern a visible novelty. This distinction affects the reveal of the surprise, and research [1] suggests that superficially it seems possible that a "Hidden Novelty" (HN) strategy could elicit a stronger sense of surprise due to the lack of an expectation of novelty (p. 31). "Visible Novelty" (VN) strategies explore a different angle on surprise, where the user enters the experience with a larger degree of uncertainty. While it appears that on the surface, an HN strategy might be more successful at providing immediate surprise, a VN strategy could potentially have a longer lasting effect of delight, which research corroborated by saying "people often viewed VN products as more interesting than HN products" [1].

In lighting design, most familiar systems generally favor two types of controls: on/off switches and dials (generally used for dimming light). These are the physical components that people interact with through their sense of touch and offer an opportunity for eliciting VTIs. By offering a different tactile sensation to the one visually apparent, this could layer the surprise directly into the interactive system. As a result, "the beneficial aspects of eliciting surprise through interactions with products will have the potential to be prolonged" [7]. Touch is responsible for a lot of our emotional investigation and investment, as well as our bodily awareness [9, 10]. As a result, this surprising reveal could have a greater emotional impact than if it were revealed through another sense.

There are a variety of sensors that can interpret tactile interactions, including flex sensors, capacitive touch sensors, potentiometers, pressure sensors, knock sensors, and many others. These sensors can each facilitate different aspects of tactile interaction. Pleasurable tactile interaction with products has been connected with usability [11, 12]. Ross and Wensveen [12] explored interactive product behavior, suggesting that the interactions with a product are of significant importance and should underpin the entire process of designing the product. These understandings provide a clear opportunity to emotionally and experientially extend these interactions with electronic systems and to enhance the experience and engagement with the interactive system.

3. Methods

Exploring how the unique qualities that 3D printing offers could generate surprise involved a two-phase process. Phase 1 investigated and critiqued the Ludden's strategies through an iterative research, through design process [13] and through developing sets of criteria. These criteria formed the basis for a morphological analysis [14] that was used to develop 23 physical experiments. These experiments were all designed in the constraints of the Ludden's strategies, with five experiments being developed for each of the three Hidden Novelty strategies and two experiments for each of the four Visible Novelty strategies. More experiments were developed for the HN strategies, as these appeared to offer more opportunities to distinctly experiment with the capacity of PPP multimaterial printing to elicit a VTI. Designed to incorporate all the distinct material qualities (soft, hard, gradients between soft and hard, transparent, opaque, translucent) available through PPP, the 23 experiments explored the visual and tactile perception of two sets of opposing visible material qualities: "softness to hardness," and "texture to smoothness" (**Figure 1**).

All 23 initial experiments were tested with 10 participants who were unfamiliar with PPP. The participants, between 17 and 20 years old, were first-year design University students, of which half of the participants were male and half were female. While they were aware of 3D printing technologies and had worked on projects by using Fusion Deposition Modeling (FDM) technologies, they had not seen or worked on PPP or other multimaterial 3D printing technology. Data were collected following a procedure similar to Evaluative Research or Product Testing [15], while also using observation and self-reporting techniques, including questionnaires [16], the Geneva Wheel of Emotions [17], and interviews [18]. Participants were shown the cubes one by one and asked to visually assess the object on scales of "hard to soft" and "textured to smooth" as well as verbally voicing their thoughts on the object through Thinking Out Loud (TOL). They were then asked to physically interact with the object and fill out the same scales again in order to gauge their tactile perception of the objects. A large difference between their visual and tactile self-reports would indicate the presence of a VTI. The participants were also encouraged to expand on their emotional experiences with the objects through the use of a customized Geneva Wheel of Emotions [17] that included segments added for "Negative-" and "Positive Surprise." Phase 1 concluded on four specific approaches to elicit VTI that were further investigated in Phase 2.

Phase 2 explored designing an individual light for each of the identified four approaches, as well as incorporating design elements from the experiments in Phase 1. The experiments from Phase 1 also informed the usage of PPP's unique qualities to develop the control mechanisms and the light-diffusing components of the lights. The lights and their corresponding interactions were designed based on qualities and features seen in the experiments from Phase 1, and the integration of sensors and microcontrollers was considered based on the specific interaction desired. The employment of the sensors and the coding around them allowed for carefully calibrated and tested interactions that highlighted and facilitated particular approaches to actually engage with the lights. All the final designs incorporated layered surprise and interaction (visual, tactile, and hidden) in order to increase engagement and delight when experiencing the object. The interactions were often hidden, encouraging users to explore, contemplate, and experiment with different ways to turn the lights on.

These lights were tested using a similar, but improved testing process from the first phase. The lights were hidden from the user before being exposed, whereupon the user had to record their visual perceptions of the object before getting to touch it. After getting to physically interact with the prototype, the user was asked to record their resultant tactile experiences of the object, as well as filling out a Geneva Wheel of Emotions in order to self-report their emotional experiences with the lights. The order of the reveal of the lights was randomized between participants, only one light was ever shown at once, and the lights were again tested with 10 participants.

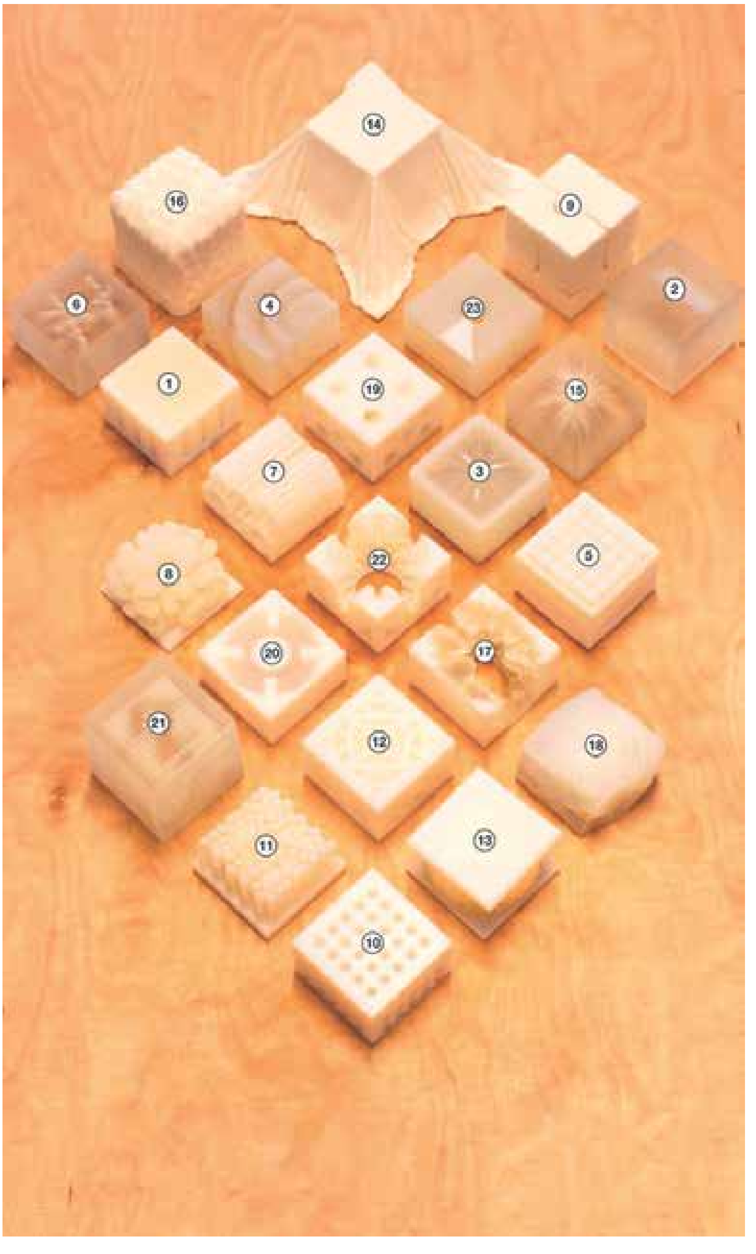

Figure 1. Resulting designs from the initial experimental approach to explore freely the opportunities PPP offers to elicit visual-tactile incongruities (see **Table 1** for names and description).

4. Results

Analyzing the data from Phase 1 highlighted that certain concepts and their strategies for creating VTIs were more successful and more emotionally well received than others. This enabled the development of four approaches tailored toward eliciting surprise through the use of PPP, adapted from the Ludden's strategies:

> "Visually referencing recognizable forms, objects and structures, but making them tactually different."
>
> "Using material variances and unfamiliar forms to encourage interaction."
>
> "Suggesting surfaces have texture when they are actually smooth, through the use of an illusion."
>
> "Using internal structures to challenge the initial visual perception of the material properties." (**Tables 1–3**).

Each of the final four lights incorporated a very different interaction, with some leaning more heavily on the coding of the microcontrollers, whereas others relied primarily on the sensors. All the lights incorporated a "reveal" aspect with the activation of the light. There is no obvious "switch" on any of the lights, so users had to experiment with the lights to discover the activation. The design of the lights (**Figure 2**) incorporated various elements that were designed to elicit VTIs, all built directly into the means of activating the lights. Each of these lights was designed as an expression of one of the four approaches identified at the end of Phase 1.

Design one (**Figure 3**) was based off a crystalline structure, using this recognizable structure as a basis for creating a VTI where the structure was revealed to be soft on touch. This reveal of the soft structure also showed the user what the interaction was; by flexing each crystal individually, the bend sensors within would allow the user to tune the amount of light emanating from the base of each crystal. A series of carefully calibrated sensors and coded responses allowed the individual an intuitive control of the lights. This design explored the potential of the "Visually referencing recognizable forms, objects, and structures, but making them tactually different" approach. The 3D printed structure made use of the advanced material composition possible with PPP, with fine blending between the softest materials at the tips and a rigid structure at the base to keep the crystal structures in place. The design also included an internal semi-flexible skeleton as well as a procedurally generated series of minuscule opaque volumes to simulate occlusions and sharp-looking edges in an attempt to carefully replicate the visual appearance of a crystal. This VTI proved to be the most surprising out of all the designs, as the visual reference was the most well understood, and a clearly visually rigid quality was being challenged with a malleable, soft, and tactile structure.

Design two (**Figure 4**) relied on the user's exploratory curiosity, hiding six different switches under the myriad of soft, organic forms that yielded to the touch. The forms, each a series of intersecting 3D volumes of various densities and rigidities, were parametrically developed to incorporate small variances between each other, emulating variety between the individuals of

1	*Intangible Depth*	Used an under-the-surface gradient in PPP materials to alter depth perception of a seemingly transparent material.
2	*Collapsing Construct*	Used a textured cavity to create the look of a filled centre, which readily collapsed when touched.
3	*Citrus Resistance*	Used variance in PPP material to create a squishable and heavily tactile form referencing a citrus fruit.
4	*Dynamic Onion*	Used intense layering of PPP materials to achieve an onion-like object with variations in material properties.
5	*Compression Mosaic*	Hid soft material structures underneath harder components, in order to create a flexible hard surface.
6	*Hidden Red Peak*	Hid a disjointed series of pieces that form an image when viewed from a specific angle.
7	*Collapsing Tubes*	Created a structure that does not make an explicit reference to anything specific, and makes use of soft PPP materials to collapse in a bizarre way.
8	*Dendritic Coral*	Created a reference to coral-like structures, a structure that most people do not get to touch, only look at. Make object that is soft with hard detailing.
9	*Hidden Articulation*	Object was designed to explore the potential of internal mechanisms and explosive motion.
10	*Hidden Light Tubes*	Created a cube that uses clear PPP material to allow light to pass through the model in unexpected locations.
11	*Tentacle Grasses*	Explored the potential of the PPP material blending in order to create an intense tactile experience.
12	*Textural Variance*	Explored the ability to suggest softness where there is rigidity, by layering the softer PPP materials over a hard core.
13	*Twisting Expections*	Created an object that translated an inputted twisting motion into a sudden expanding motion, through PPP material variance.
14	*Fabric Falsification*	Used hard materials and intense texturing from fabric simulations in order to visually suggest softness and familiarity.
15	*Frozen Reflection*	Created a structure using PPP printing that looks very similar to an ice cube but ends up being soft and warm.
16	*Liquid Hesitance*	Explored the potential making printing look like a thick, pasty liquid, attempting familiarity.
17	*Rubberised Geode*	Referenced crystal structures through the form as well as the optical quality of PPP. The crystalline structure is actually soft.
18	*Stress Stone*	Explored making soft PPP material variants look like stone. Explicitly explored form as well as surface texture.
19	*Disconnected Light Tubes*	Created a cube with light tubes that are connected in abnormal ways, encouraging curiosity and exploration.
20	*Dynamic Button*	Created a single moving structure using PPP that reveals new components when a button is pressed.
21	*Illusion Die*	Explored the possibility of different points of view revealing different symbols to the user.
22	*Rubberised Thorns*	Created a cube that references hard, dangerous forms and have them revealed to be soft and pleasant.
23	*Spiral Collapse*	Created a form that looks like a solid textured cube, but that is actually revealed to be a dynamic and smooth spiralling structure.

Table 1. Name and description of the 3D printed design experiments from Design Phase 1 (see **Figure 1** for photos of each experiment).

Approaches To Surprise / 3D Printing Qualities	VN: Combination with Transparent Materials	VN: New Appearance for Known Product or Material	VN: Hidden Material Characteristics	VN: New Material with Unknown Characteristics	HN: Hidden Material Characteristics	HN: New Material that looks like Familiar Material	HN: Visual Illusion
Build internal structures or mechanisms.	Intangible Depth	Citrus Resistance Dynamic Onion	Compression Mozaic Hidden Red Peak	Collapsing Tubes	Hidden Articulation Twisting Expectation	Frozen Reflection Rubberised Geode	Disconnected Light Tubes Dynamic Button Illusion Die
Build simultaneously with different materials showcasing distinct properties.	Intangible Depth	Citrus Resistance Dynamic Onion	Compression Mozaic Hidden Red Peak	Collapsing Tubes Dendritic Coral	Hidden Light Tubes Tentacle Grasses Textural Variance Twisting Expectation	Frozen Reflection Rubberised Geode Stress Stone	Disconnected Light Tubes Dynamic Button Illusion Die Spiral Collapse
Create gradients in material from hard to soft.	Collapsing Construct	Citrus Resistance Dynamic Onion	Compression Mozaic	Dendritic Coral	Tentacle Grasses Twisting Expectation	Rubberised Geode Stress Stone	Dynamic Button Illusion Die Spiral Collapse
Create gradients in material from almost clear to almost opaque.	Intangible Depth	Citrus Resistance Dynamic Onion	Hidden Red Peak	Collapsing Tubes Dendritic Coral	Hidden Light Tubes Twisting Expectation	Frozen Reflection Rubberised Geode Stress Stone	Disconnected Light Tubes Illusion Die Rubber Thorns
Create complex structures and textures with ease.	Collapsing Construct	Citrus Resistance	Compression Mozaic	Dendritic Coral	Tentacle Grasses Twisting Expectation	Fabric Falsifications Liquid Hesitance Stress Stone	Rubber Thorns

Table 2. Design Phase 1: 3D printing qualities that PPP affords and how the strategies to surprise were applied.

a species as well as creating a less homogeneous surface to interact with. Each switch activated a separate panel of light under the structure, and the organic formation created a unique diffusion of the light. This design explored the "Using material variances and unfamiliar forms to encourage interaction" approach. The two halves of the form spun independently of one another, ensuring that the user would be unlikely to be able to memorize the location of the switches, refreshing the search for the switches between uses. This design proved to be frustrating for a number of participants, as the organic structures proved too numerous to be able to reliably find a switch in a short time frame.

Design three (**Figure 5**) built the interaction around the relation of shapes and the "Suggesting surfaces have texture when they are actually smooth, through the use of an illusion" approach. The 3D printed structure needed to be stretched and attached to the other half of the form to light up. The VTI emerged out of the sinuous "slinky-like" form of the 3D printed component, which is not apparent until it is touched. When the structure is stretched and attached to the other half of the design, a sensor detects the magnetic field created by a small magnet in the end of the 3D printed component, and the structure lights up through LEDs built into the base of the wooden structure. A number of participants experienced an "Aha" moment when they

Experiment Number & Strategy Code	Name of Prototype	Notable VTI achieved
#1 - VN1P1	Intangible Depth	
#2 - VN1P2	Collapsing Construct	Tactually found to be softer than visually perceived.
#3 - VN2P1	Citrus Resistance	
#4 - VN2P2	Dynamic Onion	
#5 - VN3P1	Compression Mozaic	
#6 - VN3P2	Hidden Red Peak	
#7 - VN4P1	Collapsing Tubes	Tactually found to be smoother than visually perceived.
#8 - VN4P2	Dendritic Coral	
#9 - HN1P1	Hidden Articulation	
#10 - HN1P2	Hidden Light Tubes	
#11 - HN1P3	Tentacle Grasses	Tactually found to be softer than visually perceived.
#12 - HN1P4	Textural Variance	
#13 - HN1P5	Twisting Expectation	
#14 - HN2P1	Fabric Falsification	
#15 - HN2P2	Frozen Reflection	
#16 - HN2P3	Liquid Hesitance	
#17 - HN2P4	Rubberised Geode	Tactually found to be softer than visually perceived.
#18 - HN2P5	Stress Stone	
#19 - HN3P1	Disconnected Light Tubes	
#20 - HN3P2	Dynamic Button	Tactually found to be softer than visually perceived.
#21 - HN3P3	Illusion Die	
#22 - HN3P4	Rubber Thorns	
#23 - HN3P5	Spiral Collapse	Tactually found to be smoother than visually perceived.

Table 3. Notable VTIs achieved by the initial experiments.

understood the intended interaction but were all surprised by the emergent light quality that highlighted some less visible details of the design, such as the pattern of miniature translucent volumes inside the slinky-like component.

Design four (**Figure 6**) references a dial-like structure, which however has collapsible sections, which cave inwards when gripped tightly, showcasing this design "Using internal structures to challenge the initial visual perception of the material properties approach. The dial is a potentiometer that can be turned to cycle up through all the light combinations; however, these emerge in an interesting way, using a four-way binary coding system, which was linked to four physical relays, allowing a gradual "mechanical dimming" through the individual cycling of differently numbered groups of lights. The interaction here was rewarding and delightful, incorporating an auditory component as well through the opening and closing of the relays, with the reveal of light patterns being particularly praised by research participants. However, the reveal of the collapsible structure was not noticed by a number of the participants.

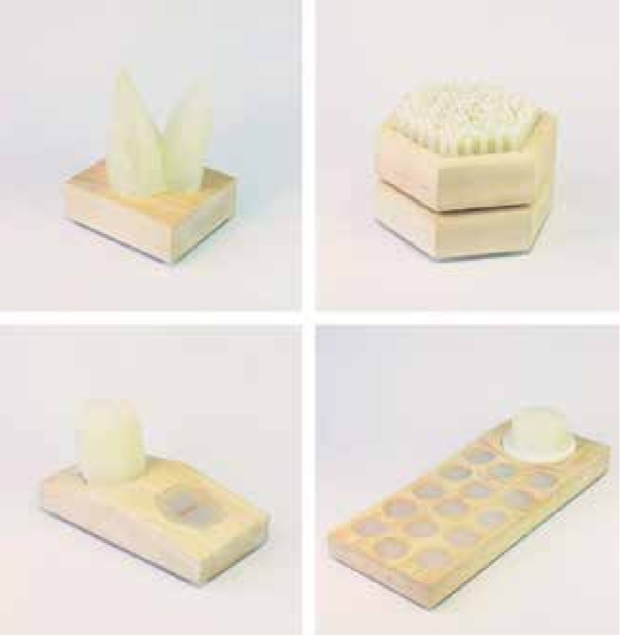

Figure 2. (Clockwise from top left): design one: malleable structures; design two: organic formation; design four: rotary relays; design three: spiral connection.

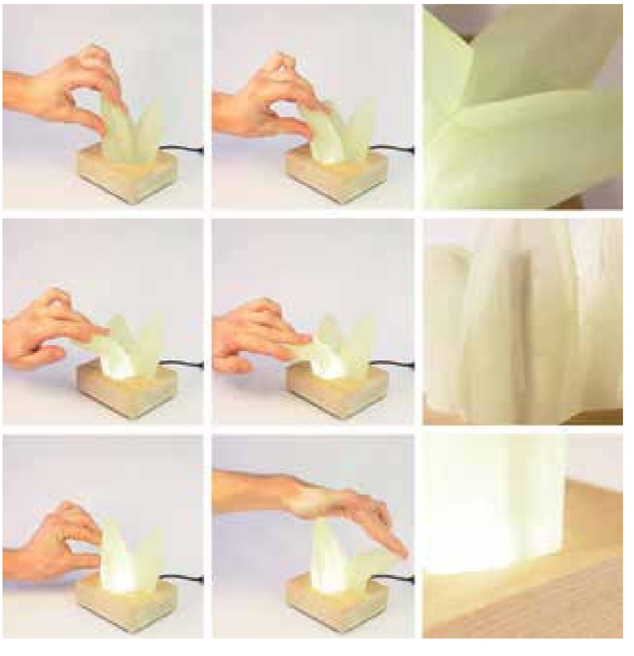

Figure 3. Design one: malleable structures. PPP 3D print, wood, Arduino microcontroller, flex sensor, and LED lights.

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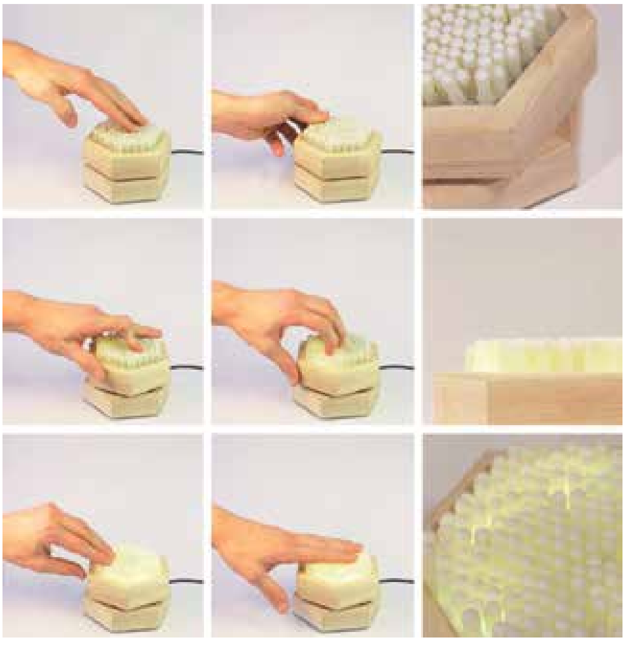

Figure 4. Design two: organic formation. PPP 3D print, wood, Arduino microcontroller, switches, and LED lights.

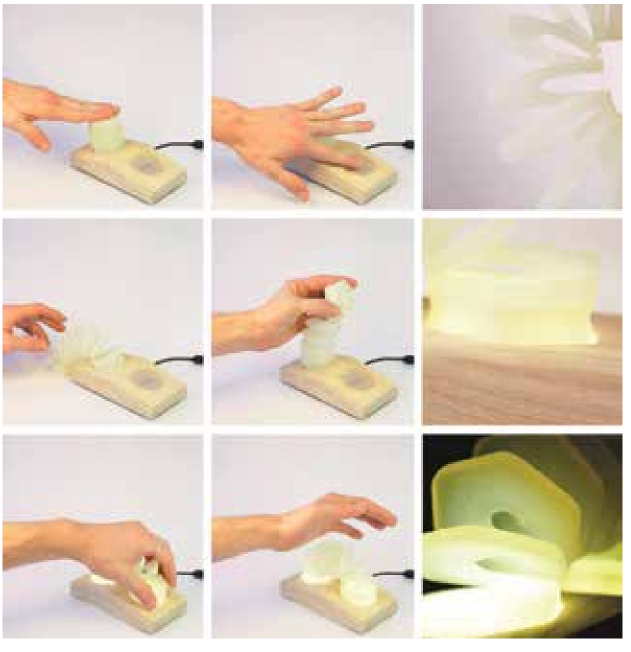

Figure 5. Design three: spiral connection. PPP 3D print, wood, Arduino microcontroller, magnetic sensor, and LED lights.

Figure 6. Design four: rotary relays. PPP 3D print, wood, Arduino microcontroller, potentiometer, and LED lights.

5. Discussion

Ludden developed strategies through looking at existing products that evoked surprise; yet there was only one example of a product employing 3D printing, namely the "Konko Lamp," designed by Willeke Evenhuis & Alex Gabriel. Exploring the possibility of using PPP 3D printing to elicit surprise through the use of VTIs, particularly using its capabilities to print in soft and hard material combinations, yielded interesting findings that suggested 3D printing appears to show a greater usefulness for the '*Visible Novelty*' (VN) subset of the Ludden's strategies, as the designs based around these strategies tended to invite interaction and speculation.

After conducting research into the applicability of these strategies, it would appear that some of her strategies do offer viable angles for exploring surprise through the use of 3D printing. However, given the still somewhat limited visual qualities of PPP printing at present, achieving effective expressions of Ludden's '*Hidden Novelty*' (HN) strategies is still out of reach. Ludden et al. highlighted that the "HN surprise type includes products that seem familiar to the perceiver, but have unexpected tactual properties" (p. 30). While this appears to sound like the effect seen in the prototype *Malleable Structures*, participants still mentioned that "*It looks odd*" (Participant 8) and "*It looks like a crystal, but I'm not sure*" (Participant 2). A number of participants made comments suggesting that they were not convinced about their visual perceptions, suggesting a more predominant presence of VN in the designs, despite the best efforts to truthfully emulate the real qualities of the desired structure. Finding materials that PPP can specifically emulate, and designing familiar forms and structures around those could address achieving true HN designs.

We believe this primarily due to the "look" of PPP 3D printing. Many participants picked up on the visual strangeness of the materials (most of the prototypes ended up looking somewhat like complex arrangements of various kinds of candle wax). Based on their responses, it simply does not appear to have been possible to fully deceive the viewer's perception enough to make them believe the materials they see are not "odd." However, having a fundamental understanding of the qualities and possibilities of PPP can still offer designers specific ways to elicit surprise. Ludden et al. [2] noted that "people tended to exhibit more exploratory behaviors when interacting with VN products."

People often viewed VN products as more interesting than HN products" (p. 37). For the designs developed in Phase 2; which all incorporated aspects of VN, almost all participants spent well over a minute exploring most of the lights. The reverse of this was seen in several of the purely HN strategy cuboid prototypes from Phase 1, which usually elicited only very brief interactions and comments such as "Oh, it's just hard. That's disappointing." (Participant 4).

Ludden's strategies in the HN category were still essential to the development of the final designs, but the final light designs themselves actually end up fitting predominantly into the VN category, due to the inherent inability for PPP to accurately simulate the visual qualities of other recognizable materials. The four designs developed in Phase 2 explored combining specific PPP capabilities with the Ludden's [2] strategies. The approaches put forward are based on a systematic exploration through the Research through Design approach, as well as the questionnaires and interviews employed during the user testing. These approaches are not exhaustive, and there is potential for research to develop further approaches related more specifically to other 3D printing technologies beyond PPP.

3D printing is an incredibly important growth area presently, with the latest Wohlers Report highlighting that "the 3D printing industry has grown by US$1 billion" [19]. Understanding the state of the art, what can be done with the technologies, as well as how it can be pushed to the limits is vital in ensuring designs utilizing it can remain surprising. Surprise has, as discussed in previous sections of this chapter, a lot to offer to designers. Exploring the potential of 3D printing, how it can surprise and challenge our sensory perception through the use of VTIs is a topical, relevant exposition. Its application to the comprehensible field of lighting design is one particular angle that this chapter pursued. There is a myriad of other areas dependent on interesting, engaging interactions that this research could potentially inform.

6. Conclusion

Designed for Delight sought to expand on existing strategies for the elicitation of surprise to include the new, advanced manufacturing technique of 3D printing. The strategies, suggested by Ludden [2], were based around visual-tactile incongruities. This chapter systematically explored and critiqued the possibility of applying these strategies to the 3D printing technology Polyjet photopolymerization (PPP), using this to then generate new and specific approaches. This was achieved through designed objects exploring all the Ludden's [2] strategies, and these approaches then inform the design of lights that incorporated interactive controls imbued with VTIs. The exploration of lighting design was chosen due to the expectation of illumination from the interaction. This offered the opportunity to counter expectations of the interaction as well as the reveal of light.

Upon reflection over the data from user testing and the resultant developed lights, it was realized that a key determinant for the success of these approaches in these contexts was how well the approach for eliciting a VTI was combined with the interaction designed for the lights. The importance of this marriage between the approach, the interaction and the possibilities of the 3D printing technology cannot be overstated in this context. In order to generate surprise through a VTI, the designer needs to clearly comprehend their chosen 3D printing technology. This requires a display of sensitivity toward the qualities achievable and carefully employing the desired approach. This will allow designers to craft products that can surprise and delight, conveying more meaning and allowing the end-users to build better person-product relations.

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Chapter 28

Using Shape-Change to Express Dynamic Affordances of Intelligent Systems

José E. Gallegos Nieto and Yaliang Chuang

Additional information is available at the end of the chapter

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Abstract

As intelligent systems permeate the world, our everyday lives are made easier and less tedious. However, there exist too many "intelligent" systems whose lack of communication or low intelligibility frustrate users. In this study, we present a tangible interface aimed to bridge human-system interaction. It expresses behaviors through shape-change, and its body movements indicate system status and are responsive and rapid enough for perceptual crossing. Based on preliminary results of a user study conducted with 16 participants, the prototype's implicit interactions show promise in establishing a basic dialog and point to goals and challenges in designing technology that feels truly "smart."

Keywords: shape-changing interfaces, machine-learning, intelligent systems, implicit interaction, anthropomorphism

1. Introduction

In a technology-driven market, a main area of focus is designing "smart" products to improve people's daily lives. It is estimated that by 2020, people will have more than 20 smart devices on their body or in their immediate surroundings [1]. Those intelligent agents will continuously sense and proactively suggest changes with goals including: better energy efficiency, improved productivity, and greater entertainment. To reduce the efforts of controlling increasingly numerous, complex, and capable technologies, many systems will also be able to *learn*. User preferences will be computed along with outside factors to automatically adapt devices and the environment. However, there is a problem in that an excess of automation often leads to user frustrations [2]. Lack of user control and machines' failure to effectively communicate with users are two important challenges surrounding interactions with intelligent systems [3, 4].

Several studies, for example [2, 5, 6], suggest that users want to at least feel a degree of control over an intelligent system's decisions. One possible strategy is to communicate system reasoning to the user [7]. However, a notable study [6] highlighted two challenges in improving users' mental models (understanding) of a system. First, users' knowledge and skills might be insufficient for understanding the complex reasoning of their machines. Second, users often lack the interest or time to invest in learning how a system works. To address those problems, this study aimed to explore interactive designs that could provide incidental intelligibility from the interactions with intelligent machines or systems. We investigated the means by which machines might express their reasoning, their willingness to cooperate, and their ability to negotiate conflicts. With an intelligent lighting system as an application area, we developed a tangible interface that utilizes movement to acknowledge the user's approach, invite their interactions, convey its learning, and show its subjectivity in an implicit way. Our focus is to learn to foster successful social relationships between humans and intelligent systems so that they may coordinate and perform tasks together smoothly and pleasurably.

2. Theoretical background

As intelligent systems enter everyday lives, people often encounter very basic problems in communication [8]. Users move through interactive fields often without knowing which objects or spaces to interact with because too many systems are "faceless" and not revealing themselves to be "smart" until the user produces a correct interaction cue through the medium (s) that the system anticipates [9]. Such a lack of a prompt, or feedforward, represents a total decoupling of actions and functions. Deckers et al. [10] proposed the concept of perceptual crossing to show the system's "face" and let users know their approach is acknowledged: a reciprocal interplay of perceiving while being perceived. With perceptual crossing, users can not only recognize the possibility to initiate interactions with machines but also engage in a more continuous way with something akin to an artificial living creature.

The notion of "calm computing" proposed by Weiser [11] is a pattern for intelligent systems in which designers use implicit communication for informing without annoying. Relatedly, a tendency is that as systems develop their perceptional capabilities and intelligence, they require less of an explicit command and control relationship with humans [12]. Implicit interactions can take us far in managing attention, controlling expectations, and minimizing cognitive load. These are helpful factors in applying our research to the successful control of an environment [13].

In implicit human-to-human interactions, body language is a medium through which information is transmitted easily, intuitively, and both continuously and subconsciously. The physical body given to the prototype (as described in the following section) aims to use body language to similarly evoke and even convey emotions (statuses) on this behavioral level. The use of body language also left us with a satisfying amount of ambiguity, allowing for interpretation which along with perception is a crucial pillar for implicit interaction [12]. Ambiguity, in this case, was also a design resource to encourage close engagement with the artifact, an approach detailed by Gaver et al. [14].

3. *Anthox*: a physical hypothesis

The name of our prototype, *Anthox*, is an abbreviation for "Anthropomorphism Box." None of the preceding research directly focused on the design theories of anthropomorphic products. However, it is apparent that the topics of perceptual crossing, implicit interaction, and body language use human interactions and qualities as a starting point for study and analysis. As such, anthropomorphist qualities were an intuitive goal to aim for in the overall characterization of our design.

With the objective of testing reactions to the prototype's interaction styles as well as their intelligibility level, an experiment (Section 4) was designed in conjunction with *Anthox*. As to what would be communicated, the plot chosen was a machine-learning scenario in which *Anthox* represented system change over time. In such a scenario, the system would need an amount of training data to learn to serve its users. At first inexperienced, *Anthox* would need to elicit interactions from the user; it might be "needy" or even "insecure" at its lack of knowledge. Later on, a more "self-assured" *Anthox* might try to communicate its confidence in what it has learned and even offer resistance to a user's input; the message might then be interpreted as a gentle assertion of the intelligent system's competence or superiority. With this evolution in mind, a vocabulary of movements for *Anthox* was designed. Overall, the expectation was that its implicit and tangible methods of interaction would not only enrich the expressiveness of intelligent systems but also be more intelligible and accepted by users.

3.1. The intelligent system

The system in this case is a speculative, intelligent lighting system deployed within an office environment. The exact capabilities of this imagined lighting system were left open ended. It would have some autonomy and be more than a reactive setup, where, for example, lights turn on when you enter the room. Instead, it would incorporate information gathered from sensors in its physical context and other data such as the weather forecast or the office's calendar and agenda. It might compute employees' levels of fatigue by tracking sleep patterns, caffeine intakes, eye movements, or any other related parameters. Emotions could also be tracked, as today it is possible to read these *wirelessly* and with astonishing accuracy [15]. With all of these data, the automatic control of light (color temperature and brightness) could be optimized to be energizing and to enhance comfort and efficiency [16]. Said benefits are measurable, and it is well-documented that light affects humans on psychological, physiological, and emotional levels [3]. Although this system remains mostly speculative for now, it will soon be possible for our lighting environments to be automatically improved in a way that would be infeasible with conventional, manual controls.

3.2. The design

Anthox serves as the physical face and locus of interaction for an otherwise largely intangible lighting system. As presented in **Figure 1**, *Anthox* is a white cube with a circular opening on the top surface. This is where interaction happens. Under a layer of mesh fabric, there is a circular control surface consisting of a graphic mapping of light color temperature and brightness (**Figure 2**). This control plate is translucent and backlit. The light enables the graphic to be read through the stretchy fabric mesh above it. Single-touch inputs are received on the control plate (through the fabric) as in **Figure 1**. Users are given functional feedback through connected Philips Hue lights which change according to their inputs.

Figure 1. *Anthox,* a controller for an intelligent lighting system.

Figure 2. Graphic mapping of light color temperature (left to right, kelvins) and brightness (up and down, lumens).

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The circular control plate is the place for both the input and the output on the *Anthox*. The control plate is capable of moving up and down relative to the top surface of the cube; it can rise above the rest of the box, be flush with the top surface, and also sink down (**Figure 3**). The fabric is attached to the box around the circumference of its (stationary) top circular opening and also in the middle of the rising and falling control plate. Therefore, when the control plate sinks below the top of the box, the fabric is pulled down in the middle, creating a cone shape pointing down (**Figure 4**). This middle point on the control plate to which the fabric is attached is also capable of rotating. The rotation produces a twisted, wrinkled spiral in the fabric. This resulting spiral can be created while the circular control plate is at any height, be it protruding over the box or sunk down inside of it, as diagrammed in **Figure 3**.

These two parameters of body movement constitute *Anthox's* potential for expressivity and natural interaction [12]. The level change and spiral motions work to change the controller's affordances. When the control plate rises or is flush, the colored graphic (**Figure 2**) is legible and highly accessible to touch. When the control plate falls, the graphic becomes less visible

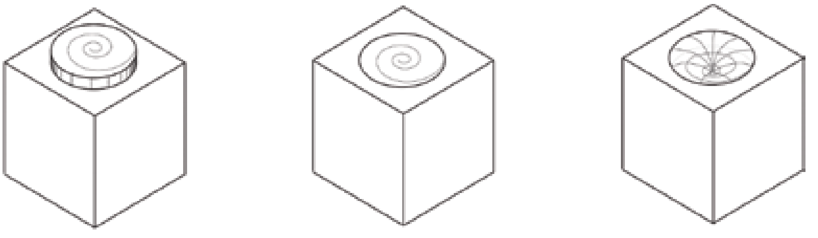

Figure 3. The control plate rising above, flush, and dropping below the top surface of the box.

Figure 4. The *Anthox* with control plate sunk down inside, fabric twisted into a spiral. Compare legibility of control surface with that of **Figure 1**.

because the fabric becomes separated from the plate, and the fabric itself becomes a soft barrier between the user's hand and the control surface (**Figure 4**). The spiral which can be formed by the fabric similarly serves to partially conceal the control plate and to make the surface uneven and less receptive to touching. Through shape-change, *Anthox* alters its affordances to present dynamic relationships to the users in an implicit way.

4. User study

A lab format user study was conducted in order to understand whether *Anthox* could facilitate users' perceptions and interactions with an invisible intelligent system. The study sought to learn if these interaction styles could successfully establish a feeling of communication and if so, to what degree it was intelligible. This mainly involved testing for perceived evolution or change over time in the system. Finally, the study sought to learn about the relationship established with the artifact on an emotional level.

As mentioned, the design of *Anthox* was done in conjunction with the design of the experiment. For said testing, two behaviors were developed: *Scenario A* and *Scenario B*. The latter behavior, *Scenario B*, was designed to match the designers' narrative of machine learning. Detailed below, it gradually removes affordances and thereby becomes less accessible to the user, demonstrating its "confidence" and independence from user input. In testing for intelligibility, half of the participants were shown this sequence without any prior prompts about machine learning. If they detected a change over time *and* correctly attributed it to an evolution in system status, then the system might be judged as intelligible and successful in one of its goals.

By contrast, *Scenario A* was designed as a completely inverse behavior. The purpose of testing a completely opposite sequence (where affordances were gradually added, not removed) was to avoid confirmation bias. By also not adhering exclusively to our own interpretations of *Anthox's* implicit interactions, more room was left for other users' interpretations. Additionally, *Scenario A* was a point of comparison to *Scenario B* when it came to analyzing results.

4.1. Procedure

The test began with a short introduction to the topics of artificial intelligence (AI), automated lighting systems, and highly-capable LEDs. Machine-learning, or evolution in that AI, was designedly not mentioned. The prototype was then introduced as a controller for a 'smart lighting system in an office', but the exact capabilities of said system (i.e. amount and types of sensors, data) were left undefined. Participants were first able to interact with *Anthox* freely, with no particular tasks given. After becoming briefly acquainted with the control of light on the immobile prototype, participants were put through five hypothetical scenarios of use over time, during which the prototype then became animated.

The *Anthox* was controlled in a "Wizard of Oz" method by the evaluator via a hidden set of controls. This method was favored over preprogrammed sequences in order to maintain flexibility in the responses. The goal was to increase the likelihood of users feeling that they

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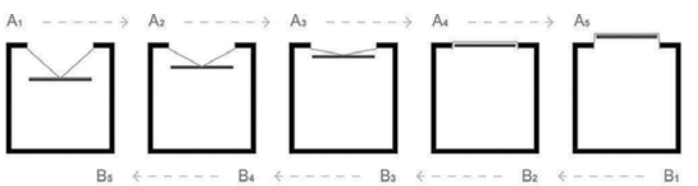
experienced a perceptual crossing or engaged in a dialog with the *Anthox*. As far as the connected lights that the system would be controlling, we used a Philips Hue color bulb (placed in a table lamp next to the user) and a Hue Lightstrip (above the user, near the ceiling). Both capable of displaying 16 million colors, they are an example of the highly capable technologies that AI may help us use to fuller potential in the future.

Figure 5 details the procedure used. The graphic in said figure represents five sectional views of the *Anthox* over time. Here one can see that *Scenario A* is an inverse of *Scenario B* in terms of movement of the control plate. That is, *Scenario A* sees the control plate rise over the course of the five hypothetical scenarios that the users were put through, while *Scenario B* sees it falling over the same scenarios. The left column (labeled Scen.) shows that progression with reference to the labeled graphic above.

The middle column in **Figure 5** (labeled Narrative) is what the participant heard during each of the scenarios. Here are the actual scenarios verbalized by the evaluator during the test as a directive of what users should imagine and respond to. They mention the passage of time but make no mention of *change* over time by the AI itself. Again, this and any other judgments are up to the user to interpret from the *Anthox's* movements.

The column on the right in **Figure 5** (labeled controls) is what the evaluator used as rules for the behavior of the movements of the *Anthox*. These are the movements the evaluator executed



Scen.	Narrative (participant)	Controls (evaluator)
A_1 | B_1	**Scenario:** "Your company moves to a new building which has a 'smart' lighting system in it. It always turns the lights on automatically, but you decide that your office will need more cool and bright light for the work that you do. You approach the controller, observe it, and set it." **Task:** cool and bright	**UP/DN:** bounce up and down, 2-3 times - upon approach retreat slightly (shy) **SPIN:** (eliciting) rotation back and forth (135°), continuously -*[user input]*- CONFIRM * **Light Setting:** from initial 'Concentrate' (70%) - to 'Energize' at (100%)
A_2 | B_2	**Scenario:** "One or two weeks pass, and you're pretty settled into the new space. It's now Friday afternoon, and you are tired and just want to relax. So you go to the light controller and set a warmer color temperature." **Task:** warm color temp, same brightness	**UP/DN:** bounce up and down slightly, once or twice - upon approach repeat slight bounce **SPIN:** (eliciting) slight rotation back and forth (45°), continuously -*[user input]*- CONFIRM **Light Setting:** from 'Energize' (100%) - to 'Read' (100%)
A_3 | B_3	**Scenario:** "On most days, you ride your bike to work. Today you arrive first in the office, and you notice as you step inside that your smartwatch indicates that your heartrate is still a bit elevated from the ride. - The lights inside try to ease you back to a relaxed state, but you are ready to start the day, so you walk to the controller and set the usual cool and bright light you use to work. **Task:** cool and bright	**UP/DN:** slow up and down slightly, once or twice - upon approach slight bounce **SPIN:** rotation back and forth (30-40°), once or twice -*[user input]*- CONFIRM **Light Setting:** from 'Relax' (55%) - to 'Energize'(100%)
A_4 | B_4	**Scenario:** "It's Friday, and the end of another long week. Again, you are incredibly tired. You decide to end your day several hours early, and you go to the light controller to set more warm and relaxing light, at a lower brightness." **Task:** warm color temperature, lower brightness	**UP/DN:** come up very slightly, remain still - upon approach remain still ** **SPIN:** still, upon approach rotate and remain at (30°) -*[1st user input]*- ask confirmation, (elicit) rotation back and forth (30°), wait -*[2nd user input]*- CONFIRM **Light Setting:** from 'Energize' (100%) - to 'Relax' (65%)
A_5 | B_5	**Scenario:** "You are working on Tuesday afternoon with the usual cool and bright light you usually use. Today, for no reason at all, you decide to change the light settings to make it slightly darker in here." **Task:** cool, less bright	**UP/DN:** sink down very slightly, remain still - upon approach remain still - upon *[1st input]* jump slightly, once ** **SPIN:** still, upon approach rotate and remain at (45-50°) -*[1st user input]*- ask confirmation, (elicit) rotation back and forth (30°), wait -*[2nd user input]*- CONFIRM **Light Setting:** from 'Energize' (100%) - to 'Energize' (75-85%)

* CONFIRM stands for fabric SPIN a full 180° and then returning to the default (smooth) position
**UP/DN movements stopped upon [user input]. Only in scenarios (A_5 | B_5) did they resume after the *[1st user input]*, and then cease again upon *[2nd user input]*.

Figure 5. Procedure table.

through the prototype. These rules are described in terms of the two parameters possible: up and down of the control plate and spinning of the fabric. Note that UP/DN is relative to the position of the control plate at the given scenario; the starting point for any UP/DN motions follows the progression of low to high (*Scenario A*) or high to low (*Scenario B*). Meanwhile, the SPIN category describes movement of the fabric above the control plate in degrees: 0° being the default and 180° being the fully twisted position. The order of movements is crucial. Apart from the gradual removal of affordances, latter scenarios require multiple inputs before the system "confirms" a command. This is meant to reinforce the notion of the system becoming independent.

Below the 'UP/DN' and 'SPIN' rules are the lighting controls executed in each scenario. The Philips Hue app was also used to covertly control the connected lights in the room. To aid in response times and consistency, preset "scenes" that Philips includes with the Hue app were used by the evaluator to respond to the users' touch inputs on the prototype. The values for brightness specified in the table can also be found and manipulated through the app for these same "scenes".

4.2. Participants and evaluation methods

A total of 16 Master's students (mean aged 24 years, 8 males and 8 females) from the authors' department participated in this study. They all are familiar with topics of AI, ubiquitous computing, connected lighting systems, etc. They, therefore, were capable of understanding and responding to queries on a high level. They were tested in a between-group design, participants being randomly assigned to *Scenario A* or *Scenario B*, with an equal split in gender.

During the evaluation, participants were asked to think out loud, and their interactions with *Anthox* were video recorded. They also filled in an affect grid [17] to help better communicate the resulting feelings or impressions. After the interactions, we used audio-recorded open-ended interviews and discussed topics including: general opinions of *Anthox*, interpretations of movements, nature of the relationship, perceived intelligence, and change over time. This was also an opportunity for the designers to discuss their opinions over the usage of implicit interactions over explicit ones. Further discussion on these and other topics are presented in the following sections.

5. Results

The result of the affect grid survey is shown in **Figure 6**. An overwhelming 81.25% of participants engaged the interaction with high levels of physiological arousal. More than half felt it was pleasant to use the prototype. Meanwhile, the movement of *Scenario B* (from high to low) was thought to be pleasant by twice as many participants than that of *Scenario A*.

A popular topic for remarks was that of the dynamic affordances, especially when the control plate sank to its lowest position. This setting elicited the most engagement, as users had to more closely inspect and probe the prototype to execute their commands. Although cited by half of the participants as the point where they doubted if they had control over the system,

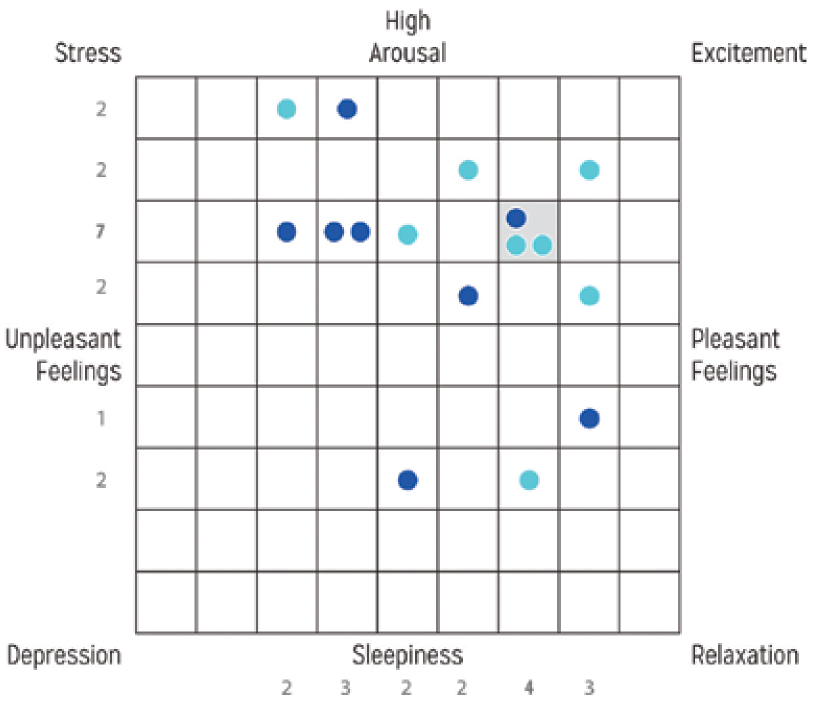


Figure 6. Affect grid responses: blue are inputs from *Sequence A* (low to high) cyan are inputs from *Sequence B* (high to low).

only one participant reported losing total control here. All others were confident in their ability to override the system, and this decreased affordance was seen more like an increased threshold and not an absolute barrier.

In over half of the open-ended interviews, participants mentioned anthropomorphic and zoomorphic adjectives as part of their descriptions of *Anthox* and its behaviors. Of eight participants who used anthropomorphic adjectives to describe *Anthox*, three also reported feeling that they were not in absolute control, indicating some sort of power struggle. However, in all cases of users regarding *Anthox* as anthromorphic or zoomorphic, responses were positive in regard to their relationship with the system.

There were only four participants who correctly interpreted the overall change in level of the control plate as a visualization of a machine-learning process. *Scenario B*, in which the plate sinks down over time, was understood by more participants (3) than *Scenario A* (only 1). The sole *Scenario A* participant who correctly interpreted machine learning even went so far as to propose a redesign of the sequence which they experienced (low to high) to match the reverse: the order of *Scenario B*.

This is yet another point in favor of *Scenario B*, which overall yielded slightly more favorable reviews in the open-ended interviews. Five of eight *Scenario A* participants had negative comments about *Anthox*, while only one *Scenario B* participant expressed any serious criticism.

This is also apparent in **Figure 6**, where cyan inputs representing *Scenario B* lean slightly more toward the pleasant (right) side of the matrix than their counterparts from *Scenario A*.

Interesting takeaways came from participants' descriptions of the human-computer relationship they felt was established. At the very least, participants felt they interacted with some sort of subordinate, often anthropomorphized (like a child or an animal). Only one participant felt that they reached a sense of negotiation with the *Anthox*. Four others reported feeling close to a negotiation, but it became clear that *Anthox* needs a way of offering *explicit* suggestions to make negotiation possible.

Overall, all but three participants felt that they reached *some* understanding of the "language" or signals being exchanged in the interactions, and most of them stated that an even better understanding could be developed with time. We can therefore suggest that implicit interactions were successful in establishing at least a basic dialog, and that certainly there is potential in making improvements toward this goal.

6. Limitations and future work

There are three limitations in the study presented in this manuscript. Firstly, *Anthox* helped us to investigate participants' opinions in interacting with a shape-changing system through the "Wizard of Oz" approach. However, further work is needed to investigate how a human user will interact with a system that is able to express its own intelligence. Secondly, in a machine-learning scenario, it would take a training period for the intelligent system to learn the human users' behaviors and preferences, and vice versa. Subtler aspects of the user experience might not have been revealed in the short period of time users participated in our experiment. Finally, although more than half of our participants found the simple movements to be pleasant and easy to understand, shape-changing forms could be further explored to express alternative semantics.

Based on the results of this study, we are currently working to give the prototype simple machine learning functions. We plan to deploy the system in an office environment to investigate how people perceive its intelligence and react to its dynamic affordances. The goal of our research is to understand how to design the interactions with human-like characteristics in order to improve the understanding between user and system. With longitudinal testing, we would be able to contribute much more valuable knowledge in designing for intelligent systems.

7. Conclusions

To address problems of technologies' intelligibility and the associated frustrations, this study applied implicit interactions through shape-change to attempt to bridge interactions between humans and AIs. With the two simple movements it is capable of, *Anthox* was able to implicitly communicate a variety of messages. In comparison to more explicit forms of signaling, our data also suggest that users might be more willing to encounter dissent from an interface with a more, "playful" interaction style or appreciable "personality." For now, only two participants imagined that over time the *Anthox's* interaction style could become tedious or annoying. While not definitive, this encourages further exploration of this paradigm.

The prototype is named for its dependence on natural interaction styles anthropomorphic or zoomorphic in nature. A risk in the investment toward this approach was the potential of creating a sense of conflict between system and user; certainly to perceive something as anthropomorphic does not equate to feeling favorably toward that object. This is especially relevant in control relationships, where a power struggle with an entity perceived as somehow sentient could become very unpleasant. However, as touched on in the previous section, all participants characterizing *Anthox* as anthropomorphic felt positively toward it, and only one participant ever felt they lost control completely. Favoring simple or playful interaction styles seemed in this case key to maintaining these positive relationships.

When anthro/zoomorphic adjectives began to be used by participants, there seemed to be an associated recognition of perceptual crossings; this is a point where the artifact started being imagined as sentient and more aware. When this happened, users also attributed more complex mental models to the *Anthox*. For example, one participant from *Scenario A* noted, "it is like a baby, you always have to guess at what it wants." Choosing instead to see *Anthox* as a being of another species, one user from *Scenario B* stated, "you never have to think about what you are going to say to your dog […] but somehow the interactions with them (dogs) are always pretty successful."

Participant preferences for *Scenario B* supported our own hypothesis in designing the removal of affordances. Through comparisons of qualitative data between the two, we found that indeed *Scenario B* was more understandable and more pleasant. With our own intuitions confirmed in this regard, future work should look toward testing and understanding more complex behaviors and distinct messages.

The most promising contributors to our experiments were the concepts of natural and implicit interaction styles. The increase in complexity of our changing technological context (has and) will be unmanageable for the human attention span and cognition. Information overload will have to be managed by artificial intelligence and diluted down to less formal and explicit communication channels, where perhaps implicit interaction will be the primary way for us to navigate through it all.

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The authors developed this project within the Interactive Lighting Squad of the Industrial Design Department at the Eindhoven University of Technology, and therefore inspired and aided by the students and staff within the squad, as well as their work. Inspiring also was previous work at the same university and department in the realm of shape-changing interfaces, notably the GHOST (Generic and Highly Organic Shape-changing inTerface) module led by Miguel Bruns Alonso and Matthijs Kwak.

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ReActive: Exploring Hybrid Interactive Materials in Craftsmanship

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Additional information is available at the end of the chapter

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Abstract

This paper presents ReActive, a design exploration aimed at embedding interactivity in traditional materials by artisanal processes. In the attempt to reconciling technology with human experience and tradition, we experimented with artisans to understand how craftsmanship can embrace technological innovations while at the same time maintaining its nature and value. We built samples of hybrid materials, where electronics and smart materials are embedded in traditional ones, in order to make them reactive and interactive. We discuss implications and new possibilities offered by these new hybrid materials both for artisans and users and new perspectives for interaction design.

Keywords: interaction design, materials, craftsmanship, flexible electronics, reactive pigments, user experience, esthetics of interaction

1. Introduction

Electronics has long been associated to technological development and considered a cold, unemotional element. During the last decades, HCI has tried to move towards more emotional and human-centered approaches to technology and electronics, trying to find new meanings to them and looking at the experience they generate [1, 2]. As a consequence, the field of interaction and experience design emerged. Recent trends in these fields are exploring how interaction with smart and tech-rich products can be esthetically pleasant [3, 4], how electronics and smart materials can enrich the product's esthetics by making it dynamic and changing [5] and how electronics and computation can be considered new kinds of materials, also called computational composites [6], able to produce innovative experiences. Such approaches are complemented by the rise of the Do-It-Yourself (DIY) movement, where people experiment new ways to integrate technologies in everyday objects and materials. Technology becomes more transparent to be seamlessly integrated into textile [7], paper [8, 9], and hard surfaces.

Although much has been done in shaping increasingly human interactions with technology, the process of *making* technological and smart objects has been more and more detached from traditional, artisanal processes, heavily relying on computational and machine-based processes like 3D printing and modeling. Technology seems to be far away from the world of craftsmanship, with its values of uniqueness, care for details, high quality and slow-paced, manual production. What if interactive and smart products manufacturing processes could be reconnected to artisanal processes? What if electronics and technology could be treated and approached as traditional materials, used to shape not only new product functions, but also new static and dynamic esthetic qualities of physical objects?

Some researchers have experimented in this field [11], by proposing new ways to merge electronics and traditional crafting activities and materials. We used a similar approach to develop a project, ReActive, in which we tried to explore how to reconcile craftsmanship and technology, with the aim to achieve three goals: (i) studying traditional artisanal craft processes to identify points of intervention with smart materials and fabrication methods; (ii) advancing and enriching artisanal works by adding a layer of interactivity and smartness to the materials of tradition; and (iii) softening technology and smart products by introducing esthetic qualities and values proper of the artisanal world.

Compared to previous experiences, we do not address DIY or artistic movements. Instead, we focus on the world of artisans, to provide a framework that connects hybrid materials to artisanal processes, in order to inspire new artisanal work. Can these new trends really be leveraged and absorbed by artisans, to modify and add new competences and open up new opportunities?

2. The ReActive project

ReActive was a collaborative project performed in collaboration with traditional artisans in the Florence area of Italy, aimed at exploring the potentials in utilizing electronics and smart materials in their crafts. The goal was to try to develop new types of hybrid materials with dynamic appearances and interactive qualities, starting from the traditional materials and processes used by artisans. We identified a number of conductive and smart materials that could be coupled with such traditional materials to make them reactive and smart. The aim was to create new experiences with these materials of tradition, without changing their nature, instead adding a layer of interactivity to them, that still allowed to keep their properties and that could be smoothly embedded into matter by artisanal processes.

In our exploration, we experimented with the following three sets of elements:

- traditional materials: paper, ceramics, fabric, and leather;
- crafting techniques: fusing, painting, knitting (weaving), embroidering, and gilding;

- smart and conductive materials: conductive fibers, conductive ink, metal leaves, and reactive pigments.

We investigated the results that could be obtained by merging these materials and processes. Samples of new coupling between traditional materials and smart materials/electronics were generated and are described in the paper. Finally, new possibilities opened up by these hybrid materials, possible applications and scenarios transformation for artisans and users are discussed.

3. Experimenting with hybrid materials

Figure 1 illustrates the experiments we performed on different materials. It shows how we embedded conductive and smart materials into traditional materials by artisanal crafting processes.

In the following sections, we describe the experiments we performed on each class of materials, starting from the study of the Florentine artisans' activities.

3.1. Paper

3.1.1. Painting

Florentine paper is famous for the decorative marbling patterns. It is used in many products, from stationary items to the wrapping of small household objects. As a versatile material used in our everyday objects, we wanted to explore ways to add interactivity to this sheet material.

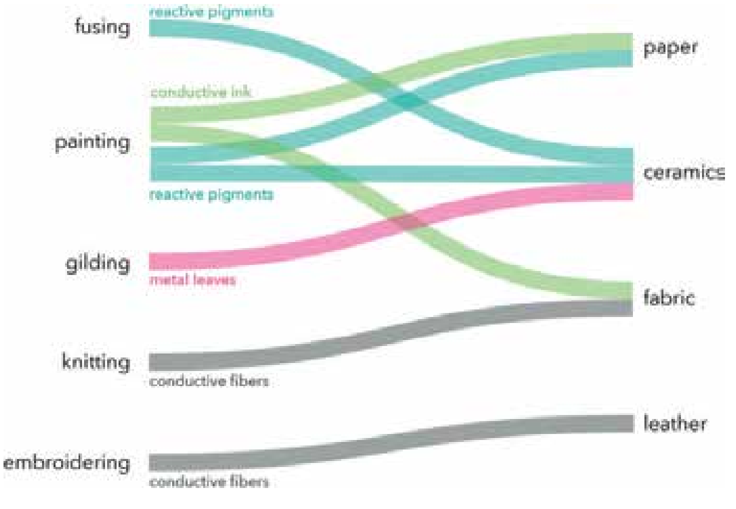

Figure 1. The experiments we performed on embedding advanced materials into traditional ones by artisanal processes.

We studied the hand crafting process of traditional paper making, which involved two methods: first was using marbling technique by 'capturing' floating oil-based metallic paint with paper (**Figure 2**), and second was using pattern blocks to individually press print inked patterns on paper (**Figure 3**).

In this process of decorative paper making, we identified 'painting' with ink as main method of introducing interactivity. Within this method, we explored two types of interactivity. First, we created recognizable and visible interactivity with the use of flexible electronics through painting/writing with conductive ink. Second, we 'embedded' the interactivity into the paper itself—in a decorative form as done in paper marbling process observed above—by painting with reactive pigments such as thermochromic, photochromic, and hydrochromic pigments.

Flexible circuits can be easily created by using conductive ink to draw circuit patterns on paper. Small sensors and actuators can be added to the circuits, as shown in **Figure 4**, to transform a sheet of paper into an interactive material that reacts to external stimuli and user actions (ambient light, pressure, slide, sound, pushing, or rubbing), triggering effects like sounds or light. We explored typical gestures users perform on paper, like folding, rubbing, and touching, and generated responses to these gestures thanks to different actuators. These conductive metallic inks could be potentially used in the marbling process of decorative paper making to create a conductive 'base' (a 'substrate') for paper circuitry. For example, users can create interactivity by adding micro LEDs, sensors, and actuators to the conductive base, and completing the circuit with a hand drawing/painting with conductive ink.

As mentioned previously, we also explored reactive pigments applied to paper by painting and stenciling (inspired by block press printing technique from the Florentine paper maker).

Figure 2. Creating organic 'marbling' patterns using oil-based metallic paints.

Figure 3. Using pattern blocks to print (stamp) colored patterns on paper. For complex prints with multi colors, multiple pattern blocks and inks are used during the process. A full pattern is separated into multiple blocks to allow multi-color press printing.

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Paper becomes reactive to interaction with users (e.g. hand temperature) and to external stimuli (humidity, temperature, and UV light). These reactive inks can be easily applied to the block printing process of the traditional hand making of Florentine paper as well. For example, thermochromic ink can be used to press print selective patterns of the multi-step block printing process as explained in **Figure 3**. An interactive paper would be produced, similar to examples made in **Figure 5**. Upon touch, the temperature of the hand can unveil unexpected patterns of this reactive paper.

3.2. Ceramics

In ceramics, again two explorations were made around the idea of shaping new esthetic interactions: fusing/embedding of interactive elements to the material itself (pigment powder in glazing base), and applying interactivity through visible decoration through metallic gilding. The experimentation started with the observation of the ceramic making process by artisans (**Figure 6**).

3.2.1. Fusing

One of the key processes we learnt while visiting the artisans' workshop in Florence was the final 'decoration' step, which involved hand painting and glazing (**Figure 7**). Starting from this knowledge, we asked ourselves: what if we embed interactive elements such as reactive pigments to the glazing base? In this exploration, we tested the fusing of thermochromic pigments to the glazing base. Pigments were added to the base at incremental concentration

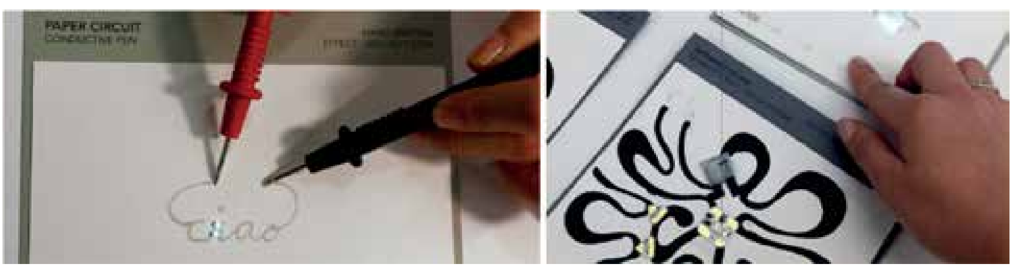

Figure 4. Using conductive ink to create interactivity through writing on paper.

Figure 5. Using reactive pigments such as thermochromic pigments to create interactive decorative patterns on paper by painting and stenciling.

Figure 6. Observing the process of ceramic making of Florentine artisans: painting/glazing, and hand molding a lamp with clay. Many of the ceramic lamps were minimally decorated (no gilding with metallic leaves, etc.), and finished with basic glazing.

Figure 7. Thermochromic pigment powder was added to the glazing base at different concentration for glazing ceramics. However, the thermochromic glaze lost its properties under high heat during the baking process in the kiln.

amounts, as shown in **Figure 8**. However, due to its heat-reactive properties (the pigments turn transparent when under heat), the pigments completely disappeared during the firing process in the kiln.

3.2.2. Painting

Following the unexpected outcome in the previous experiment, we applied reactive pigments to glazed surface of ceramics in order to avoid exposure to extreme heat, which would cancel out all reactive characteristics of the pigment. Interactive pigments such as thermochromic, photochromic, and hydrochromic pigments were painted on tiles as smart decorations. These pigments would change its visible qualities under multiple stimuli (humidity, temperature, UV light, etc.). The reactive pigments can be layered with non-reactive paints/decorations to create various visual effects, as the reactive pigments will appear/disappear under changing outside conditions.

3.2.3. Gilding

In addition to surface application of reactive materials through painting (stenciling), we tested the use of decorative metallic leaves to create touch-sensitive (capacitive) circuits through the process of gilding. These metallic leaves would withstand high heat during the glazing process, and thus would be applicable for the use in ceramics. A quick conductivity testing was done using silver, copper, and gold metallic leaves. Then we focused on creating patterns (organic shapes) that everyday users would recognize as decoration, and not as apparent interactive circuits. Various patterns were made by laser cutting stencil base, and we used gilding technique to apply these patterns on ceramics. Actuators and sensor inputs in miniscule scale were added to the conductive circuitry to generate interactions (**Figure 9**).

By this process, ceramics becomes conductive and can be made responsive to a number of environmental stimuli and user's actions, depending on the sensors and actuators embedded. This new conductive ceramic can be used to generate different types of interactions and applications, from interiors (tiles) to everyday products (pottery). We designed a mug that can change its aesthetics (lights up) in response to actions like touching, talking, or rubbing (**Figure 10**).

3.3. Fabric

3.3.1. Knitting

Florence is also known for its textile industry, producing both woven and non-woven textiles. We also collaborated with a local textile mill, and observed the production of these fabrics (**Figure 11**).

Figure 8. Thermochromic pigments were painted on ceramic surfaces: these patterns are responsive to differences in temperature, such as cold or heat.

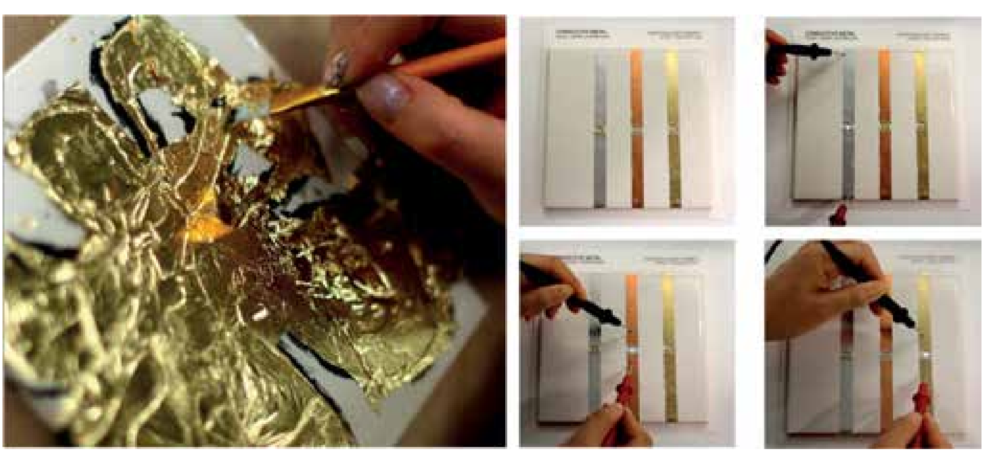

Figure 9. Metallic leaves (copper, silver, and gold) were applied to ceramic surfaces using gilding technique. Due to its conductivity, gilded patterns can become circuits to create interactivity.

Figure 10. Testing of adding simple LED light interactivity using gilded metallic circuits.

Figure 11. Left: textile mill near Florence that produces performative textiles. Middle: the woven textile inspired the potential integration of conductive fibers. Right: testing the idea of adding sensors to the conductive substrate for added interactivity and performance.

Using the sample of woven textile received from the mill, we started weaving very thin flexible wire to the fabric. A simple parallel circuit could be made with this conductive substrate, by adding a simple LED and a switch.

Next step in the exploration was to embed the conductivity to the textile itself during the production of the woven textile. Using a knitting machine, conductive yarn was knitted together with regular yarn to create striped patterns, which would become touch-sensitive areas when connected with a microcontroller. As shown in **Figure 12**, conductive fibers can be used both as decorative elements (visible) and as hidden substrates. In this exploration, upon touch of the conductive stripes, various sound tracks were played: producing an unexpected outcome from an everyday material like knitted textile.

3.3.2. Embroidering

Another technique that is often used on fabric is embroidery. Using conductive threads (such as stainless steel threads) to embroider alternative patterns on textiles can be used as visible decorations, that becomes part of the esthetics of the material itself.

3.4. Leather

3.4.1. Embroidering

Similar to the exploration with fabric, conductive fibers were embroidered/stitched on leather as visible patterns to create interactivity. These conductive stitches can be combined with

Figure 12. Conductive fibers were knitted together with regular yarn to create conductive areas for touch interactivity to generate output, such as sound in this example.

regular stitches (on small leather goods such as wallets) to keep consistency in esthetics, yet provide interactivity through the use of actuators and sensors.

4. Discussion

4.1. Making materials reactive: substrates, pointers, and dynamic patterns

The samples production of hybrid materials allowed us to reflect on how technology and interactivity can be embedded into traditional materials. As a result, it emerged that hybrid interactive materials can have three different natures. Indeed, conductive and reactive materials can be embedded into traditional ones by craftsmen through artisanal processes in order to:

• Create *invisible conductive layers* that are hidden in materials but make them interactive and therefore able to respond to external stimuli, by being connected with sensors and actuators (e.g. LEDs). We call the conductive materials used in this way as "substrates". Examples are conductive fibers knitted into hidden layers of fabric and becoming invisible. In this area, artisanal skills can be used to create high quality and performing hybrid materials, which at the same time have an esthetic quality that is the one of the original material, which hides its "smartness". This can be achieved thanks to high expertise and knowledge of the material production process (e.g. fibers manipulation in fabrics or paper).

• Create *visible conductive elements*, which at the same time are noticeable, transform the static visual appearance of materials and make them interactive when connected to sensors and actuators. We call the conductive materials used in this way as "pointers". Examples are metal leaves gilded on ceramics, conductive ink painted on ceramics or fabric, and conductive fibers embroidered in leather. Artisanal skills can help making pointers both esthetically pleasant and functional.

• Create *smart decorations*, which dynamically change the materials' visual appearances according to external stimuli (light, temperature, and humidity). We call the reactive materials used in this way as "dynamic patterns". Examples are interactive pigments painted on paper, tiles, or fabric. They do not need additional elements like sensors and actuators to transform the esthetics of the material, as they are interactive *per se*. They usually are visible on materials and can be used as decorations (**Figure 5**) but they can also be transparent and become visible only when a reaction to a stimulus occurs (**Figure 8** of transparent reactive pigment). Artisans' expertise can be leveraged to assure reliable painting processes and to provide final products with innovative esthetics.

Figure 13 shows how the conductive/smart materials we used in our experiments can be classified as substrates, pointers or dynamic patterns.

Substrates and *pointers* make materials conductive, therefore can be used in many different applications and can be coupled with any kind of sensors and actuators. Thanks to their properties, they can be used both to dynamically change the appearance of the material, creating new esthetic experiences (e.g. touching a conductive fabric turns on embedded LEDs), and to create functional interactions (e.g. rubbing a conductive fabric a signal is sent to my smartphone and a call to my boyfriend is initiated).

Dynamic patterns can be used only to change the appearance of the material they are coupled to, therefore they can be used to create dynamic *esthetic* experiences, where function is left aside. However, transforming materials' or products' esthetics in a dynamic way can have not only esthetic but also functional goals, as dynamic products [5] and ambient interfaces [10] demonstrate. Indeed, changes in the visual appearance of a product/surface can be used to communicate information to users (e.g. the temperature of a room, the presence of UV radiations, or the humidity level in the environment).

4.2. Potentials

Making traditional materials interactive and smart while at the same time maintaining their physical and sensory properties and manufacturing processes opens up new perspectives and possibilities.

As far as the artisanal world is concerned, such materials represent a way to transform and innovate craftsmanship while at the same time preserving its nature and values. Indeed, we

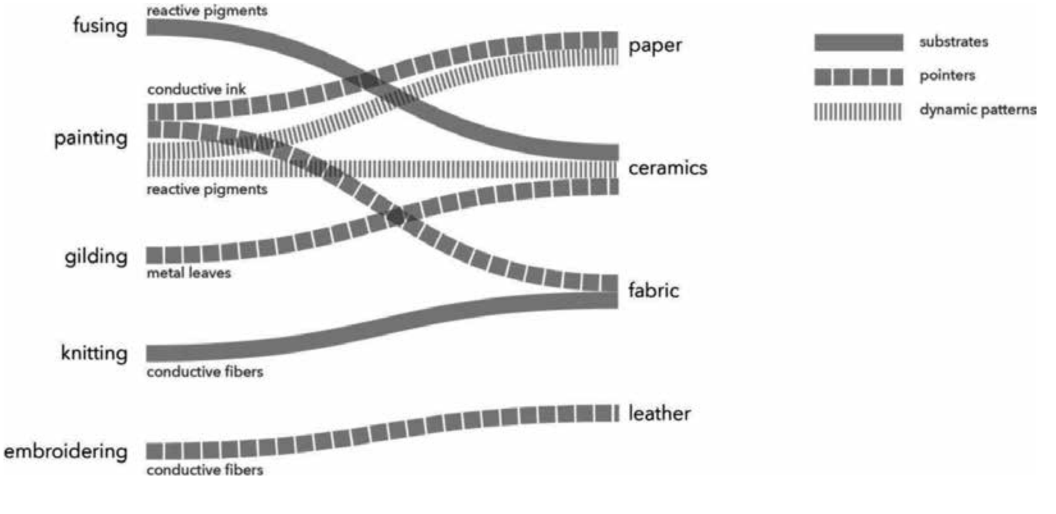

Figure 13. How conductive fibers, metal leaves, conductive ink, and reactive pigments are used as substrates, pointers, and dynamic patterns.

explored how it is possible to use the traditional artisanal processes and gestures to embed electronics into paper, ceramics, leather, and fabric. This provides the possibility to use all the fascinating sets of manual and crafting activities to shape materials and objects that are smart and interactive. Instead of focusing on the DIY movement, this work explores how "smartness" can be embedded into matter and objects thanks to well-established processed performed by skilled and expert artisans. This approach is a middle way between the electronics industry, perceived as technical and cold, and the hobby-ist or DIY movements, where usually inexpert people produce single pieces, sometimes for fun or just as experiments. Through our exploration, we showed that there is a still unexplored area, that of artisanal industry, where well-established and traditional artisanal processes can be enriched by hybrid materials, towards the creation of high quality, manufactured materials or products realized in small series.

From the users' perspective, we can imagine completely new kinds of experiences that are enabled by these hybrid materials, where technology is made more familiar and contributes to the creation of new sets of interactions and experiences with well-known materials. Indeed, by seamlessly embedding interactivity in traditional materials, we can exploit the typical gestures users perform on such materials to shape new kinds of interactions.

In order to bring these hybrid materials into the processes of traditional artisans, new fabrication knowledge may be required. Is a new "artisanal" interaction design needed to push forward innovation in traditional craft products? In the subsequent collaboration with the artisans following this material exploration phase, we tried to address this issue by working closely both with the artisans and their young trainees, who tried to implement the interaction design approach in the traditional processes of artisans. As a first result, it emerged that this process is not always smooth and a balance between understanding traditional processes and embedding visible/invisible technology is needed to create new traditional materials with dynamic esthetics and interactive properties. However, this experiment was a first attempt to explore possible ways to reconcile craftsmanship and technology, by putting the user experience at the center.

5. Conclusions

We started from the analysis of traditional artisanal manufacturing processes and techniques, and identified a number of processes that could be used to generate hybrid, interactive materials. We proposed a framework to categorize these materials and to highlight their different possible uses in artisanal processes. By creating such framework, we intend to provide a tool to explore, with artisans and by artisans, new evolutions of their activities and to inspire their work.

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This year we celebrate the 10th edition of the DeSForM conference series. In 2005, DeSForM was born in (Eindhoven) the Netherlands with the premise of creating meaning through objects, interactions and people. Over the years, the DeSForM community has explored and designed objects through a multi-sensorial approach always aiming at enriching users' experiences with them. Throughout previous editions, we have seen the development from digital and mechanical objects that had enriched sensorial presence to adaptive and intelligent objects that feel almost analogous to reality given their increased information processing power and sensory resolution. These are thanks to the recent developments in the material sciences, robotics, information and sensor technology, and improved production techniques. Consider, for example, developments in wearables and embedded or computational materials. Consequently, the arena that belongs to design researchers and practitioners has gotten more sophisticated by being more technical, but also raises new questions regarding the effect and the impact of the new technologically rich designs. In 2017, DeSForM is returning to its place of birth opening up to a broader audience with deeper insights to debate about the future of dynamic 'form' giving and its effects on people and their environment.

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