Engineering through Designerly Conversations with the Digital Material

The Approach, the Tools and the Design Space

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Abstract

The role of IT devices and technology in our everyday lives is growing. The commercial availability of sensor and wireless communications technologies has led to an increase in the number of systems utilizing these to provide compelling experiences. Designing embedded systems is challenging, as the properties involved are often hard to observe, touch, and experiment with. Being that these technologies can inspire, drive, or limit design processes, methods and tools must be developed to create a shared knowledge for multidisciplinary design teams. This thesis focuses on how engineers can better communicate their knowledge of digital materials to non-expert technology designers and multidisciplinary design teams.

In particular, this thesis focuses on a class of embedded systems that we have named Proxessories. Proxessories consist of sensors, actuators, and wireless communication together forming accessories placed on or around the body that communicate with other devices, acting as accessories to other devices and objects. The goal of this research is to contribute new approaches and tools to help engineers convey their technological knowledge while working within a multidisciplinary design team. To accomplish this, the emerging topic of materiality in interaction design is introduced and used to discuss how an engineering perspective can be altered to cater to processes wherein digital materials are utilized as a design resource to create a better understanding of their experiential properties.

The research method of this work falls broadly under the header Research through Design (RtD). That is, this work claims that through designing a range of Proxessory applications, a set of tools and methods can be extracted to better support the dialogue between engineers and other competencies in a multidisciplinary design team.

This thesis results in providing an engineering design approach that is instantiated and materialized through hardware and software tools. The first tool, Inspirational Bits, is an approach where bits and pieces of technology are revealed to a multidisciplinary design team in a playful manner, exposing them to the interactive, dynamic properties of digital materials. The second tool, the rFlea, is an Arduino-based board, with an inbuilt ultra-low power wireless connection, the size of a coin cell battery. rFlea can connect wirelessly to another rFlea or existing tablets and mobile phones by means of pre-made libraries. The third tool, Insbits Studio is a cloud-based visual programming platform that can connect to the rFlea, adding cloud services abilities and connections to Internet of Things products and services. Together these three tools point to a novel philosophy of how to approach engineering. Instead of solving a given problem, engineers must open the design space and expose the material properties and affordances in such a manner that the team can experience them in the early phases of a design project.

Sammanfattning

IT produkter och teknik spelar en allt större roll i våra liv. Den kommersiella tillgängligheten av sensorteknologier och trådlös kommunikation har lett till ett ökat intresse för att använda dessa till att designa tillämpningar som erbjuder engagerande upplevelser. Att designa med inbäddade system är utmanande eftersom teknikens egenskaper ofta är svåra att se och uppleva vilket gör det svårt att experimentera med dem i design. Därför finns ett behov av att utveckla metoder och verktyg som kan skapa förståelse för teknikens egenskaper och möjligheter så att den på ett framgångsrikt sätt kan inspirera, driva på och avgränsa designprocesser. I den här avhandlingen så kommer jag att fokusera på hur man kan underlätta kommunikation rörande teknikens egenskaper mellan ingenjörer och andra, mindre tekniskt kunniga deltagare, i multidisciplinära designteam.

Mer specifikt så kommer detta arbete att fokusera på en sorts inbäddade system som vi kallar för Proxessories. Sådana system består av sensorer, aktuatorer och trådlös kommunikation som vi bär eller har nära kroppen. Proxessories kommunicerar trådlöst med andra enheter, eller agerar som accessoarer för andra enheter och objekt. Målet med min forskning har varit att bidra med nya angreppsätt och verktyg som gör det möjligt för ingenjörer att bättre förmedla teknikens möjligheter och begränsningar till team-medlemmar med annan bakgrund, t.ex. medlemmar som är experter på design. I den här avhandlingen så diskuterar jag hur den typiska ingenjörsattityden kan ändras, till att bättre stödja arbete där tekniken, det digitala materialet, blir en viktig designresurs. Jag gör detta genom att utgå från den växande diskursen kring materialitet inom interaktionsdesign och människa-datorinteraktion.

Min forskningsmetod utgörs i huvudsak av så kallad "forskning genom design". Genom att designa ett antal Proxessory-tillämpningar, så har jag tagit fram metoder och verktyg som stödjer dialogen mellan ingenjörer och teammedlemmar med andra kompetenser.

Resultatet är en ansats för ingenjörsdriven design med tillhörande mjukvaru- och hårdvarukomponenter. En central komponent i ansatsen är Inspirational Bits, en metod där egenskaper i teknologier utforskas och görs synliga för teamets alla medlemmar på ett lekfullt sätt. Detta bidrar till en ökad förståelse för interaktiva och dynamiska kvaliteter hos det digitala materialet. Hårdvarukomponenten i ansatsen består av rFlea, ett Arduiniobaserat kretskort, stort som ett knappcellsbatteri, med inbyggd trådlös lågenergianslutning. rFlea kortet kan trådlöst ansluta till andra rFlea kort, surfplattor eller mobiltelefoner genom ett specialutvecklat kodbibliotek. Slutligen så består ansatsens mjukvarukomponent av Insbit Studio, en molnbaserad visuell programmeringsplattform som kan ansluta till rFlea korten och lägga till molnfunktionalitet, samt ansluta korten till andra tillämpningar. Tillsammans så ger Inpirational Bits, rFlea, och Insbit Studio ett stöd, grundat i ett materialitetsperspektiv, för design av Proxessories. Dessutom gör de det möjligt för ingenjörer att arbeta

på ett nytt sätt. Istället för att lösa ett givet problem, så blir ingenjörens roll att öppna upp en designrymd genom att göra det möjligt för andra teammedlemmar att uppleva teknologins materiella egenskaper tidigt i en design process.

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Since I arrived to Sweden back in 2008 lots of things have changed my life: personal and professional. New country, new people, new weather. I arrived as a party person, and no one could convince me at that time that I would eventually turn to bikes, run marathons and go bike touring and camping around the nature, big changes all thanks to the amazing people I have met in these 8 years. I arrived as a master's student and never expected to stay so long, or that I would become a Swedish citizen! So many changes, so great.

The following list of names is in no particular order, and if I missed someone my biggest apologies, it is hard to remember all the people who have helped me, and in so doing contributed to this thesis over such a long period of time.

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From here on out, new adventures, new people and new places will come. To be honest I have no idea, but whatever happens in my near future, you all will be a part of me and I will carry you everywhere I go. Thanks thanks and thanks.

Stockholm, November 2015
Jordi Solsona Belenguer

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Chapter 1

Introduction

1.1 Problem formulation

This thesis is concerned with Information Technology (IT)[1] engineering and ways to extend an engineer's design methods and to make it possible for affordances and properties of technology to open the design spaces and create a broad range of future devices. More specifically, it looks at engineering issues connected with working in a multidisciplinary design team, in highly varied contexts and using different aspects of technology as design material. Through this research, methods and tools are proposed and described. The methods and tools are evaluated through using them in several different case studies where they support the design process, making it easier to develop relevant design concepts and working prototypes rapidly. Most importantly, this thesis shows an approach and attitude that can be employed by engineers in order to successfully turn the properties and affordances of technology into a multidisciplinary design resource.

Designing and developing today's interactive artifacts is a complex task, involving a wide range of disciplines. In almost any design of an interaction artifact, many competences such as industrial design, hardware and software engineering or Human Computer Interaction (HCI) are involved, just to mention a few common disciplines. As technology is growing and getting more complex, non-IT professionals encounter problems in grasping the technology and understanding it in order to contribute to the interaction design discipline (Figure 1.1).

Better ways of communicating and working together with other disciplines need to be found, taking into consideration the varying areas of expertise that a multidisciplinary design team has. Engineers need to find ways to illustrate and

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[1] From now on, whenever technology, design or engineers are mentioned, it should be understood as only those technologies, designers and engineers engaging with digital or information technologies of some sort.

Figure 1.1: IT technology is growing into many disciplines, there is a cloud, to which you either connect the things directly or via e.g. mobiles and other internet-enabled artifacts.

explain the properties and behaviors of technology in a way that turns them into resources for design. At the same time, engineering practices need to realize that both engineering and non-IT disciplines can influence other disciplines' methods and learn from one other. In this thesis the word "designer" refers to a person classically trained in non-IT-engineering, such as art, fashion, sculpture, industrial design, and interaction design or similar areas.

In other words, it is important that we combine competencies since many of these systems are meant to be used by a diverse range of users in different contexts, often requiring that the interaction is positive in order for them to engage and make good use of what is there. Understanding those users requires skills in how to study and engage users in the design process. Understanding contexts requires skills in how to approach cultural and design practices. Not only is it inevitable that we have to move to multidisciplinary design teams, but it can also be a good thing. If we find better ways of communicating and sharing goals, whether they are in interaction design or in a design process, the multidisciplinary design team can:

- Become a shared practice — one where we utilize each other's expertise to the fullest.
- Make use of the materials at hand to their fullest, both hardware and software, seeking their affordances and their potential for interesting user experiences.
- Avoid fighting with the technology to make it fit the goals of the interaction; and instead use the potential of the technology to shape the interaction in dialogue with the multidisciplinary design team and user-centered methods.

The diversity of today's technology is such that it is going into traditionally non-IT artifacts such as clothes [58][48][14], furniture, houses, cars [66] and personal healthcare devices [61]. As shown in Figure 1.2, new, commercially available means for sensing and actuating have led to a growing number of systems that use information technology to provide compelling user experiences. Figure 1.2 shows three examples of an intersection of crafting and interaction technologies, the Estimote[2], Bluetooth beacons that connect to your phone, Flic[3], a Bluetooth button that can trigger functions in your phone, and the Peripie [13], an interactive pipe that can control certain functionalities of your phone such as changing music and volume. Examples such as smart phones, tablets, heart rate monitoring, sports watches, wireless sensor networks and more are systems that rely on communication, sensing the environment and interaction technologies. This is an interesting class of applications to be explored as it lies in the forefront of technological development and is, in fact, pushing the evolution in the area of the involved technologies: wireless, sensors and actuators.

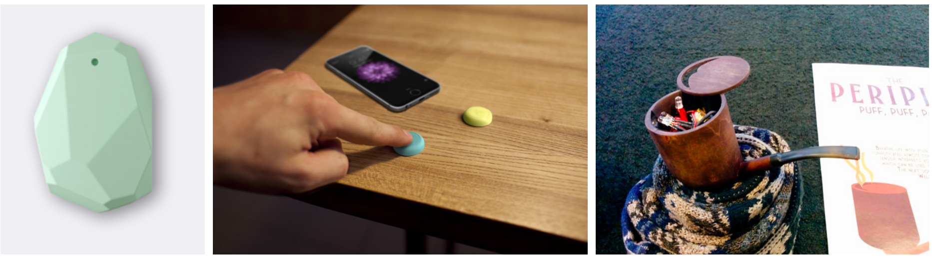

Figure 1.2: Left: Estimote, low energy Bluetooth beacon. Center: connectedness, table and chair connected to perform different purposes. Right: The Peripipe, an interaction exploration on crafting and interaction technologies.

As seen in the late 2000s and beginning of the 2010s, new concepts emerged from this success in IT technologies. The concept of Internet of things, which

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[2] http://estimote.com/

[3] https://flic.io/

relies on IT technology, has a great ompact in our everyday lives, industry, research or medical fields. Leading companies like Ericsson or Cisco talk about 50 billion devices connected by 2020 [68][12]. This growth has to be taken seriously to harvest the full potential of the technology, but at the same time, to design new devices in a thoughtful way, in a manner sensitive to sustainability needs and ethical considerations, where multidisciplinary design teams will play an important role in this task.

Traditionally-schooled designers engage in a “conversation with materials” [46] through sketches, mock-ups and early prototyping. In the formation of a new idea the materials are worked with in such a way that they start to “talk back” revealing new opportunities and challenges. Working with technology, however, is often complicated for most designers whose background, knowledge or experience is not in engineering. To be helpful in this process engineers will require tools and methods to translate technology into properties and design opportunities in a way that enables designers to engage in conversation with them.

It is not only about designers lacking the necessary knowledge of a technology; it is also about how the material is complex [52] and has qualities that are sometimes intangible [49] [44]. Our material manifests itself at many different abstraction levels. You might learn how to deal with computers as zeros and ones, as ASCII, as Java-programming, as machine language, or as ready-made interactions that can be only minimally configured. By each abstraction level, the material changes its properties. In addition, it is only when you interact with something over time that its dynamic gestalt will reveal itself to you. This is different from creating a wooden chair for example. It will not change its feel, look and interaction while you are sitting on it, but a digitally enabled chair might actually do that. That is, you can know what wood is, what it feels like, how to design with it, without engaging with its properties as they unfold and change in response to user actions. This thesis will look at engineers trying to access and understand their own material, by means of novel methods and tools and will also look at how to deploy technology as a design material. Digital material [54] is the terminology used in this thesis to refer to technology when seen in a design context.

This thesis is following what has been termed the material turn in HCI [15][54][72][18]. The material turn has a stronger focus on practice and the skills that engineers and designers learn to embody in their tinkering and dealings with materials [4]. Ultimately, the material approach may lead to better, more evocative and interesting design as well as potentially feeding back into the engineering practice as well as material design.

Introducing Proxessories

Information technology is often defined as using computers and communication devices to manipulate, store, transmit and receive data. This definition is generic and could include almost any electronic device or system we use in our everyday lives. To constrain the broad definition of these particular technologies and confine a design space in this thesis, the term Proxessories is introduced. The design space of Proxessories is revealed over time through the projects in chapter 4, the design journey.

Proxessories are proximal accessories to common mobile devices intended to enhance, extend, or embellish interaction with those devices or services running on them. In other words, Proxessories embrace those tangible and interactive objects that rely on sensor- and actuator-technologies as well as wireless connectivity to provide their services. On their own they don't provide much of an interaction, but, when they combine with wireless, mobile phones, tablets or smart watches, they can provide appealing interactions. They become the tangible interaction accessories of our everyday gadgets through an exchange of data. They don't provide large computational complexity or power, but they have to provide the right interaction experience and aesthetics. Like accessories, they can be part of compositions or outfits that are intended for specific purposes or occasions. Hence, by changing Proxessories, you can alter the experience of interacting with a device, in the same way that changing jewelry can alter the look of an outfit. Just as the right accessories can make an outfit feel complete, the right Proxessories can make interaction with a device or a service feel aesthetically complete.

Technologies that rely on sensor, actuator and wireless communications have seen their greatest growth in the area of interaction research and consumable products. In what is considered to be the third wave in HCI [4], focus has shifted away from gathering as much functionality as possible in a single device towards tasks that are conducted through combinations of specialized technologies. New interfaces are used in changing locations; their usage contexts and application types are broadened and intermixed [4]. The underlying technologies and paradigms that appeared servicing those new developments are manifold: Pervasive technologies, wearable interfaces, tangible interaction, embedded devices and wireless communications.

Here we will introduce a range of examples of Proxessories. Some we have developed ourselves, and some are created by students. These design examples, or *ultimate particulars* in the words of Stolterman [51], are particular, fully-functioning systems, aimed to be used in a particular context, with a particular purpose; they are connected with their use context. They help us define what we mean by the class of systems that fall under the header of Proxessories, and they have also helped develop our understanding of what is needed to support the development of this class of systems. The exemplars will explain and define what the term Proxessories means in this context.

This thesis will look at how engineers can provide the multidisciplinary design team with a common background of knowledge, and it will provide a succession of different solutions, methods and toolkits that were used to explore how to engage in and communicate the affordances and experiential potential of the Proxessory materials. The thesis will serve as the beginning of an exploration as the area is growing and more methods will be required in the future.

Multidisciplinary design teams

Since the early 90s, with the explosion of IT-technology in our everyday lives, embedded computing that uses this technology has become accessible. It is easy to find off-the-shelf embedded computing platforms that have ICT components, such as the well-known Arduino platform, and also have interactive components such as sensors and actuators already in them. The availability and visibility of technology has expanded, resulting in creative non-engineers thinking about using technology in their creations. However, that does not mean it is easy or obvious how to use technology to design such things. On the other hand, new opportunities for using this technology in consumer products for social interaction are becoming important market drivers. In addition, new fields are incorporating technologies in their designs, such as textiles [22][58][48], furniture [42] or arts [70].

The engineer now works in a design space that lies in the intersection of different disciplines such as social and behavioral sciences, interaction design, industrial design, and the fine arts, to give some examples. This is what this thesis will refer to as multidisciplinary design teams, the environment where a design process takes place between different competences and backgrounds, and where each one has to influence and provide knowledge with a common end goal, for example, solving a problem, exploring some technology, or just improving an experience.

Engineering studies, in most cases, focus exclusively on technology, and teaches through a process of engineering problem solving. The expanding design demands for IT in products since the 90s include the need for the new engineers to be able to interact not only with other engineers but with other disciplines. This brings up the importance of engineers in extending their methods and tools to influence the multidisciplinary design space. Examples of established methods commonly used in interaction design that are inherently multidisciplinary include brainstorming, role playing, sketching and scenario generation [9], and design-driven innovation [67], but there is a lack of engineering methods where the engineer shows and communicates the properties of technology. Designing and building successful systems using IT technology, in this case wireless and sensor technology is not, however, just a task for engineers. For instance, the smart phone's success is tied to a design that combines hardware, software, style, fashion, and human design to work together and offer the user a new experience. The HCI community is benefitting more and more from technology, but, as this technology expands into new areas, new concerns rise in the community [6].

Therefore, designing and building successful systems of this kind is challenging because of its multidisciplinary nature. This is the case from an engineering viewpoint because many of the components and design methods represent unfamiliar "territory" [54] for engineers and also because it requires a wide range of competences. The quality of an experience arises in interaction between users and systems. The interaction is in turn affected by the hardware and software of the system. Even seemingly simple components, such as accelerometers, require thoughtful interaction design, with specialized hardware, specialized software, and specialized user interfaces. Each one of these factors is equally important during a design process, since they equally affect the user experience, each one in a unique and important way.

Context of Research

The present thesis starts in a project where my own personal experience plays an important role in understanding the teamwork in a design process where different backgrounds take an active part. This section will explain my personal experience at the point where I started my PhD studies and will describe the context.

Back in 2009, I finished my Master's degree in IT engineering having studied positioning and radar systems. Engineering was seen by me as a way of solving problems using technology with engineering methods. That problem-solving attitude came to change dramatically through the different projects I engaged with. But to understand how it changed me, let me provide some background to the setting of my projects and what I came to experience.

Since the beginning of my doctoral thesis to the present, I have worked in the Mobile Life VINN Excellence Centre[4]. Mobile Life is an internationally recognized research center focused in the area of mobile services and is a joint venture between its three research partners and nine industries. The Mobile Life Centre provides a view into our future life with digital technology, where the strength lies in its highly multidisciplinary research groups. The environment in the Mobile Life Centre was considered ideal to pursue the goals of this thesis: multidisciplinary environment in designing the future digital technology. When I started my doctoral thesis work at the Mobile Life Centre, I quickly realized that this was to be a unique and

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[4] http://www.mobilelifecentre.org/

academically-challenging experience. The method I used in order to explore the design space is described by John Zimmerman and colleagues [74], Research through Design (RtD), a method where design is used as the research method to explore research questions. This method will be explained in more detail in Chapter 3.

My first introduction to research was the Lega project, and it was to be the starting point of my multidisciplinary design journey. The Lega, see paper 1, is a hand-held device for tactile and gesture based interaction to be used by groups of friends in an art exhibition, the goal was to develop a new kind of rich communication device using interaction and IT-technology. The path to this goal was completely open and used an explorative process involving artists, HCI designers, industrial designers, software engineers, and myself as the IT hardware engineer. In that sense, this project brought many of the key ingredients to the problem statement of this work, setting the background for this thesis. The Lega project was a very important element of my PhD because it was my first experience with multidisciplinary design teams, and all the issues and experience gained during this project have shaped the following years of the research.

After the Lega-work, I engaged in a series of similar projects, but where I deliberately influenced the design process through inviting designers to explore and experience the digital materials in evocative manners. In each encounter, the multidisciplinary design team tried a different method to facilitate those explorations. Together with Sundström and some other colleagues, we developed what we named Inspirational Bits, see paper 3, that allowed the whole design team to feel, touch and engage with different properties of wireless communication, algorithms or sensors [54][49]. We explored a probes-driven method to also expose the end-users to aspects of the technological possibilities. Finally, I came to a point where it became necessary to build a specific toolkit (both hardware and software), rFlea, to address the properties in a smoother and better manner. As I will discuss later, rFlea is one of the most important contributions presented in this thesis.

All of these explorations taken together point to a different way of working — a material or practice turn in designing for UX, involving both the multidisciplinary team as well as the end-users.

In this thesis, I will talk about engineers, designers or industrial designers as examples of multidisciplinary design teams. I do not aspire to define or categorize these individuals, but rather to use them as examples that influenced my own personal experience while working with teams of highly skilled researchers framing themselves mainly as engineers, HCI-experts, designers or industrial designers, even if many of them overlapped between the disciplines.

1.2 Research questions

This thesis explores the extension of IT design methods that include technology as design material used in the creation of future artifacts by multidisciplinary design teams. In particular, in the design space of Proxessories (introduced and defined in section 1.1), that is, accessories placed on or around in close proximity to the body, communicating with other devices, or even act as accessories to other devices and objects. The research questions are primarily for the benefit of engineers, as a way to extend their methods and skills. These particular questions grew out of the first encounter with the first project, the Lega, where they have been discussed and refined throughout the rest of the projects and work processes. The main research questions that this thesis addresses are:

- How can engineers expose the experiential properties of the digital material so that a multidisciplinary team can create a shared, tangible understanding of what can be designed? In particular, how can this be done for a particular design space that can broadly be described as proximal accessories — or as we choose to name them — Proxessories?
- How to open the design space of Proxessories by exploring and probing it through engineering and design. What are the design exemplars, requirements, experiential qualities that can tell us whether this design space is of relevance and what it consists of?
- What are the engineering tools that will bring in technology in a manner that supports rather than limits design explorations?

1.3 Method overview

This thesis is a collection of the projects that have contributed in a most relevant way to the formulation of the research question and its contributions. The starting point in this thesis is how the engineer can participate in, contribute to, and influence and create a common experiential knowledge in a design space. From this question and using the methodology of Research through Design (RtD) [16], the final research questions have been stated and the contributions have been developed and proposed. RtD is a method used in interaction design and HCI, but in this thesis it will be used to find engineering requirements and develop the tools to support the design space of Proxessories. Each project presented will identify the key issues for what the technology becomes at the interface between the design space and the engineer. An aim of this thesis is to provide other engineers and researchers with an insight of design experience and how together within a multidisciplinary design team they can continue to build upon it.

Chapter 4 is the design journey, where the key issues from the engineering perspective take place; it is framed in the design space of Proxessories. A design space is a “multidimensional space containing an endless number of solutions” [71]. From an engineering perspective, a design is usually driven by a problem where one best solution can be measured, but, instead, a design space is a concept, an experience or an idea, and it can offer an endless number of solutions or designs. This thesis will look at how to combine design spaces within engineering methods for problem solving. In Chapter 3, Methods, a variation of RtD in an emphasis on engineering side method will be introduced: Engineering through Design. This concept came along the projects while applying RtD in an engineering context and with the aim to provide engineering metrics and problems within a design context. The reason for giving a different name to this way to apply RtD in an engineering context is to differentiate it from the design discipline, and customizing the ultimate goal: use of design space to engineer new tools to support it.

1.4 Contributions

This thesis has several contributions, the definition of a design space called Proxessories, extended in Section 1.1 of the Introduction chapter. Designs and prototypes built during this thesis have their own Research through Design contributions, and they can be found in the included papers [28][54][49] and in the Chapters 4 and 5 as design explorations. The main contributions in this thesis respond to the three research questions in section 1.2 from this chapter:

- Inspirational Bits, a material approach to IT technology. It shows the properties of the digital material,technology is wrapped in a black-box by the engineer to the multidisciplinary design team; it serves as a common background of knowledge and language within a multidisciplinary design team. The engineer presents the technology in a playful and quickly-realized manner but in fully working systems.

- Exploration and design examples on the Proxessory design space to point the particularities. Characteristics of a tool that should support the design and explorations of Proxessories.

- rFlea and Insbits Studio, are the engineering tools designed to support the design space in the context of Proxessories. rFlea is a Arduino-based boards, with ultralow power wireless built in, in a coin battery size. rFlea can connect wirelessly to another rFlea or existing tablets and mobile phones by means of pre-made libraries. Insbits Studio is a cloud-based visual programming platform that can connect to rFlea and include cloud services abilities and connect to other Internet of Things systems.

1.5 Thesis Outline

The thesis is divided in two parts. The first part groups Chapters 1, 2, 3, 4 , 5 and 6 tying together a number of research questions focusing on one very specific aspect of the work done in the second part — papers describing point-wise contributions. The second part is a compilation of papers that has contributed to this thesis work.

Chapter 1 is a description problem-statement that the thesis will evolve from. It includes a description of the research space and the problem statement and an account of my published papers. In this chapter the concept of Proxessories is introduced and described: Proxessories and close proximity wirelessly connected accessories that can interact with its environment by means of sensor or actuator-technologies. This chapter presents the difficulty in the prototype and design of Proxessories from an engineering point-of-view and its paper in a multidisciplinary design team.

Chapter 2 includes literature related to previous work. Also presented are the concepts of "Digital Material" and the material turn of IT technology as strategy to include it in multidisciplinary design teams. The "Digital Material" refers to use technology as a classic design material, such as wood or glass, to inspire, drive or communicate the technology. Types of prototyping tools are described and presented as those that are commercially available and broadly-used nowadays.

Chapter 3 details the involved methods used in this research. Research through design is described as a method adopted to deliver an engineering design process, the design of a set of tools that support the prototyping of a Proxessories class of systems. The author of the thesis has been involved in several design projects where the learning from it has been used to complete this thesis and design of an engineering tool to prototype for Proxessories. Finally, this chapter will introduce the concept of *engineering through design*. It will be presented as the attitude shown by the engineer to understand the sometimes difficult-to-grasp design process and formulate the needs of a set of tools that support that design space.

Chapter 4 is a chronological description of the most important projects where the core needs and design of the tool has been shaped. The first project is the Lega, a handheld wireless device designed for an art exhibition that offered haptic, visual and location interaction. The next project I got involved was Inspirational Bits, an approach to expose the digital material. I use this approach to develop a series of radio-based Inspirational Bits, in an effort to expose the material properties of the radio waves used in the communication devices. Inspirational Bits helped to understand the material approach in an IT technology context and how the current tools used at that time failed to deliver an easy way to transfer the knowledge in the shape of technology, which will be the starting point of the next project. The third project described in this chapter is The Meptaphone, in the context of a multidisciplinary design effort between myself and an artist. Rapid prototyping is carried to add to the Metaphone machine an interaction-based on biosensors and body interaction, named The Bioball. The last project described, ABB sensor box, is a playful box of wireless sensors and actuators that are connected to a cloud server and can be connected between them for exploring new interactions.

Chapter 5 is the description of all the tools developed to support the design of Proxessories. First of all, rFlea is a hardware prototyping tool based on ultralow power wireless and an Arduino all-in-one and in a small form factor. rFlea uses the same libraries, community and tools of the existing Arduino but without compromising size or complexity, as it implements the wireless system in the same board. rFlea can be connected to modern phones or tablets, together with available libraries. Together with rFlea, I present a software tool, Insbits Studio, it is a cloud-based visual programming tool that implements the most used cloud services and allows connection of rFleas directly to other IoT devices such as mobile phones or connected artifacts. Chapter 5 includes design cases using rFlea and Insbits Studio.

Chapter 6 is the discussion and evaluation of all the tools developed in this thesis. Finally, chapter 7 will include the concluding remarks and future work.

1.6 Papers included in this thesis

This thesis is a compilation of five conference papers. The key contributions of the papers are summarized next, and the full papers with contributions and results are found in the paper reprint section.

- **Paper 1:** Jarmo Laaksolahti, Jordi Solsona Belenguer, Marcus Lundén, Anna Karlsson, and Jacob Tholander, "The LEGA: A Device for Leaving and Finding Tactile Traces" Accepted for publication at the Fifth International conference on Tangible, Embedded and Embodied Interaction, TEI'11, February 23, 2011, Funchal, Portugal.

Paper 1 describes experiences from the development of the Lega, a hand-held device for physical sharing experiences during the context of an art exhibition, this paper is my first design experience and the start of my design journey. The contribution in this paper is the multidisciplinary influence from an engineering point-of-view and construction of the handheld device. The author of this thesis took an active role in influencing the design through wireless technologies, sensors and actuators.

- **Paper 2:** Jordi Solsona Belenguer, and Mark Smith, "An Extension of Computer Engineering Methods for Interdisciplinary Design" Workshop paper at the International Conference on Pervasive Computing and Communication, PerCom'11, March 21-25, 2011, Seattle WA. USA.

From learnings of the Lega project described in paper 1, reflections on the design process are described in paper 2. This paper describes how the engineer develops new design-realization methods that allow the tacit knowledge of the designer to influence the codified engineering process in a repeatable and transferable way. These processes are referred as "dreaming" and "mirroring".

- **Paper 3:** Petra Sundström, Alex Taylor, Katja Grufberg, Niklas Wirström, Jordi Solsona Belenguer, and Marcus Lundén,"Inspirational Bits — Towards a shared understanding of the digital material" Proceeding at the International Conference of Human-Computer Interaction, CHI'11, May 7-11, Vancouver, BC Canada.

Inspirational Bits is the main project where the concept of material approach was introduced. This approach helps in opening the design space by showing the properties of the digital material,technology is wrapped in a black-box by the engineer to the multidisciplinary design team. The method also aims to create a common background of knowledge and language within a multidisciplinary design team. The engineer presents the technology in quickly realized but fully working systems.

- **Paper 4:** Jordi Solsona Belenguer, Marcus Lundén, Jarmo Laaksolahti, and Petra Sundström "Immaterial Materials: Designing with Radio" Proceeding of the Sixth International conference on Tangible, Embedded and Embodied Interaction, TEI'12, February 19-22, 2012, Kingston, ON Canada.

From the results obtained and described in paper 3, a case study is described in paper 4. This paper describes the use of the Inspirational Bits method to expose properties of radio technologies that can be used by classic, non-technical designers. Designing with digital materials is sometimes challenging due to properties that are immaterial and, for all practical purposes invisible. In this paper we explore such material, in this case radio, and find ways of making radio more tangible and accessible to multidisciplinary design teams by using the method of Inspirational Bits. The Lega project has some misconceptions among the design team regarding radio: this, and the previous studies of mine, are the main motivation to pick up such intangible material. The author is involved in a design situation involving radio as design material that exemplifies some of the challenges that working with radio can involve.

- **Paper 5:** Jordi Solsona Belenguer, Mattias Jacobsson, Jarmo Laaksolahti and Martin Murer"Exploring the Design Space of Proxessories" Submission in progress for International Conference of Human-Computer Interaction, CHI'16.

Paper 5 is the final publication where the design space of Proxessories is introduced. This paper has a description of the prototyping platform that is tailored to the specific technical requirements together with a handful of resulting design examples of actual Proxessories explorations. Each design exploration illustrates different aspects of using the platform.

Chapter 2

Background

This thesis has developed over the years by involvement in several projects that all share the common thread of designing for Proxessories and how to improve that design process. Proxessories is used to define a class of systems and a design space in this thesis. This chapter will give some background on where the concept comes from and some related HCI projects. In order to understand the language and perspective of this thesis, the concept of materiality in HCI will be presented, as it is a common theme across all the projects. After presenting the basic concepts of the material turn in HCI, the most used and available prototyping tools are introduced together with a description of how they work and their implications in their design.

2.1 Proxemics and Proxessories

In 1966, Hall coined the term proxemics as the study of the human use of space within the context of culture [21]. Hall's most famous innovation has to do with the definition of the informal or personal spaces that surround individuals:

- Intimate space. The closest bubble of space surrounding a person. Entry into this space is acceptable only for the closest friends and intimates.
- Social and consultative spaces. The spaces in which people feel comfortable conducting routine social interactions with acquaintances as well as strangers.
- Public space. The area of space beyond which people will perceive interactions as impersonal and relatively anonymous.

The term proxemics relates distance with cultural context, but what if we add a mix of people and digital artifacts? Saul Greenberg et al., have used the term proxemics as a way to define Proxemic Interactions [20]. They introduce the term proxemics to the Ubicomp community and describe it as Ubicomp proxemics. It concerns inter-entity distance, where entities can be a mix of people, digital devices, and nondigital things. They present different dimensions to the distance in between those interactions: distance, orientation, movement, identity and location itself.

Another related body of work related to proxemics can be found in Proxemics play [41]. Muller et al., combine playful interaction and interpersonal distance between players. They use the new wireless technologies to facilitate novel play experiences.

While the articulation of the Proxessories design space is outlined here there are precedents in previous work. Examples of systems from the HCI-field with similar characteristics to Proxemics include The Stane [43] and The Shoogle System [73]. They are accessories to mobile phones that enable novel interactions, and both rely on sensors, novel materials, and wireless communication to provide their functionality. Furthermore, The Stane, is an interaction artifact that enables tactile interaction with the mobile phone and the user, in which its design, material, shape plays an important role in the final interaction, turning the material qualities of the design into an early design decision.

eMoto [53], by Sundström et al., is a system that includes a custom-made stylus that can be used with mobile phones. Its stylus extends the interaction with motion and temperature sensors to allow users to express themselves physically. By gesturing with the stylus, using pressure and movement, users can change the background of a text message to have colors, shapes and animations as a function of their physical movements. These messages could then be sent to other users to express various emotional content. The authors of the paper comment that eMoto in many ways was a success, but the actual shape of the extended stylus was a disappointment to them and users; the stylus became quite large in order to include battery, wireless communication to the mobile, and sensors. Users were very unhappy with the shape of the eMoto and felt embarrassed to use it in public; the limitations of the technology led to a bad user experience [15].

A similar development can be seen in industry where there is a growing segment of systems typically found in settings like sports interactions, bio-sensor-enabled systems or interaction accessories for our phones and devices. Typical commercial examples include Estimote[1], Bluetooth beacons that connect to your phone, Flic[2], a Bluetooth button that can trigger functions in your phone, or, Fitbit [3], an activity and performance tracking bracelet.

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[1] http://estimote.com/

[2] https://flic.io/

[3] https://www.fitbit.com/se

2.2 The Material turn

In multidisciplinary design teams, technology needs to be introduced in a way that enables those with non-engineering backgrounds to grasp and use this technology as a design resource. Schön, in the book *The reflective practitioner* [46], talks about traditionally-schooled architecture designers describing how they engage in a conversation with materials through sketches, mock-ups and early prototyping. In this conversation, the materials start to talk back, revealing opportunities and challenges. It seems, however, that computing technology is a more complicated material for many designers to work with [44]. It is a material that evolves over both space and time [22], that is, as more and more technology is innovated, changed, and updated; it is hard for non-engineering disciplines to learn and keep their knowledge up to date.

The main task of an engineer in a multidisciplinary design team is to introduce this technology in a way that can be understood [44] and in a way where the material and dynamic properties in time and space are exposed. It is through this process that technology becomes a design material in a multidisciplinary sense.

Previous work has been done that attempts to bring in technology as design material incorporating it as a single and unique entity. Löwgren and Stolterman [36] claim that, from a designer's perspective, working with a known material makes it possible to know and understand the material's qualities. Because technology evolves so quickly, however, there is little time for reflection or to know its qualities in a permanent sense. Because of the complexity in designing artifacts, Löwgren and Stolterman consider it a "material without qualities".

Vallgårda and Redström talk of computational composites such as aggregates made up of a combination of technology as a design material that imposes particular properties [63]. They explain that it is almost impossible to work with the technology as a material in its most raw form. In the work "Computational composites", Vallgårda and Redström [63], describe a composite of two or more materials as a single new material to enhance a specific property or to introduce new combinations of properties in a material. They provide an analysis of computational technology as material in design, showing how computational composites provide a "precise understanding of the computer as material" and also claim that computations "need to be combined with other materials to come to expression as material". They interpret computers as a "stored sequences of (practically) discrete voltage levels". Vallgårda and Redström do not think of it as a material without qualities, but rather a material that can be explored if its digital side is made more visible as in composite materials. They confront the views of Stolterman and Löwgren giving the digital material actual properties in the case of such a composite. Lately, Löwgren proposes "hybrid design materials" [35], combination of physical properties such as texture and weight with digital ones that offer properties in behavior, responsivity, mediality and transience, therefore going from a material without properties to the dynamic properties of the hybrid design materials.

If technology is approached with a material perspective, it could be worked and crafted as material with properties, and they could be combined with different materials in the same way as wood, glass, or leather [14][58], making them suitable for a design process that explores and exploits the material to its fullest to deliver the user experience. Technology can move from the "material without qualities" to a material that shows its properties and qualities, making them suitable for design.

In the work "Material focus", Vallgårda and Sokoler [65], a study of two computational properties is presented: "computed causality" and "connectability", and they give a design example for each composites property as shown in figure 2.1. The first example (figure 2.1 left), is a copper tube with sensors and actuators that can detect when it is being touched by measuring temperature. Our experience about metal objects says us that when touching metal it rapidly absorbs our temperature and gets warmer, but in this case, by using actuators in the metal that can control its temperature, the more you rub the metal surface the colder it gets, changing our experience with metal's thermal behavior. Connectedness, on the other hand, exposes the property of computers to connect to other computers they describe this property as "something physically separated is capable of behaving as were it physically conjoined". As an example, shown in figure 2.1 right, the composite does as follows: when, for instance, one entity of the composite is cooled down all the parts will gradually adjust to achieve new temperature equilibrium.

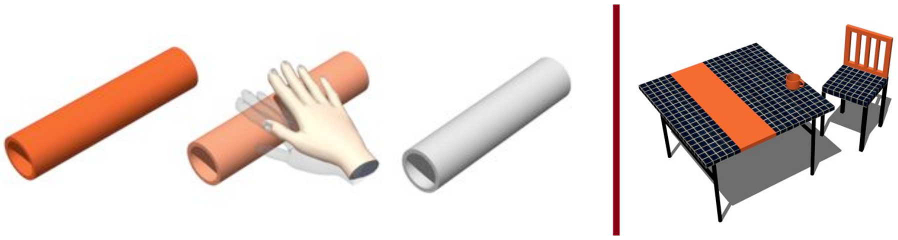


Figure 2.1: Left: causality, turning our experience with a metal's thermal behavior upside down. Right: connectedness, table and chair connected to perform different actions.

Computational composites expose the need to not only establish a vocabulary to describe computers as materials, but also a foundation on which they can be made accessible for experience. Vallgårda shows that computers have properties that can be exposed and experienced. Computational composites raise our awareness that computers can be used as a design material with properties, and, by doing so, new designs and concepts will emerge from this perspective that will influence several collectively, such as between computer science and architecture, human-computer interaction and design.

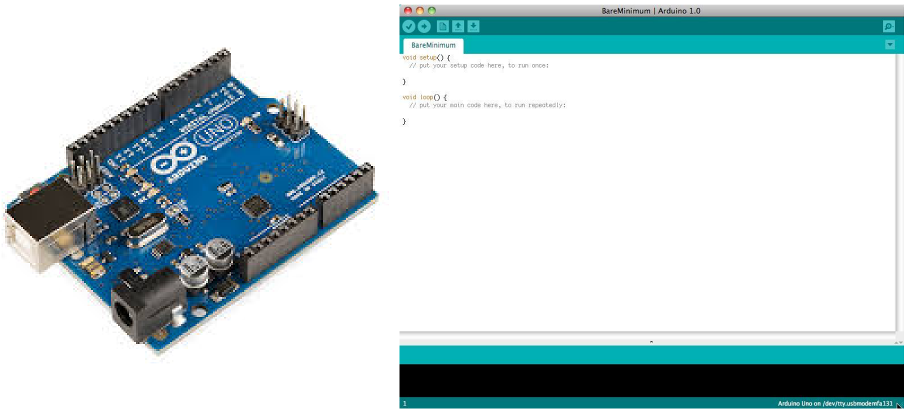
Moussette and Fallman present their idea of "Sketching in hardware" [39] as a result of the experience gained in previous projects such as the "HAPI project" [40], where they explore how researchers and designers can work in the new field of interaction design with haptics where tools and techniques are limited. Designers found that when starting to design haptics their assumptions on haptic feedback were totally ungrounded, having to move back to the technology and the human experience to understand and move on. Furthermore, the combination of different materials with the technology ended up in "haptic qualities as tightly coupled with the material used in the models", or, in other words, when using wood, plastic, metal or foam, creating a haptic composite results in "intrinsic characteristics and properties that greatly influence haptics capabilities".

Sundström and Höök expose the challenges [52] when designing for "supple" systems [24]. Supple is an adjective that is defined as "able to perform bending or twisting movements with ease, capable of being bent or folded without creases, cracks, or break". It is used as a metaphor for how systems can be embodied, following our movements or emotions without creases, cracks or breaks in the interaction, and allowing us to move and experience as we interact. A "supple" system is one that combines custom-built hardware, sensor technology, and wireless communication, to interact with end-users and create a physical, emotional, and highly involving interaction. The design process is described as too much time developing the design idea before starting to consider the digital material, therefore "getting the right design vs. getting the design right" [9]. They design Friend Sense, a system for expressing friendship and emotional closeness through movement, using wireless sensor network technologies. In this paper they took a material approach to designing for suppleness and provide three examples where they material came to play a decisive role in the design process. Without previous experiences in wireless sensor networks and movement sensors, instead of going from ethnographic studies to a design, the design process, goes through a process of experiential knowledge where the design and material evolve together and influence each other. They conclude, "We first had to live with the experiential prototypes to find the "alternative universe" of expression that the digital material enabled", referencing at the importance that the experience of the digital material in order to include it in a design process.

To be successful in the design of new interaction artifacts in a multidisciplinary space, a holistic approach must be taken. In order to integrate technology into system design with non-engineers in a smooth and intuitive way, an engineer should take a material-centric perspective where technology is worked and crafted as material with properties that can be combined with different materials like wood, glass, or iron. Technology has to move from the "material without qualities" to a material that shows its properties, making them accessible to designers and increasing the effectiveness of the engineer in a multidisciplinary space.

2.3 Rapid prototyping platforms

In interaction design and human computer interaction, prototyping platforms occupy a central point in the representation of ideas and concepts; nevertheless, prototyping tools can support a material perspective as the technology is exposed and open. One of the research questions in this thesis is about existing commercial toolkits and how they can support the design of Proxessories in multidisciplinary design teams. Prototyping tools used in interactions design, human computer interaction or design as a broad perspective have always been seen by engineers as simplified and therefore technologically inferior and not as efficient as engineering tools, mostly referred to as developer kits. Moussette refers to prototyping tools in this way, “The current prototyping toolkits use technology about 10 to 20 years old, if not more. Compared to what can be found in the latest electronic devices today, they are dinosaurs.” [39].



```
void setup() {
  // put your setup code here, to run once:

}

void loop() {
  // put your main code here, to run repeatedly:

}
```

Figure 2.2: Left: Arduino UNO. Right: Arduino IDE.

Developers’ kits are sets of programs or hardware platforms used to write applications programs or to evaluate a hardware platform. Usually they are provided by the manufacturers of a specific hardware or software, and they require engineering knowledge like programming languages or electronics. In this thesis we will focus on available prototyping tools used in IxD. The goal is the give a common experiential background, and the engineer has to be able to develop rapid prototypes in order to expose the specific qualities of a technology. Commercial prototyping tools provide a very easy access to knowledge, price and availability although they may not be the latest technology in the field. In this section, we will see the most widely-used commercially-available prototyping tools used in interaction design and human computer interaction, how they differentiate between one another and the ideas behind their conception.

In 2005, Massimo Banzi [47] designed a prototyping tool named Arduino for his students at the Interaction Design Institute Ivrea (IDII), becoming a do-it-yourself revolution in electronics, thanks to its low price or the opportunity to build it yourself, as hardware schematics and source code are available for free under public licenses. As a result, Arduino has become the most influential open-source hardware movement of its time; in addition, Arduino is the most successful prototyping tool for IxD and HCI over the last decade as well. Arduino is a platform that exposes the connections of a microcontroller in a way that can be easily accessed through conventional pin connections. Arduino hardware, see Figure 2.2, apart from the microcontroller, includes the necessary hardware to manage the power supply, clocks and pull up resistors. Arduino exposes digital and analog ports so they can be used to connect digital and analog sensors. Arduino is an already-soldered board ready to use, removing the need to solder the microcontroller, resistors and power supplies. The success of Arduino not only relies on the hardware, but it also comes with an Integrated Development Environment (IDE) that facilitates the programming and flashing of the microcontroller. Arduino is open-source; all hardware designs and software can be downloaded and modified, which is why over the years the Arduino platform has been growing as the designs have been improved and modified to fit other contexts, leading to a great variety of Arduinos in shapes, sizes, capabilities, computing power or power consumption. In sum, Arduino has a self-driven and growing community where experiences, projects, codes and designs can be used for other projects. Arduino does not provide sensors or peripherals; it only provides the programming environment and an exposed microcontroller.

In 2001, Saul Greenberg and Chester Fitchett presented a paper called Phidgets: Easy Development of Physical Interfaces through Physical Widgets [19]. They introduce a prototyping platform that over several years would become one of the most successful ones in the prototyping realm. Phidgets are physical output and input devices that can be connected directly to a controller. All components (inputs, outputs and controllers) are conveniently packaged in a way (see Figure 2.3) that can be connected directly. Phidgets hide hardware implementation and expose functionality through a well-defined application programming interface (API), they have an (optional) on-screen interactive interface.

Arduino is an example of prototyping tools commonly referred to as a breakout model. A breakout model is a design in which, while some functionalities are simplified, the main ones are directly exposed, that is, exposing the inputs and outputs of a microcontroller directly. Breakout models are not just applied to microcontrollers, but they can be applied to any electronic device; for example all

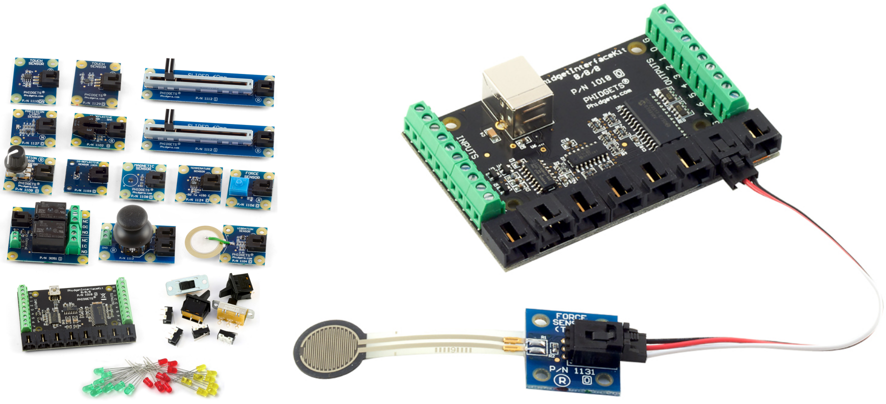


Figure 2.3: Sensors and actuators modules in Phidgets prototyping platform.

types of sensors or actuators. For example, a breakout model of an accelerometer sensor (see Figure 2.4) will directly expose the inputs and outputs of the main sensor mounting in the board. This class of sensors can be very easily combined with a breakout model of a microcontroller like Arduino, but they may require some signal adaptation in between them with specific software to be used in the microcontroller.

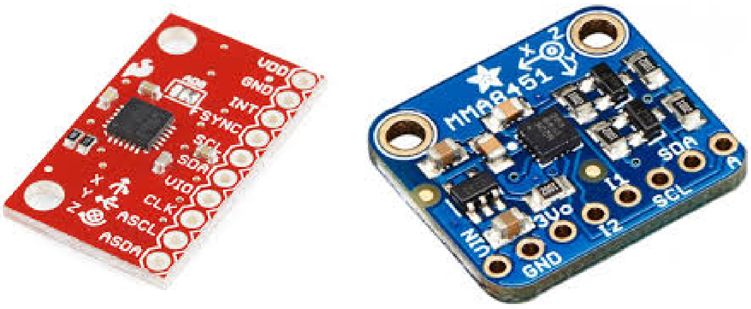


Figure 2.4: Left: Sparkfun accelerometer breakout sensor. Right: Adafruit Industries accelerometer breakout sensor.

The breakout model has been the most used for complex design situations as they can adapt to virtually any situation. In recent years the industry has adapted to breakout models, and nowadays it is very easy to find a large library of peripherals so-called breakout boards, implementing sensors and actuators. SparkFun and

Adafruit Industries are online manufacturers that sell a large variety of electronics in a breakout model, together with a community that provides all code to include in Arduinos's IDE, user guides and examples on how to use those breakouts.

The other type of prototyping tool is what is known as cricket model [39]. Phidgets are a good example of a prototyping tool using a cricket model. They are packaged in a way that they can be connected directly to other sensors that have been packaged in the same way as well so the information in between them is compatible. They make it easier to connect and play sensors and actuators but often make them incompatible with other platforms and systems, at least in a direct form. Another example of cricket model brought to hardware specifically is Little Bits [1], which is a library of preassembled electronic circuit boards. They can be stacked to each other with their specific color coded connector using magnets. The design of the connector allows only for the right connections, that is, output can only connect to input, and in the right order, and a switch will have an input and an output. Little bits is not specifically intended for prototyping, but rather, moves electronics from late stages of the design process to earlier ones. Other examples of this class of prototyping tools is Gadgeteer[4], in this case, a more complex prototyping tool implementing more possibilities and functionalities.

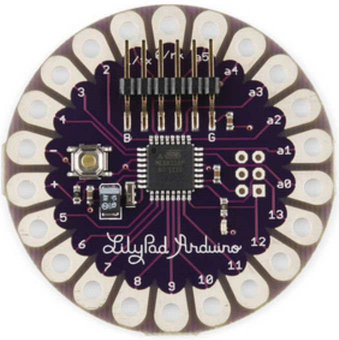


Figure 2.5: The Lilypad Arduino.

Another aspect to look at what prototyping tools can give to the design space is the form factor. An example of how the same prototyping tool but in a new form factor design can affect the design of a specific class of systems is Arduino Lilypad [7][8]. Arduino Lilypad, see Figure 2.5, is an Arduino with a very specific physical design for electronic textiles applications. It is smaller than regular Arduino boards and implements lower power and less functionality. Changing the way they interface

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[4] http://research.microsoft.com/en-us/projects/gadgeteer/

with the inputs and outputs, instead of standard electronics pins, big holes in a flower shape facilitate the use of conductive thread.

The cricket model is in nature more limited to use with other proposes and usually they are referred to as educational or explorative prototyping tools. On the other hand breakout models are used more in design and research context due to their openness. Different tools will enable different classes of experiences or enable different classes of systems. Arduino Lilypad opened the design space for e-textiles.

The level of abstraction that every single prototyping tool employs determines how quickly one can build something with them, but, at the same time, the more abstract the fewer possibilities for the explorer to do what is wanted. It becomes a trade-off between abstraction and specific functionality. It is very important that we use the right tool for every design situation. In the case of Lilypad, for the first time it allowed one to start tinkering and exploring with e-textiles. The shape, form factor, functionalities, level of abstraction is what will define a tool and make it suitable for a specific design task. Many aspects can make a specific tool successful in the design context, but in this thesis, we will focus on which characteristics of a tool can make the design of Proxessories not only easier, but also more rapid promotion of shared knowledge and material perspective.

Chapter 3

Method

Looking at the research questions in Chapter 1, my knowledge contribution comes in three different formats. The first is an approach adding to existing designerly methods, a practice-oriented way of working, opening design spaces with many different concepts, but where I show how the digital material can be given a stronger voice, and how engineers can be inspired by and contribute to design practice. The second contribution is the unpacking, and population, of a particular design space [71], the Proxessory design space, as discussed above. The third contribution comes in the shape of the actual tools that were developed to help shape and define the design space of Proxessories.

3.1 Research through Design

The methods employed in the projects included in this thesis can largely be described as belonging to Research Through Design (RtD) [74]. The research done in each of the projects served first and foremost the purpose of interaction design explorations and has largely been published as such [28][54][49][55][70]. While other collaborators in the projects were mainly interested in the RtD outcomes, I had a slightly different focus. Each project lead to reflections and ideas relating back to my material and skills, in ways by which I could make those fit with the overall project aims. Those reflections led to building new tools and figuring out engineering approaches that I then subsequently applied in the next project. The reflections and insights, which I will frame below as *Engineering through Design* (EtD), could not have occurred if I had not taken an active role in these different design projects, within a multidisciplinary design team. My insights stem from and thrive off the design work done in each project, but my research path and approach was my own, not the overall teams' agenda and method.

This thesis has its basis in methodological higher level frameworks such as in Research through Design [74]. RtD was first proposed as concept by Christopher

Frayling [16] where the design researchers focus is on making the right thing through the production of artifacts. A unique point in this method is that it stresses design artifacts as outcomes that can transform the world from its current to its preferred states.

In these artifacts the knowledge of the designers is embedded in the artifact itself, and for instance they would become design exemplars as described by Stolterman in [51][31] simplifying the transfer of that knowledge and learning to the HCI research and practice communities.

Moreover, RtD was introduced as an attempt to come to grips with the struggle that the HCI community had to integrate design in research and practice while design was gaining presence and importance. Zimmerman et al [74] [75] describe the model through examples, while at the same time providing gives a set of criteria to evaluate the quality of what would count as an interaction design research contribution.

Within the context of Research through Design, I have been through a number of projects were my main role has been providing the technological knowledge and hands on practice to build interaction artifacts. Coming from an engineering background, I was from the beginning tempted to wait for design requirements and translate them into an ordinary engineering problem solving situation, where I would then try to find the technology appropriate to those requirements and finally engineer it in a way that better provides the imagined interaction. As this did not work out, I needed to tweak my approach and methods to better fit the teams general goals.

3.2 Engineering through Design

How then can RtD help the engineering process in a multidisciplinary design context? There are several parallels in my work to the argument for how RtD was introduced into the HCI community. Just as there was a struggle for how to integrate design research with its domain of practitioners [17], I struggled with how to integrate engineering practice into design research. Nowadays, we see IT technology growing in presence and importance, and at the same time struggle for several disciplines like industrial design or HCI community to grasp technology and introduce it in the design space. As we will discuss further below, the so-called material turn in HCI takes a strong role in shaping how to transfer, expose and make use of engineering knowledge, into the multidisciplinary team,turning such technology into a design resource. In RtD the gain of new knowledge comes via the act of making, that is, design and build something, and then reflecting on that artifact and how to extract knowledge from it.

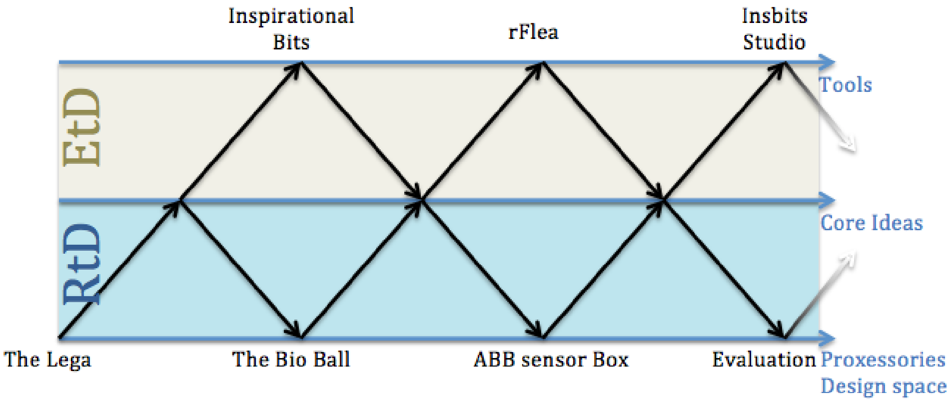

Figure 3.1: Engineering through Design in this thesis.

In this comparison, the artifact that is intended to transform the world from the current state to a preferred state is in fact, the piece of technology that the engineer wants to use to change the design space. In other words, engineers, through the creation of an artifact, want to transmit knowledge and change the current state of the particular design space to a preferred state. To not confuse the concept of RtD with engineering, we will refer in this thesis to this process as Engineering through Design (EtD), when applying RtD approach to develop and engineer pieces of technology during a design process in order to facilitate and transform the design space. Löwgren, in the work “Inspirational Patterns for Embodied Interaction”[34], describes how “abstractions of core ideas and essential elements from a class of coherent examples, pointing to promising regions in the design space”. Each of the projects described here, contain pieces of such abstracted core ideas, that together are used to describe the design space of Proxessories from an engineering perspective, and that were helpful in shaping tools and methods in that particular space. Those core ideas, extracted to be used in the tools for the engineering practices, are design elements that are abstracted one level up from the specifics of the design exemplars. As such they should be usable in many different design situations. At the same time, they are not generic and usable to build any applications, but specifically adapted to the design space of Proxessories. This is sometimes referred to as “intermediary IxD knowledge” in the HCI literature [23]. They have the potential to be appropriate by designers and researchers to extend their design repertoires (in the words of Schön) and help to generate new “ultimate particulars” [51].

Figure 3.1 is a representation of my EtD process in this thesis, where the top line is representing the knowledge contributions to engineering that grew out of the engaging in the different design projects, while the bottom line represents the different RtD-projects that spurred those explorations. During each project design knowledge (Research through Design) is produced in core ideas that will influence the following project. Engineering is also influenced from those core ideas and generates its own engineering knowledge. The particular situation here is that the engineering ideas will not live isolated from the design space but will bounce back down to influence those core ideas and therefore the following explorations. This process takes place in parallel and both design practice and engineering talk back influencing each other and increasing the overall knowledge over the design space. The space between the two knowledges becomes the common background of conversation, the knowledge interface.

Engineering through Design is not proposed as an entirely novel research method, instead it can be broadly framed as part of the family of RtD research methods, but with a specific emphasis on engineering practices and how those can be incorporated in designerly approaches. What engineering then means in terms of practice involves many everyday methods and approaches, for instance, and is not limited to, sketching, soldering, programming. One very important difference between engineering as in solving problems and engineering through design, regards coming up with an artifact that describes or facilitates the design process and has several ways to solve it.

To give two examples of methods that I picked up on, tweaked and used I will now talk a bit more about rapid prototyping and methods for observations and reflection.

3.3 Rapid prototyping

Rapid prototyping [56] consists of quickly creating, building, testing, rebuilding, and retesting the product's basic structure, menus, feedback mechanisms, and metaphors during the initial product planning phases. Rapid prototyping gives a tangible demonstration of what the system is about and provides metric-based evaluations for interactions of a final prototype. Engineering design processes are generally part of an entire product development process of which there can be several kinds depending on the type of product being developed [60]. IT devices frequently follow a version of these called a “spiral development” (see Figure 4.5) process which combines aspect of the waterfall model [30] and rapid prototyping methodologies, in an effort to combine advantages of top-down and bottom-up concepts.

In this thesis the tools presented have been designed and built using a method that borrows from Rapid prototyping. As seen in Figure 3.1, the process of creating the tools involves building the tools and putting them in practice into the design space, while using the tools their ability to support design within it, was constantly put to the test and evaluated. Learnings from such practice based evaluations became the basis for reflections on the nature and demands of the design space itself, as well as how to better support design within it.

3.4 Observation and Reflection

In HCI it is common practice to study, observe and reflect upon ones tools and prototypes — either by self-reflection, study users or interviews.

Chapter 4 describes a Design journey, it was used to evaluate the tools build through a rapid prototyping method. I was the engineer who was using those tools to provide to the designers in the team an experiential technology in order to influence their decisions, therefore, self reflections were used to redesign the tools and go to the next quick prototype to be used. In the same way a designer is described in "The reflective practitioner" [46], through a reflective practice, learnt skills and knowledge about what works when and where, I was building up new prototypes that best fit the design space.

After the tools were designed, students and interaction designers used them in multidisciplinary design teams, always one of them at least familiar with IxD most common prototyping tools. Each team went through creativity methods to bring up a design concept and start working on providing sketches to support their interactions, to finally, after interactions and explorations on the design space, build a final prototypes. Some of the most representative projects will be explained in detail in Chapter 5. I was in all the projects myself and saw how people attempted to work with the tools, showing the limitations of what the tools were offering, When the design work was progressing in a good manner and when it was not. The whole setting and design context provided feedback as designer of engineering tools and methods.

Chapter 4

Design Journey: Engineering through Design

When designing a tool that has to fit into a design process, inspire and influence it, not only electronics or software is required. Understanding the context where those prototypes and their design process took place is also very important. This chapter details the design journey that was followed in order to understand first the role of an engineer in a multidisciplinary design process, what mindset can be approached from the engineers to take the future decisions while engineering those tools, and finally, the engineering challenges while designing and evaluating those tools. The chapter is therefore structured chronologically. Figure 3.1 from chapter 3, Methods, is an overview of this design journey and how this chapter will be structured. The journey kicks off with the Lega Project and moves along projects building up in cumulative knowledge, in constant influences between the engineering and design space.

The goals of these projects are to deliver interaction design artifacts in various contexts of research. They are not intended mainly for the realization of this thesis research; instead, I have been involved to gain knowledge and practical background to design and test the tools. During the realization of this thesis more projects have been carried out [70][55][14] than those presented or covered in this chapter, but it is rather a representative collection of projects.

4.1 The Lega Project

The first design exploration and starting point in this PhD thesis was The Lega project. The project was developed in Mobile Life VINN Excellence Centre, and used in an art exhibition by its visitors. The design learnings from The Lega have had significant influence on the initial direction of this PhD thesis.

Figure 4.1: The Lega in the art exhibition.

The Lega is a hand-held device for tactile and gesture-based interaction to be used by groups of friends in the art exhibition. The device and system is called The Lega [28], see figure 4.1, after the Swedish word for a place in the woods where you can see that an animal has slept. The Lega device is touch-, motion-, and location-sensitive. By stroking it and gesturing with it users non-verbally express some of their experiences of the art exhibition and leave them behind as a trace for other group members to find. When a visitor decides to leave a trace, it will be left in the room, where the next visitor will be able to experience it when passing by the same spot. Traces are experienced as vibration patterns that roughly correspond to the actions taken to create a trace, and light patterns that show which of the other devices left the trace. Tactile user interaction, both as input through touch and as output through vibrations, were a key factor of the design. This was a very challenging part of the system hardware to design and implement. In this section we describe that process and learnings that can be drawn from it.

The Lega is in the domain of Proxessories. It is an interaction device that uses wireless technology, sensors and actuators, and interacts in close proximity with the user. The Lega system is also an example of what in HCI research have been referred to as designing for Suppleness [24]. A “supple” system is one that combines custom-built hardware, sensor technology, and wireless communication to interact with end-users and create a physical, emotional, and highly-involving interaction [52]. The design of Supple Systems provides good examples of multidisciplinary design team interaction and the knowledge of the Digital Material. Each of the concepts embodied in a Supple System plays a relevant part in the final goal of a project, device or design. Designing such supple systems [25] is a complicated process that must approach hardware, software and design issues holistically to succeed. Hardware that does not feel right to the touch may ruin an otherwise enjoyable experience, an inefficient software implementation might destroy an otherwise good experience, and design that does not consider the physical and computational properties of the involved materials may lead to an experience that does not harmonize with the material. An engineer should design from a holistic point of view in order to reach a good final experience with the design. This is why in most cases a broad range of disciplines will be involved in the design of the future IT devices and supple systems. Designing and building supple systems is challenging because supple systems involve unfamiliar "material" for interaction designers, whether that it was unfamiliar materials to this particular group of designers, or that it was early days for these kinds of systems. At the time the Lega was using them at the forefront of development and research, as such, there were no "role models" for how to design it or even what materials to use, and also because supple systems require a wide range of competencies that are often unfamiliar to hardware designers.

The initial design involved vibration to play back patterns. Vibrators benefit from being easy to drive as they are activated by simple application of voltage. Vibrators generate a high level of vibration when compared to other vibration generating technologies (Speakers, solenoids and piezoelectric actuators). Vibrators also come in robust packages that make them a good option to use in wearable devices [57]. However, over a large surface, one single vibrator cannot direct the vibration to a single spot, a vibrator grid, placed in a foam base, was the first iteration for the interaction tests (see figure 4.2 to address this problem).

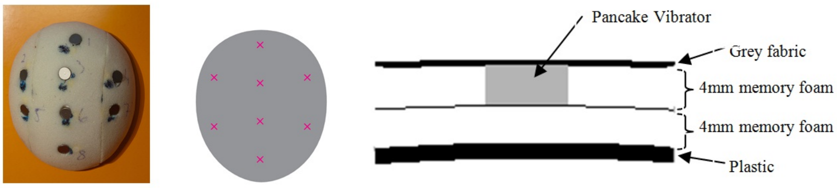

Figure 4.2: Left and center: Vibrators placement picture and schematic. Right: foam and vibrator.

The Lega also has light, movement and location interaction. On the top part, a grid of RGB leds give information about your own identification color and others' identification colors (see figure 4.1). When the visitor is about to leave a trace, she will push a button located in the top assembly that is provided with a servo mechanism that will keep the button in the low position as long as the time to leave the trace lasts. During this time, gestures sensed by an accelerometer and tactile sensors will get information about the trace. The traces are pre-set to 5 seconds. When the time is over, the button goes to its upper position indicating the trace has been recorded.

Figure 4.3: Bottom shell with the foil as electrodes for the touch sensors.

In order to know where a user leaves a trace, an infrastructure is deployed in the art hall, using a wireless sensor network. The infrastructure is used to provide location information to the Legas, store the traces, and allow data logs to be stored remotely for future data analysis. The location is registered using Radio Signal Strength (RSSI). Because using RSSI is not a precise method of determining location, it is only used to determine the room in which a trace was left. The distribution of wireless infrastructures at the museum is shown in figure 4.4.

Issues during design process

The design of the Lega fell short for many reasons that are described in this section. From a technical design-process point-of-view, a lack of coordination between the design sketched and the hardware prototype was found. While all the sketches of individual technology seemed to work perfectly to transmit the digital material to the multidisciplinary design team and created a common background of knowledge and language, the effort of putting all the technology bits together to create the system and the design-decisions resulted in an unexpected final interaction with the device during its final development in the art exhibition.

Haptic tests carried by the design team consisted of determining whether the human hand can feel different patterns of vibration [5]. The vibrators controlled by a microcontroller played predefined patterns. The first tests showed that that without covering the vibrators with fabric, the user is able to distinguish individual vibrators. When putting the Lega together, the decision of adding a fabric to cover the foam increased the pressure on the vibrators and kept them tight against the foam resulting in the transmission of vibrational energy to the plastic and foam, which is in turn transferred mechanical vibrations throughout the entire device, lowering the user's ability to distinguish between vibrators.

There are technologies that, due to their immaterial nature, are difficult to design with in a classic sense and whose properties are difficult to express to a non-engineer. This is the case of the issues found when using the radio in this project. For instance, traces would seemingly be lost, or found at locations where no traces could have been left, which made it very hard to accept that the system was functioning as envisioned. Only after lengthy investigations and experimentation could we find explanations for such behavior, and it was harder to express the explanations in a way that could be understood by the entire multidisciplinary group. Examples include properties of the radio waves such as the possibility to travel through the walls, or even packets colliding due to congestion [37]. If these issues could have been identified as engineering requirements from the start, for example by understanding that they had a role in the entire design idea, they could have possibly influenced the design process such that the entire concept for the Lega would have differed from the one presented here. However, even finding the source of the problems required a substantial effort, which could have been avoided, if we had access to better tools for exploring such issues at an earlier stage in the design process.

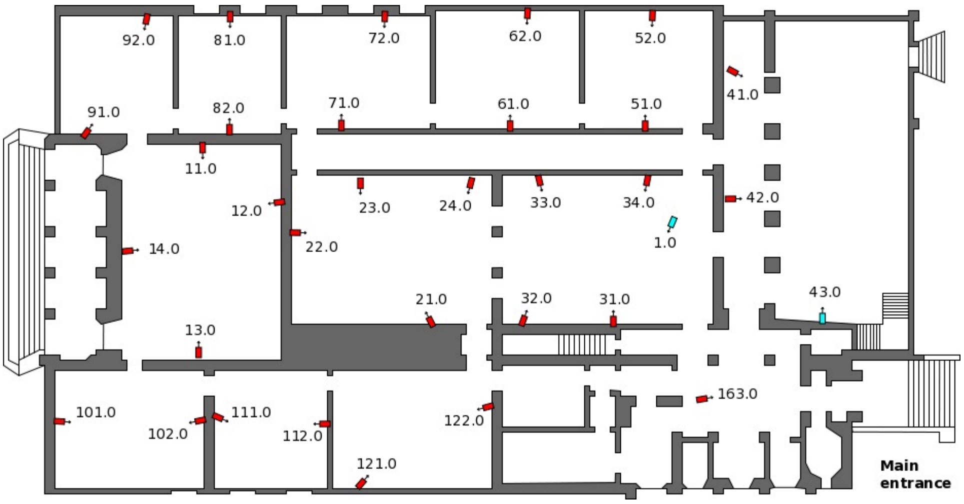

Figure 4.4: Map of the exhibition with the infrastructure nodes numbered in each room.

Dreaming and Mirroring

Four different competences participated actively in the Lega hardware design process: HCI designers, software designers, industrial designers and hardware designers. The design process was incremental and based on weekly iterations. At the end of each week, new pieces of hardware were tested, and all the members were required to interact with the entire system in order to assess the overall experience provided by the design. This process provided feedback to all involved parties. The non-hardware designers gained an increased understanding of the hardware and its limitations, and the hardware designers received interaction and design knowledge to apply in the iteration.

Although this process superficially resembles a traditional product-design cycle (see figure 4.5), it differs from such a cycle in several respects. It cycles over a much larger amount of the design process and involves all the contributors of the design space. This reduces the overall duration of the cycle, and it involves no more time than it takes to produce the next interaction sketch. Smaller design changes occur more rapidly using this model, and these design changes take into account not only the codified engineering factors, but also the non-codified usability and design factors provided by the broad range of contributors. Since the design loop is quicker and involves more contributors, each iteration of the cycle allows all contributors to converge their thinking to arrive at a common solution. This means that at the start of the design cycle, each contributor solves the problem from their own domain of expertise. As the design process progresses, each contributor is influenced by the current prototype and what it can do. From the hardware design

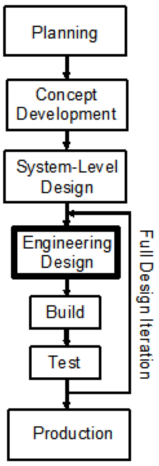

Figure 4.5: Classic spiral product development process [50].

prospective, this brings new knowledge into the design realization. By observing how the technical realization is interpreted by the other contributors, it allows non-codified design parameters represented as human factors, emotion and related behavioral knowledge to be incorporated into the next hardware design iteration. Not only does the design of the device change at each iteration, but so does the skill-set of the hardware designer by observing new interpretations of technology that occur at a very fine level of granularity. The new interpretations occur because of the influence of the broad contributors who do not share the same hardware knowledge domain.

In other words, engineers engaged the multidisciplinary team in a conversation where the channel is not the codified knowledge of the engineer, but the digital material. All members of the design team use the sketches and digital material to converge in a more collaborative design sapace. These design processes are the steps of dreaming and mirroring, and they directly alter the engineering design process used by the engineer [50]; see figure 4.6. The engineer stops talking about technology in the design process to the multidisciplinary design team, and instead, by using the sketches, listens to the designers and tries to turn this design concepts into small bits of technology that will be shown in a mirror process, where the designer can talk back again in order to influence the sketch made by the engineer. After few a iterations both, engineer, and designer, have influenced each other, enabling converging the sketch into a conversational piece of technology.

In many respects, the Lega design was also successful. It successfully deployed a

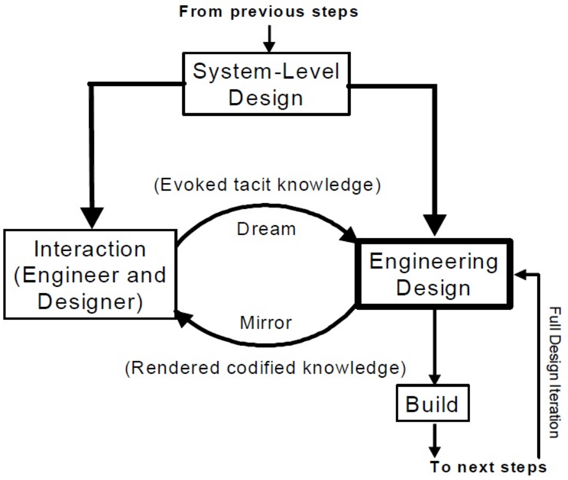

Figure 4.6: Engineering with dreaming and mirroring steps [50].

supple process [24] involving a broad range of contributors that merged hardware, software and design elements to create a system that is evocative of the type of experiences that were sought. However, it also emphasized the need for thorough exploration of the qualities of digital material under conditions that are similar to those in the finished prototype at an early stage in the design process. For instance, although the vibrator grid was tested out separately at an early stage, the way in which vibrations were experienced changed dramatically once it was mounted on the hard shell of the Lega device. Other examples of digital material are hard to explore due to their complex and invisible properties, as we found with designing with the radio. The challenge in designing a supple system involves not only exploring experiences provided by different hardware technologies, but also finding ways of keeping those experiences intact throughout the development process.

4.2 Inspirational Bits

This section is the description of the second project developed after The Lega based on the learning extracted from it. As described in the last section, one of the issues found when designing the Lega device was the use of wireless technology. The communications using radio technology are invisible, and in some respects it can be described as wired communications. But far from that, radio waves propagate in all directions and interact with the entire environment making it sometimes unpredictable from a design and even engineering point-of-view. The author of this thesis has developed several Inspirational Bits to expose some of the properties of the Radio communication, in order to expose its invisible properties to a design team and open up the design space.

In the early exploration carried out in the Lega Project, the hardware design found several issues regarding the experience of the non-technical members of the multidisciplinary design team and the properties and understanding of the digital material. In a process of iterations, designers' ideas were reflected in small bits of technology [50], but, technology was included at a stage in the design process where concepts and design ideas had been previously formulated. The engineer had to solve a design requirement and show it to give feedback. But, what if we could include the technology in an earlier stage of the design process? Would it lead to a different design where technology would have a better final interaction result? What if the design team could first experience and feel the technology and influence the final result?

Two main problems when designing the Lega were, in short, how the human body interacts with the radio waves, and how the environment can affect the communication between wireless devices. The first resulted in a completely different wireless performance when the art exhibition was empty, half, or full of visitors. The second issue was about walls, floor, furniture and art pieces, and how they influence the propagation by reflecting, blocking or being transparent to the radio waves. In the study of the digital material, the Inspirational Bits method gives the opportunity to expose invisible and non-intuitive properties of radio. Using radio as a design material becomes a challenge and a study case for this research.

From an engineering viewpoint, radio waves are electromagnetic waves. When these waves are modulated, changing some of their properties, they can be used to transmit information between devices, or be used to sense some aspect of the environment, for example, as radar can. The most common properties to be modulated are amplitude, frequency or phase, with the possibility of modulating all of them or only one at the same time. The antenna is the physical device, which, by applying an oscillating electrical current, can radiate these radio waves into the space. Receiving occurs by allowing the transmitted radio energy to set up an oscillating current in the receiving antenna which is then passed on to the receiver circuits.

Far from the engineering definition of radio waves, the more common and known wireless technologies we are used to talking about are specific examples of radio devices or standards such as, Bluetooth, ZigBee or WiFi. These technologies have in common the frequency (2.4 GHz in some of their most-used standards) of the radio waves they use to communicate. This frequency shares the same behavior with the environment, for instance, human body absorbs and interacts better with the radio waves in these frequencies than lower frequencies like HF (High Frequency) or LF(Low Frequency), due to its high content of water. The Lega system developed prior to this work is implemented using an ultra-low power IEEE 802.15.4[1] compliant wireless sensor module based on a TI MSP430 and Chipcon CC2420[2] radio, Tmote Sky[3]. In other words, the radio waves used in the Lega project to communicate and locate the wireless devices were affected by the visitors (the human bodies) at the art exhibition.

The invisibility and unpredictability of radio waves for non-IT backgrounds make this material very hard to design with, but, in some cases, some work has shown the possibility to use it as a design material, The Yourban[4] project at the Institute of Design at Oslo School of Architecture and Design has worked on several prototypes specifically addressing the immateriality of radio: for instance, "Light painting Wi-Fi" where they visualize Wi-Fi radio signals in the streets of a city or "Ghost in the field" where a radiation pattern from a RFID antenna is visualized. These last two examples have been made by designers using radio as

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[1] https://standards.ieee.org/about/get/802/802.15.html

[2] http://www.ti.com/product/cc2420

[3] http://www.willow.co.uk/TelosB_Datasheet.pdf

[4] http://yourban.no/

a design material and source of inspiration, but it is not always that one person alone is skilled [11][10] in both creative design and explorative engineering, nor are collaborations between designers and engineers always easy and productive.

Using the experiences in the process of designing the Lega and the work done by Petra Sundström et al., who developed an approach to expose the properties of the digital material in the design space [54], this section will show the Inspirational Bits and how they expose the properties of the digital material to the multidisciplinary design team. An Inspirational Bit is an effort to expose the properties of the digital material to a multidisciplinary design team, in order to show, through playful and experience-based process, all the contributors what the technology can and cannot do. By experiencing the properties, the design process can be influenced by the technology.

Inspirational Bits are a rapid realization method developed with the single aim of exposing the properties of digital materials, here radio, in a way that all members of an multidisciplinary design team can understand and use. Bits are not meant to be early iterations of a prototype but rather, as the name indicates, are meant to be “one bit” designs that highlight particular properties of a design material and point out possibilities for design.

Several workshops were carried out to experience, test and improve Inspirational bits, for example, a two-day workshop at the Mobile Life Centre where we allowed everyone to experience and learn more about the materials we had worked with so far. Approximately twenty designers and researchers took part in this event. Details of more workshops and their findings can be found in the papers [54][49].

So far, more than ten Inspirational Bits have been developed, three of them related to the concept of radio signal strength and three exposing the properties of radio topologies. In this thesis only the three Inspirational Bits about signal strength will be explained; the others can be found in the publication [49] made within the research group. The main reason is that radio signal strength is more representative of radio waves as they are a physical property of radio propagation. Three bits exposing radio properties are presented in this thesis: Radio Sound, Gold Rush and Gymkhana.

Radio Sound

Radio Sound is an inspirational bit that transforms the signal strength, into sound. The immateriality of the radio waves is transformed into something more graspable by the design team, sound. One sensor node transmits continuously a constant radio signal, the other one, acting as a receiver, will measure the radio signal strength and reproduce a sound where its pitch is changed depending of the strength of the received signal. The bit is given to the design team letting them explore the environment by separating them, covering with their own bodies, and experimenting how the pitch changes. Some minutes of exploration give a first mapping on how the environment and human body affect the radio waves. From the categorization of the Inspirational Bits [54] this inspirational bit could be classified as "core bit" or "Give it to me in one sentence or 3 secs".

Gold Rush

Gold Rush (figure 4.7) gives the multidisciplinary design team the chance to experience the propagation of radio signals across a room, and how depending on the environment they are in, their propagation properties can change in unpredictable ways. It is a game-based inspirational bit, one sensor node is hidden in the room. Four players will try to find this sensor node. They are provided with another sensor node that measures the received signal strength coming from the hidden node. A screen displays the signal strength for each player. The first problem the players find when playing is the fluctuations that the received signal shows, as radio depends on many external factors. In order to get a more stable received signal strength, it is better if no one is moving in the room. Here users can choose to either cooperate, ask each other to stay still for a second and get a stable received signal, or move about thereby diminishing the chances for other players to get a stable reading. This bit can be used to explain and experience indoor positioning systems and the difficulties they run into in most of the cases.

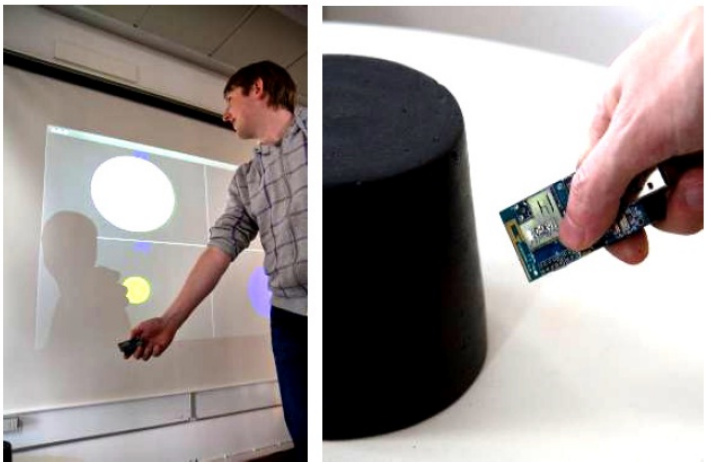

Figure 4.7: Gold Rush bit, interface and Tmote sky node used for seeking.

Gymkhana

Gymkhana (figure 4.8) is again an inspirational bit that uses the property of the body absorbing the radio waves at this frequency, in a game setting. Four players are surrounded by sensor nodes measuring the signal strength; the body of the player is in between all of them is what mainly affects the reading. The games consist of getting points by moving your body or disturbing the radio signal, after that, they lose points if they disturb it so they have to stay still to not disturb the radio signal.

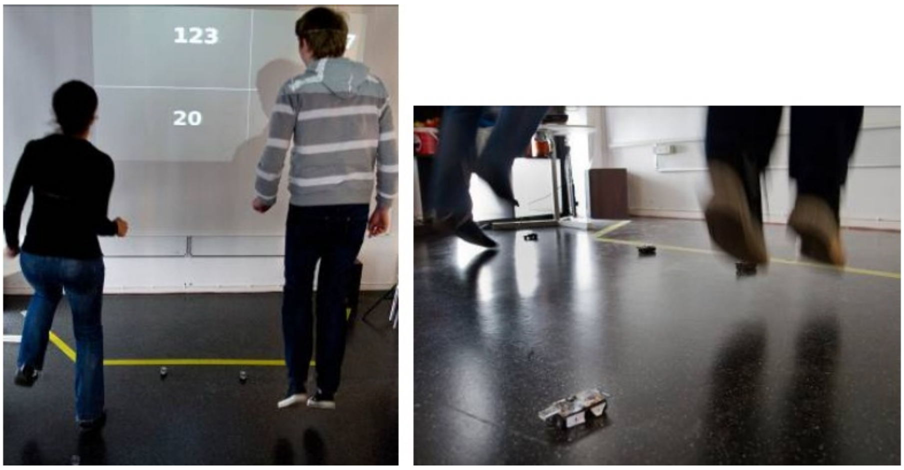

Figure 4.8: The Gymkhana bit, two players playing the game.

In summary the most important aspects of radio that were explored by these Inspirational Bits were: Radio Sound turns the RSS into sound and thereby “materializes” how the signal strength is affected by the environment and the human body, Gold Rush explains the difficulties of using the radio signal strength as a means to indoor positioning by letting the inconsistency in this usage of radio be the game feature itself, Gymkhana is meant to make the user further understand not only how her body affects the radio signal, but also how previously-thought-of limitations of this material can be used in themselves as possibilities for design.

Issues during design process

It was through the work on Inspirational Bits that I came to engage with a material perspective on design. They provided our team with a better approach to and understanding of the role of the engineering expertise in a multidisciplinary design team. All the Inspirational Bits that were designed used different technologies, platforms or programming languages. For instance, if we look at the bits developed in the radio material, they are implemented using ZigBee wireless technology, Tmote Sky[5]. They were broadly used by the time of the project by engineers in Sensor wireless networks. They run their own operative system called Contiki[6] and they need to be programmed using C programming language. The complexity in order to deliver one inspirational bit was high, as knowledge on a new operative system and hardware was required. The main observation on this set up is how those Inspirational Bits can be reproduced, kept in time or changed without having that hardware or knowledge accessible. The problem here exposes the problem of using well-known engineering tools. They are meant to serve high quality standards and capabilities, making them inaccessible for quick prototyping and reproducing the systems in other places or time, or even, access the inspirational bit and modify it or change it.

Once the project finished, the question was clear: how can we have a tool that can support quick prototyping of Proxessories or in this specific case, the radio Inspirational Bits? Is there a way to reproduce them or access its hardware and software? Those are very important questions, since having access to the knowledge of prototyping Inspirational Bits will have an impact on designing for Proxessories. They are based on individual sensors or actuators, if we can make those individual systems, accessible we can experience them and tinker them in a way that become a more complex system in the shape of a Proxessory. The use of a prototyping tool widely used is important. The background chapter includes an overview of the more used and accessible prototyping tools. At the time of this project, Arduino and Phidgets were the accessible ones. Inspirational Bits showed they can expose the technology properties to the multidisciplinary design space, but they need to make use of more of the commercially and community-driven platforms widely used in prototyping and IxD.

Early prototyping tool

After the Inspirational Bits project, some reflections were carried out regarding the hardware and software used to develop the radio bits. The usage of sensor nodes was in a way too complex and over-engineered for such a purpose: to visualize radio strength signals. After few weeks of these reflections an idea to create a far less complex sensor node, that would allow for low power, small size and the possibility to connect other prototyping platforms came into reality. It was the first working prototype of a collection of wireless nodes, with a micro controller considered to be one of its best (MSP430 from Texas Instruments[7]) for low power and complexity from an engineering perspective. It would have the possibility to connect two Phidgets sensors and would report the data to a mobile phone (see

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[5] http://www.willow.co.uk/TelosB_Datasheet.pdf

[6] http://www.contiki-os.org/

[7] http://www.ti.com/

top Figure 4.9). The mobile phone would use Javascript and an interface to bridge between the wireless and the bowser.

Figure 4.9: Top: Early prototyping tool working with Phidgets. Bottom: Gold Rush Inspirational Bit running in a mobile phone and custom made wireless boards.

In Figure 4.9 (bottom) we can see an implementation of the Inspirational Bits named Gold Rush running from a Javascript in the phone browser. This tool was used during the five-days workshop for the Bioball, next project we will discuss in the design journey.

4.3 The Metaphone: the Bioball

The Metaphone [70] is an interactive art machine that transforms participants bio-data signals into colorful spiral patterns (see Figure 4.10) and sounds, where different colors and tuned noise represent different bio-data signals from the visitors of an art exhibition. The Metaphone is constituted of three main elements, the Bioball (Figure 4.11) that fits in the palm of the hand, picking up on the biological signals of the participant, converting it into a stream of bio-data transmitted wirelessly to the rest of the machine, a drawing machine that converts sound as input into drawings on a large aquarelle paper underneath it, and a sonic core that both converts the bio-data into sounds (internal, not audible) that the drawing machine can understand, making it audible to the participants.

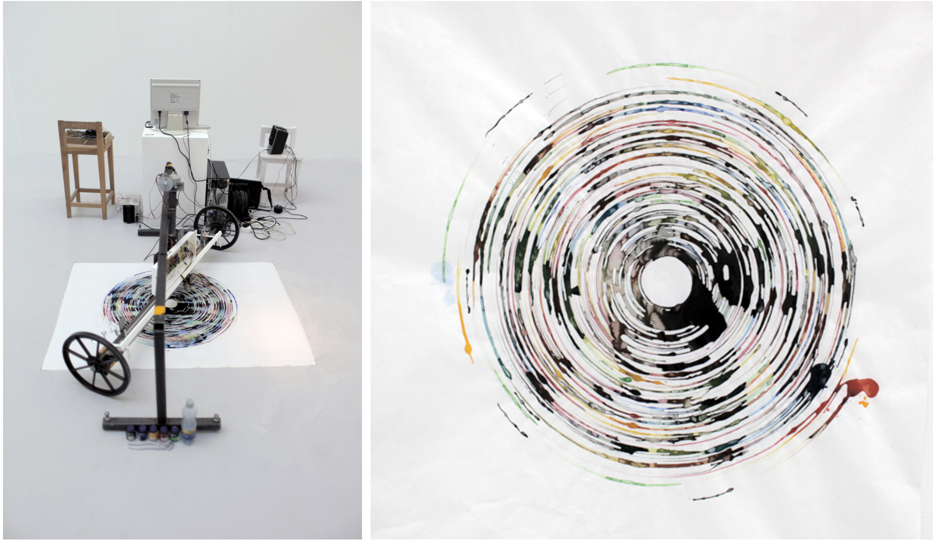

Figure 4.10: Left: The Metaphone installation. Right: spiral drawings.

The part of the installation that was designed, built and explored was the Bioball. The Bioball is a wax ball designed (see Figure 4.11) to capture bio-data and entail wireless interaction between the body and the machine. Inside the Bioball there are several PCBs (printed circuit boards) for wireless transmission, battery management, optic heart rate sensor, and electrode patches for capturing GSR. The ball also mirrors and externalizes the heart rate with several color-LED lights flashing and pulsating in accordance with the participants pulse and GSR.

The Metaphone is an exploration of interactive technology that was shared, developed and exported by a multidisciplinary design team. The process can be characterized as a reflection-in-action iterative process, from the learnings of the Inspirational Bits approach. More specifically, two competences were involved, one artist and the author of the thesis as responsible of the interactive technology and the construction of the systems. From the learning from Inspirational Bits, described in the previous section, a material approach was taken during the

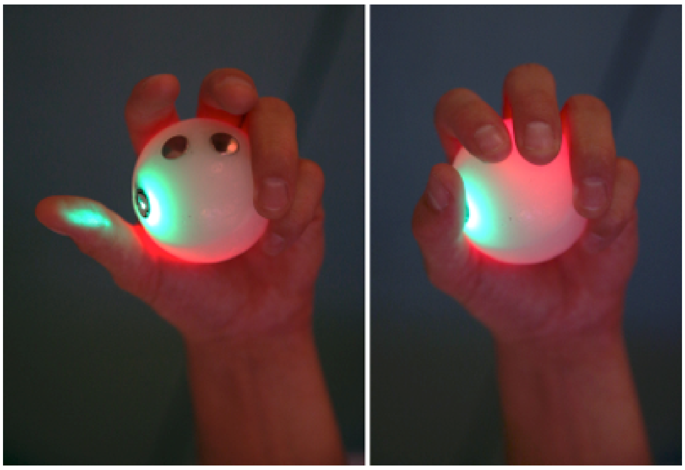

Figure 4.11: The Bioball is an interactive ball with biosensors and wireless communications.

conception of the concept and design of the Bioball. The process took five full days, dedicated to explore bio-technology, come up with a concept, build it and refine it to be ready for adding the piece of technology to the Metaphone machine.

Issues during design process

The Bioball was the first design exercise where the early tool was used, Figure 4.9 shows an early prototype of the tool. The set up of the workshop was to get as much as bio-sensor breakouts available at the moment and try them out as quick as possible, tweak them, see how they would react in different combination of material and start defining some first concepts on how to include bio-data to the art context of the Metaphone. This early prototype was fully working and helped in the construction of the final Bioball; inside the Bioball there is one of those boards together with a GSR and heart rate sensor breakout, and it is worth mentioning that it did not compromise or limit the design space during the five-day workshop. The boards run firmware programmed in C language using Texas Instruments developer environment that would collect the data form the Phidgets connectors and send it completely packaged through the wireless link to the phone. The idea behind this was to turn this prototype as a cricket model, to box the complexity and make it easier to use for those with non-engineering skills.

The issue arose when combining the prototypes with breakout models of biosenors; they require some onboard signal processing, for example, to retrieve your heart rate. It needs to filter the signal and calculate where the maximums of the signals are in order to count it as a pulse. Tests were carried out bringing this processing power in the phone, by capturing the raw signal and sending it over the wireless link, but it turn out that the reliability and bandwidth of the wireless link may bring some packages losses, in consequence not having enough packages to calculate the heart rate. To address this problem, we had to rework the algorithms on the board. Our microcontroller choice was from an engineering perspective, but breakout models provide libraries for an easy set up for Arduino. Our Phidget style wireless board was easy to use, but it compromised our freedom on tinkering, tweaking and exploring its capabilities. Being able to use the community and resources from the Arduino platform at this point was considered an improvement in the platform. Therefore the next prototype of this wireless platform was set to be fully Arduino-compatible; Chapter 5 introduces the final version of this tool, rFlea.

4.4 ABB sensor box

This is the last project of the design journey. ABB sensor box is an explorative project of sensors, interaction and wireless communications. It was developed during a four-month internship in ABB Corporate Research Center in Sweden [8]. The initial goals on this project were how to design a system that would exploit the interactivity of wireless sensors with other IoT systems, and how an IxD team could use such a system to explore those properties on their own, without a HW-expert like myself, working in the team. The initial idea then was to build a box with several sensors inside, ready to use, that would connect to a server where the IxD could connect their data, visualize it and manipulate it.

Several sensors where designed. Figure 4.12 shows some of the sensors contained in a 3D printed box, with battery and the wireless system onboard. To mention some, we included for example, infrared temperature sensors, microphone measuring noise levels, presence sensors and accelerometers. Once the system was complete, it should allow the IxD to pick up one of the sensors from the box, for example the microphone, place it in the coffee room, and connect that data to a light bulb in the office area to display in an ambient interaction so people could see how busy the coffee room was. As the hardware was complete, the big challenge and missing piece was a way to connect the flow of data coming from the sensors to other actuators, mobile devices or IoT services.

One of the earliest tools used was Spacebrew[9]. It has a simplistic interface

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[8] http://new.abb.com/about/technology/corporate-research-centers/corporate-research-center-sweden

[9] http://docs.spacebrew.cc/

Figure 4.12: Left: Accelerometer. Center: Infrared temperature sensor. Right: presence sensor.

divided into a left-hand side list with publishers and a right-hand side with subscribers. Spacebrew was first intended as a tool for dynamically re-routable software toolkit for choreographing interactive spaces. It is, in short, an easy way to connect interactive things. It uses a web-based switchboard graphical interface to enable the user to connect publishers with subscribers as shown in Figure 4.13.

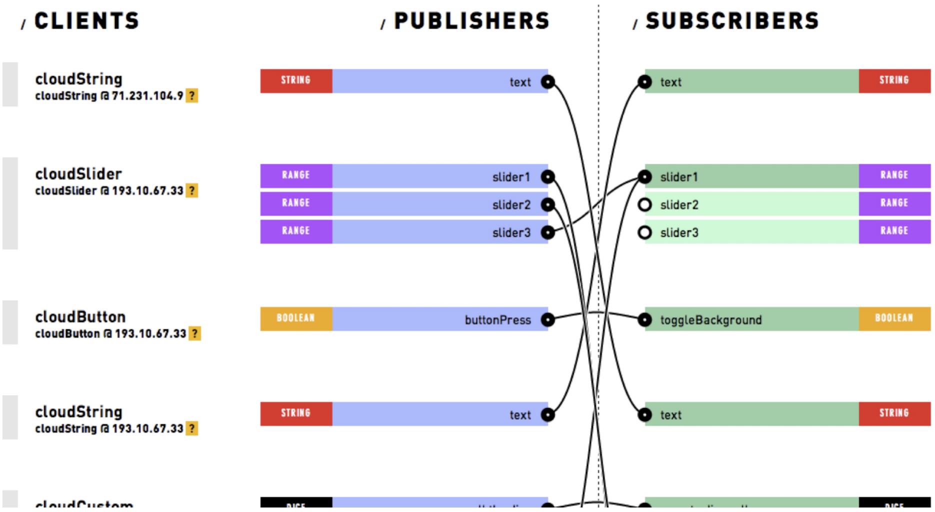

Figure 4.13: How the Spacebrew connector interface looks like.

Devices that produce data are the publishers, and devices that turn data into some kind of output like screens or actuators are the subscribers. Devices can be subscribers and publishers at the same time. The programming is, in its essence, a task of connecting subscribers to publishers through their online interface wiring (Figure 4.13). As devices are added, it will eventually become extremely messy, and what is gained in simplicity, gets lost when it comes to having any kind of logics in-between the publishers and subscribers. Yet Spacebrew has a number of very essential features that fit well with the set goals of connecting the sensors in our box. When a device is switched on and made available, its corresponding input(s) and/or output(s) automatically turn up in the Spacebrew interface. This is made possible through an implementation of WebSockets and a set of libraries that make it easy to connect to the server and present a thing's capabilities. Furthermore, every time a publisher sends data to the Spacebrew server, the connector blinks. This may be a small detail, but it certainly helps the user in getting a feeling of data flowing. Finally, changes take effect immediately.

Despite the successes with Spacebrew, some of the shortcomings were quite hard to just ignore. It lacks any sophisticated control other than linear cause and effect. Spacebrew allows for direct connections, but it does not provide an intermediate step to manipulate that flow of data to turn it into something different. For instance, in the example of the microphone in the coffee machine, it would not be possible to turn on the lightbulb when a certain noise level was achieved.

While Spacebrew was not offering enough functionality, we kept looking for other available software tools. One of the more recent systems that offers an adequate level of complexity is Node-RED[10]. In many ways, it is the opposite of Spacebrew, since it does not accept devices to automatically connect and appear. On the other hand, Node-RED provides a sleek set of features like tabbed workspaces, out of-the-box MQTT[11] messaging (machine-to-machine "Internet of Things" connectivity protocol), database support, social network integration, and, more importantly, a much more complete visual interface (see Figure 4.14). Workspaces are set into effect by the user pressing the "deploy" button, which means that any change in a program graph is not immediate. Several users can work on the same graph, but changes are not currently being mirrored consistently to all collaborators.

General purpose programming constructs can be added to the graph through the function box. The box is filled with arbitrary JavaScript code, which is then visually connected to the inputs and outputs of other processes. This breaks with the idea of having an entirely graphical programming interface that uses icons and visual cues even for the more low-level programming.

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[10] http://nodered.org/

[11] http://mqtt.org/

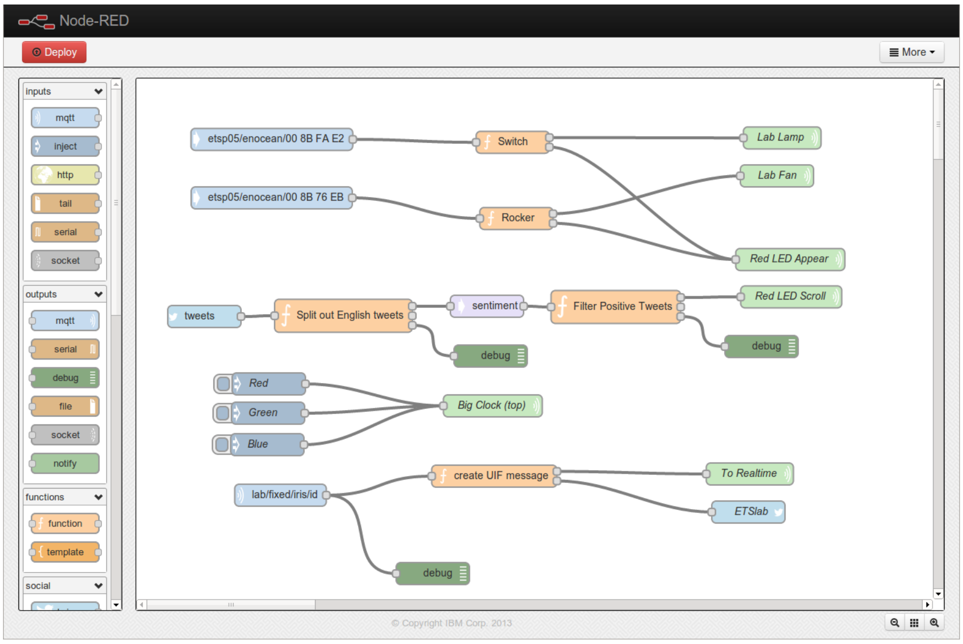

Figure 4.14: Node-RED visual interface.

Having access to Spacebrew and Node-RED allowed us to take the characteristics we considered more important in the context of Proxessories and merge them to create a new tool: Insbits Studio. In next chapter, Chapter 5, a full description of Insbits Studio can be found. Insbits Studio was originally designed to support a small set of very simple sensors and actuators, but, in the end, the project ended up supporting many more things, such as game controllers and other off-the-shelf components. This was a fortunate side-effect from mashing up two existing platforms that already had this functionality built in. The visual interface of Insbits Studio is very similar to Node-RED as shown by Figure 5.4. The main difference is that devices that are made available on the network show up in the list to the left. In short, Spacebrew acts as the back-end server, while Node-RED generates the server side scripts that make up the logic between publishers and subscribers. Furthermore, each connector has been implemented so that it blinks when there is data available on the channel, similarly to that of Spacebrew. In its current state, any rewiring in the graph is not in effect until it has been deployed through the deploy button.

The design journey helped to understand the design space of Proxessories and to through conversations with the digital material and the design space, define the characteristics of the tools that could improve the design process. In this chapter we have see an early prototyping board and Insbits Studio, next chapter, will present those tools in their final shape and will describe them in detail and how they interact and can improve the design space.

Chapter 5

Developing Tools for Creating Proxessories

From the design journey and all the experience gained during the projects described in the previous chapter, two main tools have been developed in order to explore the design space of Proxessories. These two tools are rFlea, and Insbits Studio. rFlea is a wireless physical prototyping tool, while Insbits Studio is a complementary cloud-based tool that allows online programming and connection over the internet possibilities. Having a prototyping platform provides a hands-on way for exploring Proxessories, but, at the same time, it is important to stress that it will likely not fulfill the entire spectrum of needs.

The point of a prototyping platform is not necessarily to produce the final product but to enable the brainstorming and early prototyping. It needs to have the crucial properties and cater for the key experiential qualities to improve our design explorations. The collections of tools, what we will refer as platform, has been tailored the use of two programming languages, and those, that are supported by a large existing community (Arduino [47]) or the most used (Javascript). On the other hand, the hardware has been designed to take advantage of low-power technologies, and emphasize wireless communications, all integrated in a small-sized board. Figure 5.1 shows how all the elements are connected: the Arduino wireless board (rFlea) connects to existing mobile phones, and, using its cloud connectivity, they bridge into the cloud prototyping tool (Insbits Studio). The next subsections will give more detail in each of the parts that form the platform:

- rFlea, an Arduino compatible wireless prototyping board
- Android WebbApp, app for the mobile phone that provides a JavaScript programming environment
- Insbits Studio, visual programming interface.

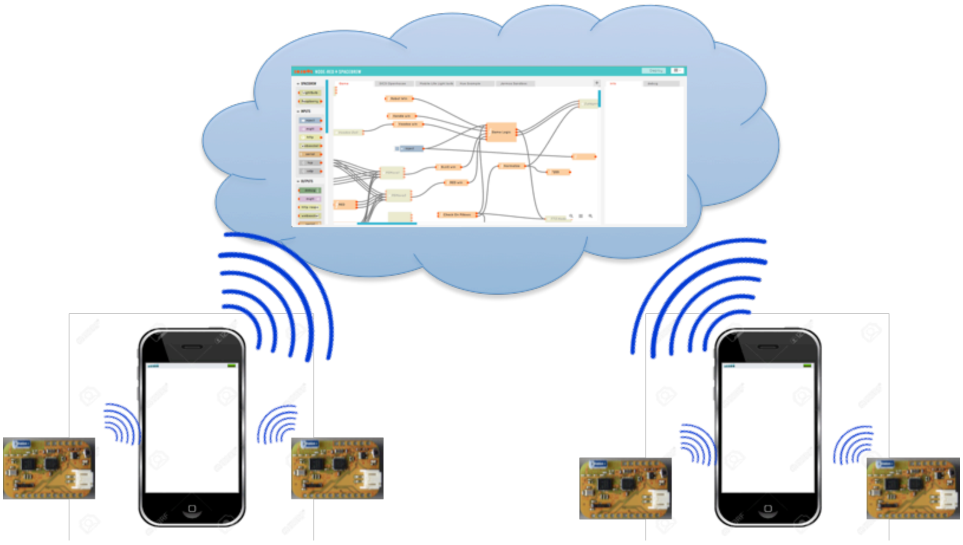

Figure 5.1: How the platform is connected.

5.1 rFlea

In the following section, we will describe the resulting design and implementation of rFlea (see Figure 5.2), highlighting how different technologies and techniques allowed us to meet the design goals. rFlea is an ultra low power (ULP) prototyping circuit board that includes an ANT+ wireless transceiver[1] and an ATMEL microcontroller[2]; it is fully compatible with Arduino platform. It can interface with various types of sensors and actuators, providing all types of input and output connections well-established in Arduino and other platforms, such as analog and digital I/Os, serial communication, I2C and other buses.

A central aspect to consider regarding the implementation of rFlea was the desired small form factor (see Figure 5.3). Balancing the tradeoffs between small size on one hand and practical usability (e.g., the number of pins that can be placed on the edges) on the other hand, we ended up with a layout of 25 times 35 mm. This footprint translates to a small size form factor that can incorporate a standard coin cell battery as well as the required electronic components with a pinout that is manageable in practical applications. Another tradeoff that had to be considered is related to functionality, resulting in limiting the system to the core capabilities, while leaving some out, e.g., not providing a USB connection directly, but rather a standard FTDI pinout to be connected to external USB-FTDI adapters, as it has

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[1] https://www.thisisant.com/

[2] http://www.atmel.com/

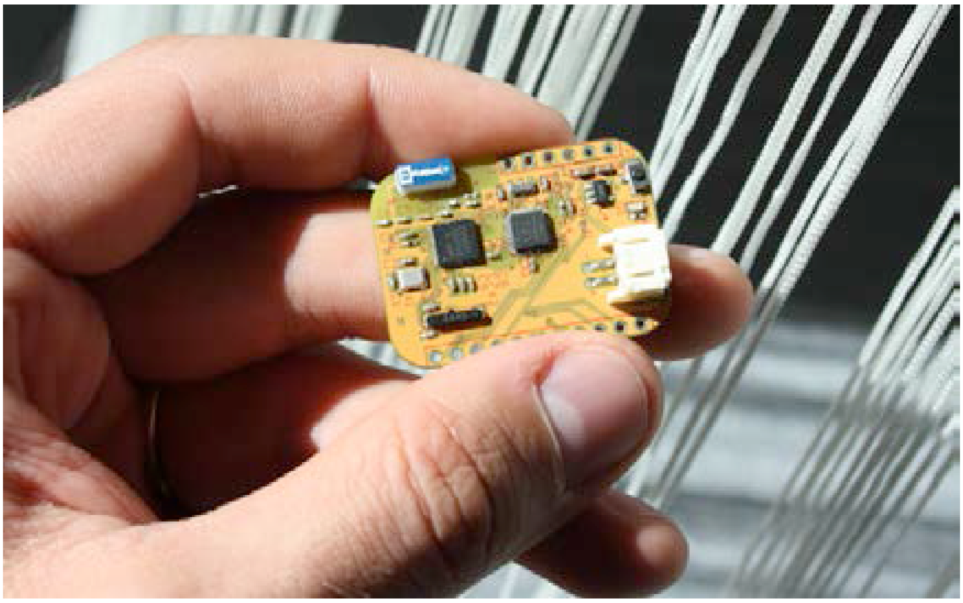

Figure 5.2: rFlea wireless board.

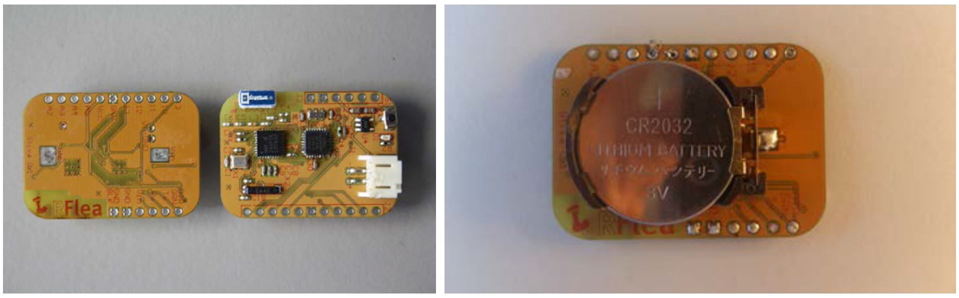

Figure 5.3: Left: rFlea view from the two sides of the board. Right: rFlea with a coin battery holder soldered on the back side.

already proven to be sustainable with other platforms such as Arduino Lillypad[7] and other Arduino variants.

Closely related to any considerations regarding size and form factor of the desired kind of prototypes and applications is power consumption, as in any untethered working system power consumption practically translates to (battery) size. Thus, rFlea is implemented using ultra low power (ULP) parts that consume a small amount of energy, with the ability to scale functionality and processing power (and thus, energy consumption) on demand. rFlea implementation together with its libraries provides fast processing and wireless connectivity when needed, while offering idle modes that consume at ultra low power levels systems, thus allowing rFlea to be deployed for long-time applications. We achieved those goals by combining ultralow power ready technologies with tailored analog electronics, resulting in a power consumption that can be about a few tens of microAmpers when in idle state. This translates to a lifecycle of several months for a simple wireless application (e.g., a switch or simple sensor that transmits data only when triggered) when powered by a standard coin cell. Moreover, rFlea being ULP allows for the exploitation of energy harvesting, i.e., powering the system from small, mobile energy supplies such as solar cells, or plainly through the movement created when interacting with the device itself (e.g., pushing a button).

In order to provide a sustainable prototyping solution rFlea is implemented on the well-established Arduino platform. As a standard that has proven to provide easy entry access to physical prototyping with its combination of a standardized, yet extendable, hardware platform and a simple integrated programming environment with an ever growing community that provides an incredible wealth of knowledge, information and sources in form of e.g., code libraries and online documentation. Specifically, rFlea is based on the reference design of the Arduino Pro Mini[3], centered around an ATMEL ATMega 328p[4], with some necessary alterations due to the desired component size on one hand and the requirements of interfacing with the wireless transceiver on the board (i.e., a reduced number of inputs and outputs in comparison to the Arduino Pro Mini). The resulting layout is composed of a standard 6-Pin FTDI pinout section that provides serial communication to, e.g., a FTDI-USB converter for programming the board. The opposing site of the board provides current to external gear, e.g., a sensor that needs power supply, and a total of nine input and output pins. Those pins and their functionality were selected in a fashion that allows the greatest amount of flexibility (i.e. most pins can serve multiple purposes), while providing all standard connectivity available on an Arduino Pro Mini.

The core-differentiating element of rFlea in contrast to any existing Arduino-based hardware is of course its incorporation of wireless connectivity. rFlea provides this specific ultralow power technology in a way that is ready to use, by means of integrating the hardware as well as the software. The spectrum of wireless functionality one can utilize based on that solution is vast: Multiple rFlea boards can wirelessly communicate with each other, as well as to host transceivers, for instance, connected to a notebook computer or any sort of relay providing extended connectivity such as a gateway to an internet service. Moreover, an even growing number of sports gear and all sorts of activity monitoring and tracking hardware

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[3] https://www.arduino.cc/en/Main/ArduinoBoardProMini

[4] http://www.atmel.com/devices/atmega328p.aspx

can be easily integrated.

In order to enable researchers and designers to utilize those features without bothering about too many technical details, rFlea provides an easy-to-use integration of hardware and software that is typical for Arduino-based tools: Tailored software on the other hand, i.e., a custom bootloader for wireless programming as well as Arduino libraries that abstract the wireless protocol in an easy-to-understand way. While simple examples can utilize the connectivity provided straightforward to, e.g., connect multiple rFleas, more comprehensive options are available in order to use the full potential of flexibility the ANT+ wireless platform provides. This includes, among many others, options to create complex mesh networks on the fly, utilize signal strength to estimate distance between multiple rFleas, and create networks that dynamically adapt their transmission bandwidth in order to minimize power consumption.

5.2 Android WebbApp

To provide high connectivity to an rFlea board, libraries are available in two forms: Arduino libraries, JavaScript libraries and a mobile app which handle all the connections and provides a Javascript environment, also known as webapp. Javascrip libraries are provided to handle all communications with an rFlea and make it fast and easy, and no Android programming environment is needed as the webapp provided includes all interfaces to talk to the mobile phone hardware and wireless connections.

The Android app interfaces with all mobile phone hardware and contains a web browser object that can be link to a webapp. All the programming can be done in HTML and Javascript for quick prototyping.

5.3 InsBits Studio

Insbits Studio, Figure 5.4, is a visual dataflow development platform that combines the power and flexibility of Node-RED with the plug-and-play simplicity of Spacebrew; both of them are open-source IoT visual programming platforms. The target user-group is interaction designers who would like to quickly sketch out both interactive settings featuring any number of sensors and actuators.

Moreover, for this case, it is important to point out that the design is focused around getting away from the often too abstract sensor/actuator model in favor of a more expressive format that can bring out more of the behavior of a thing or a device. Supporting this type of sketching activity would thus be the main defining

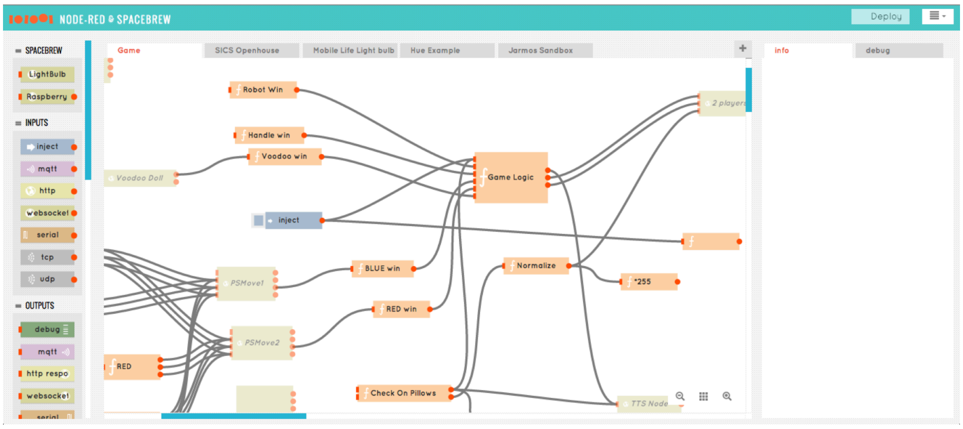

Figure 5.4: Example showing what the Insbits studio connector interface looks like.

design characteristic for such a programming platform. Based on the knowledge of working in the interaction design research field, the following is a list of requirements that the tool should have:

- Connecting things (physical and virtual) should be seamless and direct
- Objects should make themselves available as resources in the platform (with little or no hassle)
- Representation is highly important
- Possibility of complex behaviors
- Facility to incorporate new technologies through standard libraries
- It should support collaboration
- Open-source and community-driven

Furthermore, it should be a modern platform making use of the latest cloud and web-based principles. What started as a small survey of existing systems ended up as a mash-up project where different parts from different systems were stitched together. Here are short descriptions of the two platforms that are being used.

The server is waiting for new artifacts to connect, where each artifact has a unique ID, and can define outputs and inputs. New artifacts appear automatically in the top left corner (see Figure 5.5). For example, if we connect a new rFlea, with name rFlea 59411 (see Figure 5.5 left) a box with that name will show up in Insbits Studio graphical interface. Each box has the inputs on the left side

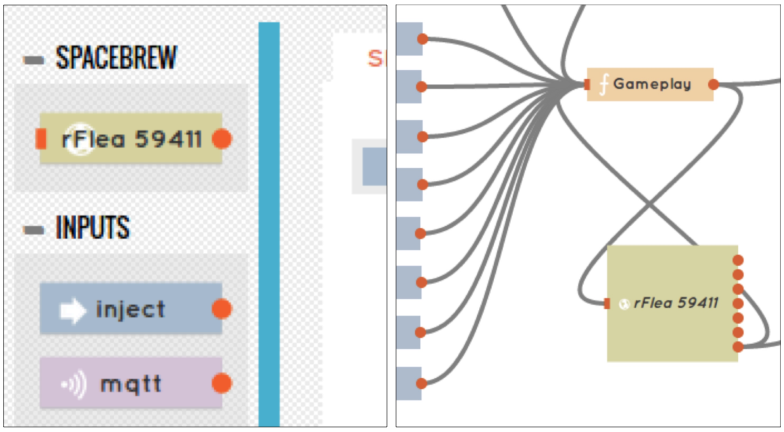

Figure 5.5: Left: tool bar with online artifacts. Right: workspace of Insbits Studio.

(orange square) and outputs in the right side (orange circle). Once it is visible, we can drag and drop into the workspace (see Figure 5.5 right) and start connecting inputs with outputs and vice-versa from other boxes. Other boxes are available, like JavaScript functions boxes, inputs generators, debugging, IoT protocols like MQTT(machine-to-machine (M2M)/“Internet of Thing” connectivity protocol) or websockets in general.

5.4 Designing with rFlea and Insbits Studio

During the design journey, in chapter 4, we introduced a range of examples of designing Proxessories through many projects and we could see how the tools shaped in accordance to every projects' learnings. In paper 5, from the paper compilation part, we bring out some examples that we will briefly go through here. A whole course at KTH, DH2400 Physical Interaction Design and Realization[5], has been centered on rFlea and Insbits Studio. We will describe some of their design work here. The examples following in this section are design projects using rFlea and Insbits Studio by students coming from different backgrounds: computer science, electronics, industrial design and interaction design. Taken together, these show how rFlea and Insbits Studio are filling the gap we wanted to fill not only as a tool for a skilled engineer (such as myself) but also to others, less knowledgeable (IxD students) in how to design with the typical Proxessory materials: radio, sensors, actuators, body-worn and with the right form factor to fit aesthetically. We have also carried out other projects, like designing an interactive bicycle gear shifter, Galvanic Skin response interactive ambient lights, or arts and crafts explorations,

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[5] http://www.kth.se/student/kurser/kurs/DH2400?l=en

to mention some, but we will stick only to those examples that show the qualities of the Proxessories design space.

The Peripipe

The Peripe [13] is a tangible remote control for a music player in the shape of an old, crafted, wooden smoking pipe, see Figure 5.6. The interaction is based on breath control, using sips and puffs as control commands. The Peripe has an air pressure sensor and detects changes in air pressure, processes what air interaction is happening and wirelessly sends commands to a smartphone running a music player written in Javascriipt. Additionally, the Peripipe provides fumeovisual feedback, using color-illuminated smoke to display the system status.

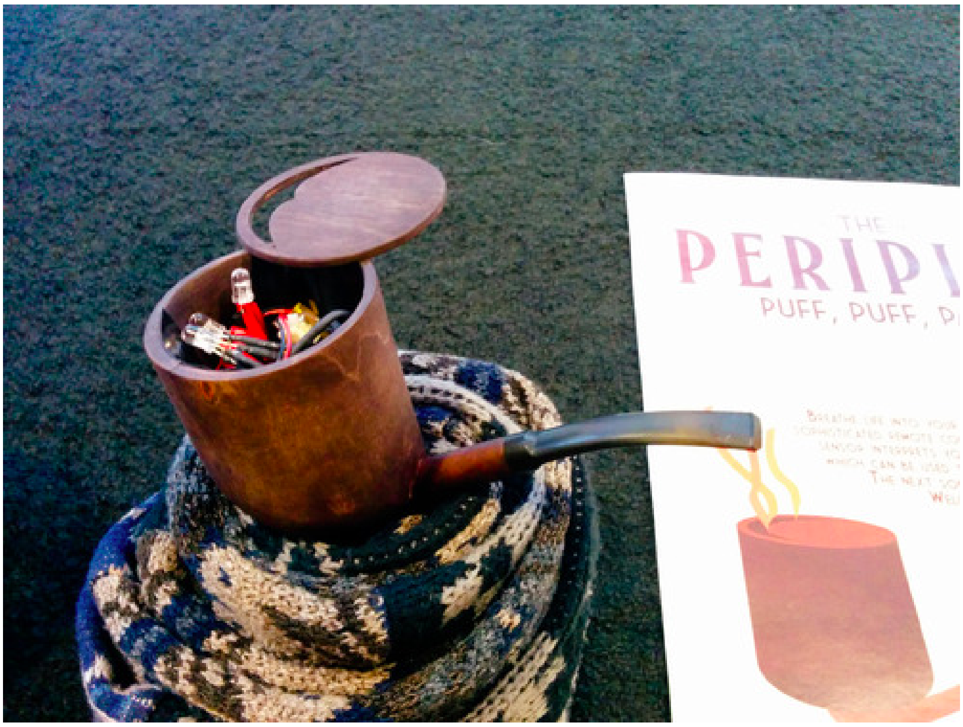

Figure 5.6: The Peripipe.

This project was effected by a group of five students. At the beginning the students didn't use rFlea as prototyping platform. During the experimentation and test of different sensors and actuators, they used an Arduino Uno successfully (see Figure 5.7), they could test and verify how the pressure sensor, the smoke generator and the LEDS could work together to provide the desired interaction. If we look upon a smoking pipe as a Proxessory, given its small size, it becomes clear how it needs to be both very small and wirelessly connected to achieve any of the user-experience qualities the students were after. By the end of the project, after attempting to find commercially available tools that could help them to fit all the system inside the pipe without having to redesign or add more work, they decided to use rFlea and Insbits Studio with all the Arduino framework and wireless libraries.

Figure 5.7: Left: the Peripipe prototyping with Arduino Uno. Right: the Peripipe with rFlea.

This project showed the potential for rFlea from three enabling: first, the Arduino compatibility allowed the design team to test sensors and actuators out of an Arduino Uno, and, once the tests were finished, move all the work to an rFlea without adding extra work to complicate and delay the building phase. Another aspect of rFlea that was highlighted by the students was the small size, robustness and all-in-one format, microcontroller and wireless. Finally, the third aspect of rFlea was the possibility to work with media resources in the phone, by adding a Javascript off the shelf Javascript code and putting it together with the rFlea commands.

The Copernicus

Another student project that was realized in three days was called The Copernicus[6]. In short, it is a pulse-controlled multiplayer game. It consists of a wristband with a light-based pulse sensor (see Figure 5.8). One or more players will play the game at the same time and also compete against each other. The goal is to reach a particular pulse-window, indicated by a green light, and if the player manages to keep the pulse in that window for a certain while, the player wins and a light sequence will appear. The losing player(s) will get a bright white blinking light. The game can then be externally reset, and a new goal pulse can be set.

Figure 5.8: The Copernicus heart rate game bracelet.

This project was sketched and then shifted into a functioning prototype and tested in about two days of work. It uses the advantages of Insbits studio where the game logic is programmed in the Insbits Studio, in the cloud. Figure 5.9 shows all the game logic in a visual form. As the students made heavy use of all the readymade libraries provided by rFlea, the mobile web app as well as the Javascript libraries, they were liberated to focus instead on the interaction and material aesthetics of the prototype. For example, they did not have to solve the connectivity between Copernicus, the mobile and the server.

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[6] http://dh2400-copernicus.blogspot.se/2014/12/video-presentation.html

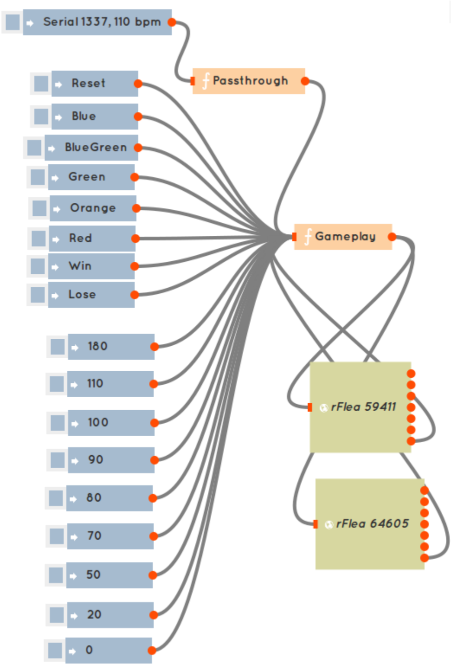

Figure 5.9: Copernicus Game logic in Insbits Studio.

The Memonile

The Memonile [59] is an accessory to a mobile phone that is worn around the neck like a necklace and wirelessly records notes, messages or drawings through its touch screen. Messages created on the Memonile can later be retrieved through an accompanying app in the mobile phone. The design exploration of the device revolved around having little or no feedback when pointing at the touch surface, and completely leaving out the visual element of the screen.

The Memonile (see Figure 5.10) is a small device built from hand-crafted and laser cutting materials (leather and wood), which, when combined with the technology, gives a very unique aesthetic expression.

The Memonile ended up being a fully-working and operational demonstrator. The artifact together with all the software (mobile app) is not only complete, but actually also provides the interaction outlined in the first conception of the idea. This was possible since the rFlea provided an all-in-one hardware solution, while the webapp together with the libraries allowed them to create an easy app that would

Figure 5.10: Left: The Memonile. Right: the Memonile app with the timeline of drawings.

talk to the Memonile. In this case, most of the effort was dedicated to crafting a distinctive look for the Memonile instead of struggling with the technology and communication parts.

The Meya Bag

The Meya bag [3], Figure 5.11, is a leather bag that communicates wirelessly to smart phones and controls certain functions of the mobile phone and reacts to incoming calls. It uses common elements in clothing design to implement the interaction elements and combines with and rFlea and conductive thread implements an example of a Proxessory in fashion accessories. The bag has a metal snap button (see Figure 5.12) acts as switch, a padded ball wound inside with tubular knit stretch sensor made of resistive yarn can be used as a potentiometer by squeezing it. Finally the front face of the bag is filled with LED using conductive thread and a servo-motor that gives the fabric movement. An app available for Android phones will connect with the bag to enable its functions. When the phone receives a call, the LEDs and motors will go on in a pulsating pattern to alert the owner. By squeezing the ball the call can be rejected without taking the phone out of the pocket, and finally, the snap metal switch can be used to set the silent mode of the phone on or off.

In terms of technology, the Meya bag used a battery. The digital outputs from the rFlea were used to connect the power LEDs and the motor directly, using standard Arduino libraries for PWM servo-motors, and the analog and digital input were used to connect the metal snap switch and the squeeze ball. On the phone side, Insbits Studio app was downloaded and used in the mobile phone, and all the interaction was coded in a Javascript file, without the need to use an Android SDK and Java programming language. The simplicity in hardware structure and the usage of two known programming languages allowed the students to focus on

Figure 5.11: The Meya Bag.

Figure 5.12: Left: LED with conductive thread. Center: Squeeze ball from resistive yarn. Right: Snap fastener switch.

the interaction side of the project and combine the crafting and textile elements into their project without compromising the aesthetics and fragility of the bag.

Space-Time Convolution

This exploration was carried out in collaboration with ABB corporate research in Sweden and Martin Murer[7], an interaction designer from Salzburg University

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in Austria. The exploration is one of several explorations, all realized using rFlea, carried out in a project aiming to find ways of turning control rooms into more alive and engaging workplaces. The overall thrust of the project was to not interfere with the work process per se, but instead build on and reinforce social aspects of working in a control room.

Figure 5.13: Space-Time Convolution.

The design consists of a set of portable, tennis ball sized spheres made from transparent silicone (Figure 5.13) that glow and blink in response to human movement in their proximity. The globes are meant to be distributed, across an area of interest, e.g., a shared working space or an office building where they show traces of people that have passed by. The intensity of the glow increases with the number of people that pass by a globe, while the speed of the blinking increases with the rate at which people pass by. Hence, a brightly shining and rapidly blinking globe represents a popular spot, with high traffic. Over time the globes become dimmer, so that if no person passes by, the lights will eventually switch off. Thus the globes allow workers to make pathways through the control room visible by making peoples movement visible. We imagined that this would be particularly interesting at shift changes, when a new crew could immediately get a sense of where people had been moving about in the previous shift. A person's presence and movement in our close surrounding is in most cases immediately perceptible, e.g., when entering or leaving a room, or through one's presence in our surrounding. In contrast, the longer-term patterns and more complex dynamics are not transparent. The design goal for this project was thus to find an aesthetic and temporal form that unfolds this space-temporal complexity while still replicating the blurry, somewhat unpredictable nature of movement in social spaces. Correspondingly, we aimed for an aesthetic that fluently blends with diverse environments.

The people would interact with the balls by carrying rFlea boards, powered by coin cell batteries, constantly transmitting a unique identifier. The small form factor of those pins, or tokens, together with its almost two-year battery life allowed them to be kept a small tailor made enclosure on a keychain. The balls on the other hand, consist of battery-powered rFleas that continuously scan for tokens carried by people nearby, that is, the different people, as well as calculate their approximate distance to the ball based on signal strength.

The key points highlighted in the use of rFlea as main platform were the onboard coin battery, small size and long duration allowed for small design without extra hardware design. On the other hand, the Arduino libraries to set up the wireless allowed the use of Arduino code and other existing libraries the using the Arduino community, and finally, as rFlea contains processing power in both ends (spheres and pins), the system can work independently of other devices such as mobile phone networks or wireless networks. On the other hand, mobile phones could be used to act as pins or balls, but the project requirements only permitted the usage of independent systems.

Chapter 6

Discussion and Conclusions

Looking back at the projects I have been involved in during the years as a PhD-student, it is obvious that my view on multidisciplinarity and how to design Proxessories was shaped by the specific setting. If I had worked in a different lab, with a different combination of competencies, without the RtD-perspective, my explorations would have likely been different. I would like to argue, however, that the overall philosophy of letting the digital material speak with a stronger voice in the design process will be equally useful in projects with, e.g., a participatory design perspective or a commercial project starting from a sale's requirement. My quest here has been to show how the engineer can help a team to gain shared knowledge of digital materials that allows design spaces to be opened up in better ways. At the same time, this can also be read as a critique of the engineering education with its strong emphasis on solving a given problem rather than opening a design space based on the affordances and experiences provided by the material. Below I will develop and discuss this idea in the light of the three research questions outlined in the introduction:

- How can engineers expose the experiential properties of the digital material so that a multidisciplinary team can create a shared, tangible understanding of what can be designed? In particular, how can this be done for a particular design space that can broadly be described as proximal accessories — or as we choose to name them — Proxessories?

- How to open the design space of Proxessories by exploring and probing it through engineering and design. What are the design exemplars, requirements, experiential qualities that can tell us whether this design space is of relevance and what it consists of?

- What are the engineering tools that will bring in technology in a manner that supports rather than limits design explorations?

The starting point of my work was to reveal experiential qualities of technologies used in design. In particular, Inspirational Bits is presented and used as an approach to explore digital material in a multidisciplinary design space, Chapter 4 describes how I used radio as a design material. The second question is answered by the numerous exemplars that have been produced throughout this thesis work. Together, the exemplars illustrate what Proxessories can be and reveal interesting properties of the design space in a tangible fashion. Throughout this work I have used a methodological dyad consisting of RtD on the one hand, and an engineering approach which we have come to call EtD, on the other. The latter focuses on the engineers role in design processes and how they can benefit from and contribute to a design process, which is a necessary aspect of exploring the design space. Finally, rFlea and Insbits Studio are tools tailored to fit into the design space of Proxessories.

6.1 Material turn and InsBits

The presented work is an effort to extend engineering processes with tools and methods that allow an engineer to both make use of and contribute to multidisciplinary design teams. Throughout the work presented in this thesis our research has shown that the design process requires effort from the entire design team to understand, feel and experience the technology. The role of the engineer in the multidisciplinary design team is to direct exploration of technology towards increased understanding of inherent and emergent experiential qualities, so that the technology becomes a useful design resource. In addition, it is important to understand that, when designing complex interaction devices, some intended design features may be lost during the design process due to the team misunderstanding the capabilities of a technology, or encountering a mismatch between design intentions said capabilities [28][53]. Our solution to this challenge is a design material approach, presented in this thesis. This work has presented one way of turning technology into a design material for interdisciplinary design teams.

While increased material knowledge may prevent some missteps in the design process, sometimes a design-led inquiry might lead us to change the technology itself. In the Lega project [28] part of the design journey, Dunkels and Lundén changed Contiki operative system and added Politecast [37], as a result of exploring the wireless technology in the project. Taking advantage of the fact that the Lega was designed to be used by people moving about an art exhibition, the Politecast radio communication primitive can save up to 98% of energy by using that fact to time and trigger broadcasts. This illustrates an interesting point about digital materials: that they are partly physics (and therefore limited to what physical laws tell us) but also partly exactly what Löwgren and Stolterman [36] talk about when they say “a material without qualities” as it is so easy to change it. Digital materials are not like wood or plastic in that sense. As my material is in particular

Proxessories — a form of embedded systems — the limitations and properties that arise from physics are more present than in many other settings. Sensor, actuators and wireless communications have certain properties that can be shaped somewhat, but overall they are limited by a range of properties that are given.

What does material mean to an engineer? And why is it a useful thing to look upon “digital materials” as design materials? A material perspective is not a property of things-in-themselves, but manifests itself when combined with knowledge of how to shape a material and the skills required to do so. Without knowledge and skill, there is matter rather than material. For example, wood becomes a material when you know how to work with it; otherwise it is just wood and difficult to use for anything. Hence, material is not a physical manifestation, but instead, and this is how we engineers would benefit from this approach, a material manifests itself when combined with accumulated knowledge of the material and contexts in which it is used. In “The reflective practitioner” [46], professionals, Schön maintains, “know more than they can put into words”; they have been taught engineering in school, but then have, through a reflective practice, learnt skills and knowledge about what works when and where. Each design case has contributed to this persons growing repertoire of contexts and solutions that forms the backbone of their professional skill. By knowing their materials, interaction designers are able to craft and shape various experiences using technology.

The Inspirational Bits project has been a playground to explore and put into practice a material approach where technology becomes a design resource and is used as the starting point in the generation of new ideas and concepts. The method exposed many particularities of the material approach, but, instead of focusing on the outcomes of the approach from a design perspective, let me focus on the technological side, in particular the questions that arise when an engineer starts using such an approach. How do you initiate a design process that builds upon Inspirational Bits? How do you know which technology will be of benefit to the particular project, and thereby influences which bits you choose to introduce? Such early choices by engineers profoundly influence the trajectory and outcome of a design process. The technology, the specific properties of the technology and the way they are manifested will influence the design from the very beginning. The responsibility and importance of the engineer and their knowledge in a material approach is to expose the experiential qualities of the material. The starting point of Inspirational Bits is the properties of a technology, which are explored at such an early design stage that no concept has been developed yet. This is very important from an engineering design process, as the engineer is not coming from a set of requirements and is not prematurely bringing up a solution. Rather their role is to expose the material with regards to experiential qualities as discussed above, and negotiate within the multidisciplinary design team emerging requirements and problems to solve during the process.

Inspirational Bits is an approach that doesn't give specific guidelines to follow in a repeatable way; instead it allows the engineer to work with their own technology as their own material and help them to understand how to work in a designerly way. It also shows the engineer that the way the material is approached will have a large impact on the later design stages and in the overall process of the multidisciplinary design team, giving the engineer an important responsibility, not just of designing and building a specific system from design requirements as most engineers, like myself tend to think when we finish our engineering education. From a practitioner's perspective, Inspirational Bits approach is not a method; it does not compete or pretend to change existing engineering (for example the waterfall method [30]), design (for example the double diamond method [29]) or interaction design (user centered method [69]), it is an approach that can be used in many methods. Therefore, it can be described as a mindset that in either both methods the engineer can approach. In the same way, other product development methods can be used without compromising the material approach: User-driven design [33], Technology-driven design [32] and Interaction-driven design [38]. From wherever the design starts (user, technology or idea driven), at the moment that the technology is added into the design space, it will influence the process and care must be taken to learn and reveal the experiential qualities of technologies used to successfully guide the process.

Just to take one example: you could be using your tools also in a process where an expert user is leading the design process. Let us say this expert is a surgeon convinced that she can invent a new tool to make surgical theaters much better. Your role as an engineer would be to help imagine different technologies in ways that are similar to, but not the same as current ones. In this example the technology still has to be shown in an experiential way to the design team in order to benefit the understanding and in consequence the outcome of the design process. On the other hand, in another example when there is a new interaction technology, a design team can be exploring the possibilities of such technology, and again, the engineer will have to expose those qualities to the team for the exact same reason.

This brings us to an important role of Inspirational Bits, it can help to bring attention to the material approach and an understanding of the importance of the engineer in educational contexts and improve multidisciplinary skills of the engineer. Therefore, Inspirational Bits is an approach on how to tackle material in a multidisciplinary design context from an engineering perspective. Inspirational Bits and the material approach are also a way to convey engineering knowledge in an experiential way, helping the group communicate and creating a background of experiential knowledge that can help the overall process of a multidisciplinary design team. Trying to explain a technology as it works from a technical perspective is not a guarantee for understanding, nor is it gaining experiential knowledge; but in a design context, the experiential knowledge play an important role in the understanding, and therefore the material approach may improve the final result of a design.

6.2 Proxessories design space

Looking back at some of our early design explorations, before rFlea and InsBitsStudio, we struggled with attempting to design interaction within the Proxessory design space. Our early explorations often ended up being bulky, uncomfortable and in many cases aesthetically unappealing. Because of this, it has sometimes been challenging to shape and probe the user experience.

To provide an example of this type of situation, let us have a look at a real design case from our own research. We were trying to design a sports app that would give feedback while running or skiing through vibrations on different parts of the body. The aim was to test different vibrators, in action in different places and patterns in a quick manner. Using existing tools, we developed a test system that would be used in action. As expected the user portrayed in Figure 6.1 was not able to perform his sports freely, which, in turn, impacted the test and subsequent design iterations. As cables and soldering points tend to break due to bulkiness and body movement, we repeatedly experienced severe breakdowns of the system and interaction. In the end, it became almost impossible to test the things that we needed in order to advance the project unless we spent extra time making the system robust and usable.

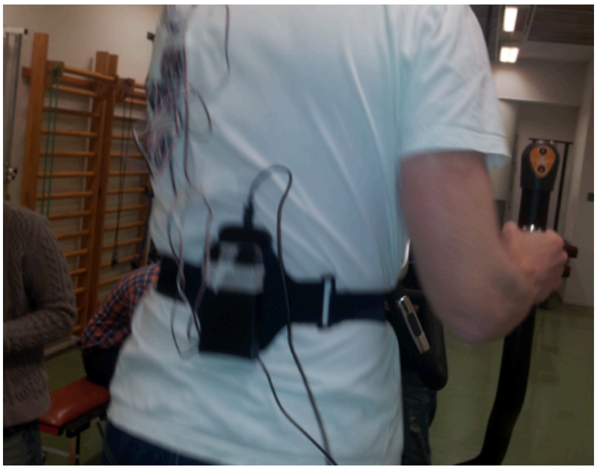

Figure 6.1: Interactive feedback in a sport system set up.

Since this early exploration, a series of projects have taken place, as we have described in this thesis in Chapter 4, the design journey. Through that journey, which took place within a Research through Design context, the design space of Proxessories has opened up in many directions. Figure 6.2 is a detailed figure from the one in Chapter 3, Figure 3.1, which described the design journey over time through the projects and how RtD and EtD influenced each other in building up design space knowledge. Figure 6.2, shows the most important learnings from EtD(red) and RtD(green). Note that they don't have to have similar learnings, but overall, they influence each other and form a whole.

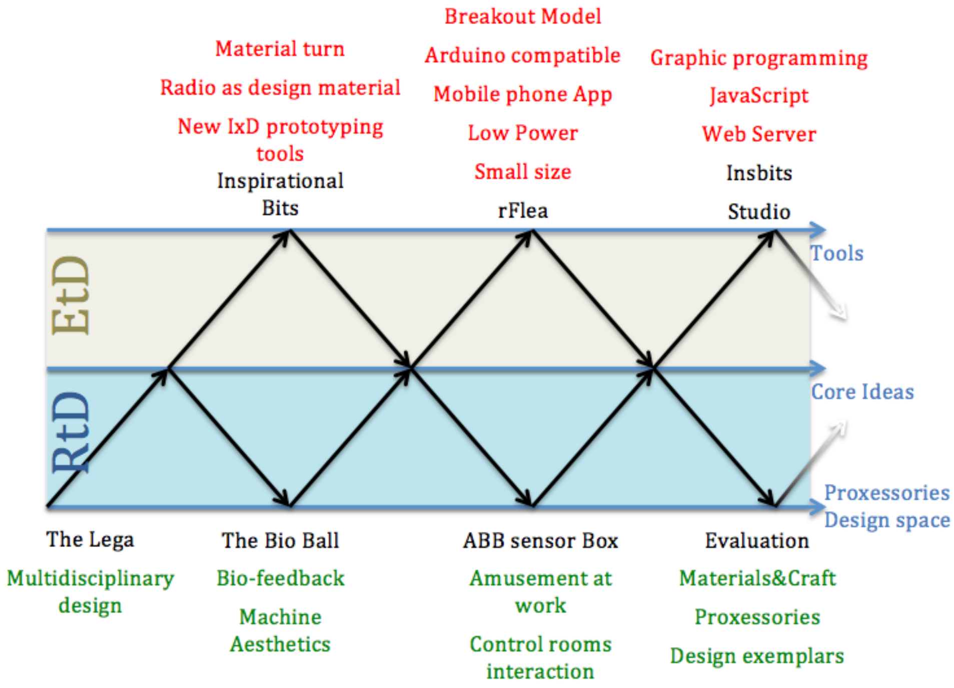

Figure 6.2: Detailed description of Engineering through Design in this thesis.

Starting with the Lega project, the design team realized when designing with technology, unless all the team had a common background understanding its interactions, design features and ideas could vanish in the process. That provided an important incentive to understand why we should focus on the way multidisciplinary teams work with technology together, and, in my case particularly, the engineering way to achieve it. Moving through the design journey, the properties of what tools would improve the design explorations show up and turn into engineering challenges. rFlea, Insbits Studio and the definition of the design space of Proxessories can be tracked back to the design journey in Chapter 4.

In some of the early design cases some outcomes could have been predicted beforehand: for example, the need to use wireless technologies to remove cables. Others, however, were not that obvious, and, unless we had made that journey, they would not have revealed themselves. For example, the strong connection between the tools and the design space on one hand, and crafting and material qualities on the other. The outcomes of this thesis are a particular instance of the design journey, its projects and participants. As in Research through Design, rFlea and Insbits Studio would have been different if we changed the context of the research. Overall, in this thesis, the context of Research through Design has shaped the engineering process of creating tools in a way that an isolated engineer solving a problem would have struggled to deliver.

An important topic when designing for Proxessories is the close relationship between aesthetics and material crafting. In all the examples given in chapter 5, the material qualities of the accessories were an important part of both the design process as well as the final prototypes. Therefore, it is important that a tool supports and does not limit such a practice. Sometimes materials and the corresponding skill-set for using these set the boundaries for what kind of designs that are being looked into from an arts and crafts perspective. Over the years we have seen people in the CHI community looking into various material practices e.g., old-school book binding [45], using leather [62], or even silver smithing [14] to name a few.

6.3 rFlea and Insbits Studio

The example from Figure 6.1 shows a clear need in the Proxessory design space: bulkiness and cable can slow down the exploration process and affect the interaction outcomes of a prototype. If we want to explore the design space of Proxessories a tailored tool has to be designed that allows for wireless and small size factors. In addition, the IoT revolution adds the need for connectivity and cloud services. rFlea and Insbits Studio represent a step forward from the tools used in that early example. In Chapter 5, the tools were presented and up to five design cases illustrate the kind of support rFlea and Insbits Studio provided for designing Proxessories. The development of the platform was in itself a designerly process applied to an electrical and software engineering problem. The process contributed to our growing understanding of the characteristics of the design space itself as well as what kind of tools that might be helpful to support design efforts within it. The end result is a set of tools that provide better support for design-led explorations of Proxessories. The selected design cases presented in this thesis are samples from a much larger collection of design cases that have used the tools [14][70][59][3][13][49].

Looking at the projects presented here — one of the more appreciated features was having something that was truly self-contained regarding low power and small electronic board size. This is certainly the case for all the presented examples. If one starts to design something that runs out of tethered power, it is often the case that the design will have to be adjusted around it. Starting with low power and limited supply in mind already from the beginning changes the outset of what is seen as possible. High power consumption also increases the size of the prototypes, as they require bigger batteries, which make it harder to achieve the desired aesthetics. Hence, the small form factor of the whole prototype has been an enabler in all projects presented in this thesis.

One of the main outcomes of the Inspirational Bits project was the realization that interaction-designers often find themselves fighting their physical-digital material. For instance, using Bluetooth in a design often turns into a struggle with the technology rather than a fruitful exploration of possible qualities in the interaction. Reducing complexity of wireless connections through Arduino libraries, mobile phone app and the effort to allow for a unification of programming languages (JavaScript) in the phone and in the cloud-based programming language had a big impact on the students' work to explore the design space. From early experiences, mobile phone programming has a steep learning curve. However, using Javascript with libraries to control the wireless connections allows interaction designers to focus on the tangible interaction and aesthetics of the prototype.

An important aspect from looking at the projects presented here is how the tools may work in favor of working with a particular set of materials. It seems important that interactive technology does not get in the way of the crafting practices, but rather supports them and possibly even pushes them further. Moreover, there are many new and perhaps more significantly — affordable tools available to work with materials in new ways. Recently there have been examples of laser-cutters and 3D printers entering the scene and becoming widely used in industry as well as academia and maker community contexts. An effect of having such tools as well as suitable technology like rFlea and Insbits Studio is that design practitioners will be able to spend time with materials that we have rarely combined with electronics before, or demanding materials,like glass, leather and bamboo. With such materials, then come other qualities like fragility, patina, reflection and suppleness, to name some that become both interesting and desirable, and, in some cases, enrich the design space in unforeseeable ways [64][73].

6.4 Concluding remarks

Accessorizing can be thought of as a generic activity that can be traced through the examples that provides an alternative to thinking about novel interfaces [27]. Similarly, Proximity expresses a sense of nearness, being close to, attached to or having a spatial relationship with something. To sum up, this thesis has explored interaction design in the intersection of proxemics and accessories. Designs have been presented that inhabit this space, Proxessories, to indicate how they thrive in proximity to other devices and users, and their function as accessories to interaction. As such, they are part of interactional ensembles or "outfits" that provide their value as a whole. We have seen a trend in recent years towards accessorizing, moving all functionalities of our devices outside them, moving out of the screen and app paradigm in case of themobile phones and tablets or turning our everyday objects into "smart" objects. This is a new design space; interaction design should look together with engineering design in order to grow and impact society.

In Chapter 3, Engineering through Design was described as an approach to how a tool that is meant to influence in a specific design space could be built. rFlea and InsBits Studio went through an iterative design process where each of the projects shaped different characteristics of the tool, each one changing it from an engineering design to a specific tool for designing Proxessories in a design context. Thus, the traditional engineering process was not only based on specifications, but rather driven by designerly ways of working and thinking. This is an explorative approach where one has to try out things in order to get a feeling for what works and what doesn't through tinkering [26]. Here, I framed my own process as Engineering through Design. While this worked for this particular design space, it remains to be shown whether and how this can be brought into other design spaces.

rFlea and Insbits Studio are the tools designed and built during the projects presented in this thesis. The aim was to support design of a very specific class of systems: Proxessories. Up to five projects have been presented in Chapter 5 as examples of using rFlea and Insbits Studio in different contexts, but within multidisciplinary design teams and the Proxessory design space. At the same time new aspects of designing for Proxessories have opened up the design space like material and crafting practices.

The tools presented are not final designs, since improvements could be applied, for rFlea switching to the latest wireless technologies, upgrading microcontroller or including USB programming port could be added, for Insbits Studio to improve its graphical design and add cooperative programming modes. Nevertheless, the current state-of-the-tools fulfills the main characteristics of the design space of Proxessories in a way that new designs and exploration have emerged through the examples.

My work has illustrated how engineering as a field can learn from design by adopting more designerly ways of working. It has also illustrated how design can learn from engineering through novel ways of exploring and experiencing material qualities of technology. Hence, my work marks the start of what appears to be a mutually beneficial exchange for both fields. How that exchange will evolve in the future remains to be seen, but I firmly believe and hope that the fields will continue to work together as they have much to contribute to one another.

Bibliography

[1] Bdeir, Ayah and Rothman, Paul. Electronics as material: Littlebits. In *Proceedings of the Sixth International Conference on Tangible, Embedded and Embodied Interaction*, TEI '12, pages 371–374, New York, NY, USA, 2012. ACM. ISBN 978-1-4503-1174-8. URL `http://doi.acm.org/10.1145/2148131.2148220`.

[2] Bensky, Alan. *Wireless Positioning Technologies and Applications.* Artech House, Inc., Norwood, MA, USA, 2007. ISBN 1596931302, 9781596931305.

[3] Bergsmark, Moa, Koselnik, Yelena, Lagerberg, Evert, and Movin, Anna. Meya - crafting an interactive bag with e-textiles sensors and actuators. In *Proceedings of the SIDeR - 11th Student Interaction Design Research conference*, SIDER '15, pages 171–172, 2015. URL `http://www.sider2015.sdu.dk/proceedings/`.

[4] Bødker, Susanne. When second wave HCI meets third wave challenges. In *Proceedings of the 4th Nordic Conference on Human-computer Interaction: Changing Roles*, NordiCHI '06, pages 1–8, New York, NY, USA, 2006. ACM. ISBN 1-59593-325-5. URL `http://doi.acm.org/10.1145/1182475.1182476`.

[5] Brewster, Stephen and Brown, Lorna M. Tactons: structured tactile messages for non-visual information display. In *Proceedings of the fifth conference on Australasian user interface - Volume 28*, AUIC '04, pages 15–23, Darlinghurst, Australia, Australia, 2004. Australian Computer Society, Inc. URL `http://dl.acm.org/citation.cfm?id=976310.976313`.

[6] Brooks, Ruven, Graham, Nicholas, Nichols, Jeffrey, Palanque, Philippe, and Paternò, Fabio. Invited engineering community SIG. In *Proceedings of the 2012 ACM annual conference extended abstracts on Human Factors in Computing Systems Extended Abstracts - CHI EA '12*, page 1205, New York, New York, USA, May 2012. ACM Press. ISBN 9781450310161. URL `http://dl.acm.org/citation.cfm?id=2212776.2212424`.

[7] Buechley, Leah, Eisenberg, Mike, Catchen, Jaime, and Crockett, Ali. The lilypad arduino: Using computational textiles to investigate engagement,

aesthetics, and diversity in computer science education. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '08, pages 423–432, New York, NY, USA, 2008. ACM. ISBN 978-1-60558-011-1. URL `http://doi.acm.org/10.1145/1357054.1357123`.

[8] Buechley, Leah and Hill, Benjamin Mako. LilyPad in the wild. In *Proceedings of the 8th ACM Conference on Designing Interactive Systems - DIS '10*, page 199, New York, New York, USA, August 2010. ACM Press. ISBN 9781450301039. URL `http://dl.acm.org/citation.cfm?id=1858171.1858206`.

[9] Buxton, William. *Sketching User Experiences: Getting the Design Right and the Right Design*. Interactive Technologies. Elsevier/Morgan Kaufmann, 2007. ISBN 9780123740373. URL `http://books.google.se/books?id=2vfPxocmLh0C`.

[10] Dunne, Anthony. Hertzian Tales. URL `https://mitpress.mit.edu/books/hertzian-tales`.

[11] Dunne, Anthony and Raby, Fiona. *Design Noir: The Secret Life of Electronic Objects*. August, 2001. ISBN 9783764365660. URL `http://books.google.se/books?id=_49YTKJ16l4C`.

[12] Evans, Dave. The internet of things: How the next evolution of the internet is changing everything. 2011. URL `http://www.cisco.com/web/about/ac79/docs/innov/IoT IBSG 0411FINAL.pdf`.

[13] Feldt, Tommy, Freilich, Sarah, Mendonsa, Shaun, Molin, Daniel, and Rau, Andreas. The peripipe: A sip and puff remote control fro music playback. In *Proceedings of the SIDeR - 11th Student Interaction Design Research conference*, SIDER '15, pages 169–170, 2015. URL `http://www.sider2015.sdu.dk/proceedings/`.

[14] Fernaeus, Ylva, Murer, Martin, Tsaknaki, Vasiliki, and Solsona Belenguer, Jordi. Handcrafting electronic accessories using 'raw' materials. In *Proceedings of the 8th International Conference on Tangible, Embedded and Embodied Interaction*, TEI '14, pages 369–372, New York, NY, USA, 2013. ACM. ISBN 978-1-4503-2635-3. URL `http://doi.acm.org/10.1145/2540930.2567906`.

[15] Fernaeus, Ylva and Sundström, Petra. The material move: How materials matter in interaction design research. In *Proceedings of DIS 2012*, 2012.

[16] Frayling, Christopher. Research in Art and Design, may 1994. URL `http://researchonline.rca.ac.uk/384/3/frayling_research_in_art_and_design_1993.pdf`.

[17] Fu, Zhiyong, Zimmerman, John, Wu, Jiayu, Kirwan, Christopher Mustafa, and Zhao, Chen. The role of design in Ubicomp research and practice. In *Proceedings of the 13th international conference on Ubiquitous computing - UbiComp '11*, page 629, New York, New York, USA, September 2011. ACM Press. ISBN 9781450306300. URL `http://dl.acm.org/citation.cfm?id=2030112.2030249`.

[18] Giaccardi, Elisa and Karana, Elvin. Foundations of materials experience: An approach for hci. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '15, pages 2447–2456, New York, NY, USA, 2015. ACM.

[19] Greenberg, Saul and Fitchett, Chester. Phidgets: Easy development of physical interfaces through physical widgets. In *Proceedings of the 14th Annual ACM Symposium on User Interface Software and Technology*, UIST '01, pages 209–218, New York, NY, USA, 2001. ACM. ISBN 1-58113-438-X. URL `http://doi.acm.org/10.1145/502348.502388`.

[20] Greenberg, Saul, Marquardt, Nicolai, Ballendat, Till, Diaz-Marino, Rob, and Wang, Miaosen. Proxemic interactions: The new ubicomp. *interactions*, 18(1):42–50, January 2011. ISSN 1072-5520. URL `http://doi.acm.org/10.1145/1897239.1897250`.

[21] Hall, Edward T. *The Hidden Dimension*. A Doubleday anchor book. Anchor Books, 1990. ISBN 9780385084765. URL `http://books.google.se/books?id=zGYPwLj2dCoC`.

[22] Hallnäs, Lars and Redström, Johan. *Interaction design: foundations, experiments*. University College of Borås. Swedish School of Textiles.

[23] Höök, Kristina and Löwgren, Jonas. Strong concepts. *ACM Transactions on Computer-Human Interaction*, 19(3):1–18, oct 2012. ISSN 10730516. URL `http://dl.acm.org/citation.cfm?id=2362364.2362371`.

[24] Isbister, Katherine. Supple interfaces : Designing and evaluating for richer human connections and experiences. *Interfaces*, pages 2853–2856, 2007. URL `http://portal.acm.org/citation.cfm?doid=1240866.1241094`.

[25] Isbister, Katherine and Höök, Kristina. On being supple: in search of rigor without rigidity in meeting new design and evaluation challenges for HCI practitioners. In *Proceedings of the 27th international conference on Human factors in computing systems*, CHI '09, pages 2233–2242, New York, NY, USA, 2009. ACM. ISBN 978-1-60558-246-7. URL `http://doi.acm.org/10.1145/1518701.1519042`.

[26] Jacobsson, Mattias. Tinkering with interactive materials: Studies, concepts and prototypes, 2013. URL

`http://www.diva-portal.org/smash/record.jsf?pid=diva2%3A668779&dswid=3027`.

[27] Jacobsson, Mattias, Fernaeus, Ylva, and Nylander, Stina. Mobile actdresses: Programming mobile devices by accessorizing. In *CHI '12 Extended Abstracts on Human Factors in Computing Systems*, CHI EA '12, pages 1071–1074, New York, NY, USA, 2012. ACM. ISBN 978-1-4503-1016-1. URL `http://doi.acm.org/10.1145/2212776.2212388`.

[28] Laaksolahti, Jarmo, Tholander, Jakob, Lundén, Marcus, Solsona Belenguer, Jordi, Karlsson, Anna, and Jaensson, Tove. The lega: a device for leaving and finding tactile traces. In *Proceedings of the fifth international conference on Tangible, embedded, and embodied interaction*, TEI '11, pages 193–196, New York, NY, USA, 2011. ACM. ISBN 978-1-4503-0478-8. URL `http://doi.acm.org/10.1145/1935701.1935739`.

[29] Laplante, Phillip A. and Neill, Colin J. Design methods for developing services. URL `http://www.designcouncil.org.uk/sites/default/files/asset/document/Design%20methods%20for%20developing%20services.pdf`.

[30] Laplante, Phillip A. and Neill, Colin J. The demise of the waterfall model is imminent. *Queue*, 1(10):10, February 2004. ISSN 15427730. URL `http://dl.acm.org/ft_gateway.cfm?id=971573&type=html`.

[31] Lim, Youn-Kyung, Stolterman, Erik, and Tenenberg, Josh. The anatomy of prototypes. *ACM Transactions on Computer-Human Interaction*, 15(2):1–27, July 2008. ISSN 10730516. URL `http://dl.acm.org/citation.cfm?id=1375761.1375762`.

[32] Ljungblad, Sara. Beyond Users : Grounding Technology in Experience. January 2008. URL `http://www.researchgate.net/publication/279658682_Beyond_Users__Grounding_Technology_in_Experience`.

[33] Lock, Simon, Allanson, Jennifer, and Phillips, Peter. User-driven design of a tangible awareness landscape. In *Proceedings of the conference on Designing interactive systems processes, practices, methods, and techniques - DIS '00*, pages 434–440, New York, New York, USA, August 2000. ACM Press. ISBN 1581132190. URL `http://dl.acm.org/citation.cfm?id=347642.347804`.

[34] Löwgren, Jonas. Inspirational Patterns for Embodied Interaction. *Knowledge, Technology & Policy*, 20(3):165–177, September 2007. ISSN 0897-1986. URL `http://link.springer.com/10.1007/s12130-007-9029-1`.

[35] Löwgren, Jonas. Beyond conversation : palpating the hybrid materials, 2015. URL `https://dspace.mah.se/handle/2043/18744`.

[36] Löwgren, Jonas and Stolterman, Erik. *thoughtful interaction design: a design perspective on information technology*. MIT Press, 2007.

[37] Lundén, Marcus and Dunkels, Adam. The politecast communication primitive for low-power wireless. *SIGCOMM Comput. Commun. Rev.*, 41(2):31–37, April 2011. ISSN 0146-4833. URL `http://doi.acm.org/10.1145/1971162.1971167`.

[38] Maeng, Seungwoo, Lim, Youn-kyung, and Lee, KunPyo. Interaction-driven design. In *Proceedings of the Designing Interactive Systems Conference on - DIS '12*, page 448, New York, New York, USA, June 2012. ACM Press. ISBN 9781450312103. URL `http://dl.acm.org/citation.cfm?id=2317956.2318022`.

[39] Moussette, Camille and Dore, Fabricio. Sketching in hardware and building interaction design : Tools, toolkits and an attitude for interaction designers. In *Proceedings of Design Research Society*, 2010. Kompletteras 2012-09.

[40] Moussette, Camille and Fallman, Daniel. Designing for touch : Creating and building meaningful haptic interfaces. In *IASDR 2009*, 2009.

[41] Mueller, Florian, Stellmach, Sophie, Greenberg, Saul, Dippon, Andreas, Boll, Susanne, Garner, Jayden, Khot, Rohit, Naseem, Amani, and Altimira, David. Proxemics play. In *Proceedings of the 2014 conference on Designing interactive systems - DIS '14*, pages 533–542, New York, New York, USA, June 2014. ACM Press. ISBN 9781450329026. URL `http://dl.acm.org/citation.cfm?id=2598510.2598532`.

[42] Mughal, Mudassar Ahmad, Wang, Jinyi, and Juhlin, Oskar. Juxtaposing mobile webcasting and ambient video for home decor. In *Proceedings of the 13th International Conference on Mobile and Ubiquitous Multimedia*, MUM '14, pages 151–159, New York, NY, USA, 2014. ACM. ISBN 978-1-4503-3304-7. URL `http://doi.acm.org/10.1145/2677972.2677988`.

[43] Murray-Smith, Roderick, Williamson, John, Hughes, Stephen, Quaade, Torben, and Strachan, Steven. Rub the stane. In *CHI '08 Extended Abstracts on Human Factors in Computing Systems*, CHI EA '08, pages 2355–2360, New York, NY, USA, 2008. ACM. ISBN 978-1-60558-012-8. URL `http://doi.acm.org/10.1145/1358628.1358683`.

[44] Ozenc, Fatih Kursat, Kim, Miso, Zimmerman, John, Oney, Stephen, and Myers, Brad. How to support designers in getting hold of the immaterial material of software. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '10, pages 2513–2522, New York, NY, USA, 2010. ACM. ISBN 978-1-60558-929-9. URL `http://doi.acm.org/10.1145/1753326.1753707`.

[45] Schneegass, Stefan, Sahami Shirazi, Alireza, Döring, Tanja, Schmid, David, and Schmidt, Albrecht. NatCut. In *Proceedings of the extended abstracts of the 32nd annual ACM conference on Human factors in computing systems - CHI EA '14*, pages 1441–1446, New York, New York, USA, April 2014. ACM Press. ISBN 9781450324748. URL `http://dl.acm.org/citation.cfm?id=2611780.2581189`.

[46] Schön, Donald A. *The Reflective Practitioner How Professionals Think in Action.* 1983. ISBN 0465068782.

[47] Severance, Charles. Massimo Banzi: Building arduino. *Computer*, 47(1):11–12, January 2014. ISSN 0018-9162. URL `http://dx.doi.org/10.1109/MC.2014.19`.

[48] Seymour, Sabine. *Fashionable Technology: The Intersection of Design, Fashion, Science, and Technology.* Springer, 2008. ISBN 9783211744987. URL `http://books.google.se/books?id=dW89ZeeHJxAC`.

[49] Solsona Belenguer, Jordi, Lundén, Marcus, Laaksolhati, Jarmo, and Sundström, Petra. Immaterial materials: designing with radio. In *Proceedings of the Sixth International Conference on Tangible, Embedded and Embodied Interaction*, TEI '12, pages 205–212, New York, NY, USA, 2012. ACM. ISBN 978-1-4503-1174-8. URL `http://doi.acm.org/10.1145/2148131.2148177`.

[50] Solsona Belenguer, Jordi and Smith, Mark T. An extension of computer engineering methods for interdisciplinary design. In *Proceedings of Pervasive Computing and Communications Workshops*, PERCOM '11, page 584, Seattle, WA, USA, 2011. IEEE Computer Society. ISBN 978-1-61284-936-2.

[51] Stolterman, Erik. The nature of design practice and implications for interaction design research. *International Journal of Design*, 2(1), 2008. URL `http://www.ijdesign.org/ojs/index.php/IJDesign/article/view/240`.

[52] Sundström, Petra and Höök, Kristina. Hand in hand with the material: designing for suppleness. In *Proceedings of the 28th international conference on Human factors in computing systems*, CHI '10, pages 463–472, New York, NY, USA, 2010. ACM. ISBN 978-1-60558-929-9. URL `http://doi.acm.org/10.1145/1753326.1753396`.

[53] Sundström, Petra, Ståhl, Anna, and Höök, Kristina. In situ informants exploring an emotional mobile messaging system in their everyday practice. *Int. J. Hum.-Comput. Stud.*, 65(4):388–403, April 2007. ISSN 1071-5819. URL `http://dx.doi.org/10.1016/j.ijhcs.2006.11.013`.

[54] Sundström, Petra, Taylor, Alex, Grufberg, Katja, Wirström, Niklas, Solsona Belenguer, Jordi, and Lundén, Marcus. Inspirational bits: towards a shared understanding of the digital material. In *Proceedings of the SIGCHI*

Conference on Human Factors in Computing Systems, CHI '11, pages 1561–1570, New York, NY, USA, 2011. ACM. ISBN 978-1-4503-0228-9. URL `http://doi.acm.org/10.1145/1978942.1979170`.

[55] Sundström, Petra, Vaara, Elsa, Solsona Belenguer, Jordi, Wirström, Niklas, Lundén, Marcus, Laaksolhati, Jarmo, Waern, Annika, and Höök, Kristina. Experiential artifacts as a design method for somaesthetic service development. In *Proceedings of the 2011 ACM symposium on The role of design in UbiComp research & practice*, RDURP '11, pages 33–36, New York, NY, USA, 2011. ACM. ISBN 978-1-4503-0931-8. URL `http://doi.acm.org/10.1145/2030031.2030041`.

[56] Thompson, Michael and Wishbow, Nina. Prototyping: tools and techniques. In *Proceedings of the 10th annual international conference on Systems documentation - SIGDOC '92*, pages 191–199, New York, New York, USA, nov 1992. ACM Press. ISBN 0897915321. URL `http://dl.acm.org/citation.cfm?id=147001.147030`.

[57] Toney, Aaron, Dunne, Lucy, Thomas, Bruce H., and Ashdown, Susan P. A shoulder pad insert vibrotactile display. In *Proceedings of the 7th IEEE International Symposium on Wearable Computers*, ISWC '03, pages 35–, Washington, DC, USA, 2003. IEEE Computer Society. ISBN 0-7695-2034-0. URL `http://dl.acm.org/citation.cfm?id=946249.946871`.

[58] Tsaknaki, Vasiliki, Fernaeus, Ylva, and Schaub, Mischa. Leather as a material for crafting interactive and physical artifacts. In *Proceedings of the 2014 Conference on Designing Interactive Systems*, DIS '14, pages 5–14, New York, NY, USA, 2014. ACM. ISBN 978-1-4503-2902-6. URL `http://doi.acm.org/10.1145/2598510.2598574`.

[59] Turesson, John, Chen, Anxiao, Dahlstrom, Erik, Carino, Dan, and Ericsson, Niclas. The memorial. In *Proceedings of the SIDeR - 11th Student Interaction Design Research conference*, SIDER '15, pages 162–164, 2015. URL `http://www.sider2015.sdu.dk/proceedings/`.

[60] Ulrich, Karl. Product Design and Development. URL `http://www.amazon.com/Product-Design-Development-Karl-Ulrich/dp/0071086951`.

[61] Vaara, Elsa, Silvăşan, Iuliana, Ståhl, Anna, and Höök, Kristina. Temporal relations in affective health. In *Proceedings of the 6th Nordic Conference on Human-Computer Interaction: Extending Boundaries*, NordiCHI '10, pages 833–838, New York, NY, USA, 2010. ACM. ISBN 978-1-60558-934-3. URL `http://doi.acm.org/10.1145/1868914.1869043`.

[62] Vallgårda, Anna and Fernaeus, Ylva. Interaction Design as a Bricolage Practice. In *Proceedings of the Ninth International Conference on Tangible,*

Embedded, and Embodied Interaction - TEI '14, pages 173–180, New York, New York, USA, January 2015. ACM Press. ISBN 9781450333054. URL `http://dl.acm.org/citation.cfm?id=2677199.2680594`.

[63] Vallgårda, Anna and Redström, Johan. Computational composites. In *Proceedings of the SIGCHI conference on Human factors in computing systems*, CHI '07, pages 513–522, New York, NY, USA, 2007. ACM. ISBN 978-1-59593-593-9. URL `http://doi.acm.org/10.1145/1240624.1240706`.

[64] Vallgårda, Anna and Sokolar, Tomas. Material computing. In *Proceedings of the 12th ACM international conference adjunct papers on Ubiquitous computing - Ubicomp '10*, page 383, New York, New York, USA, September 2010. ACM Press. ISBN 9781450302838. URL `http://dl.acm.org/citation.cfm?id=1864431.1864447`.

[65] Vallgårda, Anna and Sokoler, Tomas. A material focus: exploring properties of computational composites. In *Proceedings of the 27th international conference extended abstracts on Human factors in computing systems*, CHI EA '09, pages 4147–4152, New York, NY, USA, 2009. ACM. ISBN 978-1-60558-247-4. URL `http://doi.acm.org/10.1145/1520340.1520631`.

[66] Vasseur, Jean-Philippe and Dunkels, Adam. *Interconnecting Smart Objects with IP: The Next Internet.* Morgan Kaufmann. Elsevier Science, 2010. ISBN 9780123751652. URL `http://books.google.se/books?id=mVji-YA5kgEC`.

[67] Verganti, Roberto. *Design Driven Innovation: Changing the Rules of Competition by Radically Innovating What Things Mean.* Harvard Business Press, 2009. ISBN 9781422124826. URL `http://books.google.se/books?id=rpaj0vLzPRkC`.

[68] Vestberg, Hans. CEO to shareholders: 50 billion connections 2020. 2013. URL `http://hugin.info/1061/R/1403231/357583.pdf`.

[69] Vredenburg, Karel, Isensee, Scott, and Righi, Carol. User-Centered Design: An Integrated Approach: Karel Vredenburg, Scott Isensee, Carol Righi: 9780130912954: Amazon.com: Books. URL `http://www.amazon.com/User-Centered-Design-An-Integrated-Approach/dp/0130912956`.

[70] Šimbelis, Vygandas, Lundström, Anders, Höök, Kristina, Solsona Belenguer, Jordi, and Lewandowski, Vincent. Metaphone: Machine aesthetics meets interaction design. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '14, pages 1–10, New York, NY, USA, 2014. ACM. ISBN 978-1-4503-2473-1. URL `http://doi.acm.org/10.1145/2556288.2557152`.

[71] Westerlund, Bo. Design space conceptual tool and grasping the design process, February 2009. ISSN 1604-9705. URL `http://www.nordes.org/opj/index.php/n13/article/view/254`.

[72] Wiberg, Mikael, Ishii, Hiroshi, Dourish, Paul, Vallgårda, Anna, Kerridge, Tobie, Sundström, Petra, Rosner, Daniela, and Rolston, Mark. Materiality matters—experience materials. *interactions*, 20(2):54–57, March 2013. ISSN 1072-5520. URL `http://doi.acm.org/10.1145/2427076.2427087`.

[73] Williamson, John, Murray-Smith, Roderick, and Hughes, Stephen. Devices as interactive physical containers: The shoogle system. In *CHI '07 Extended Abstracts on Human Factors in Computing Systems*, CHI EA '07, pages 2013–2018, New York, NY, USA, 2007. ACM. ISBN 978-1-59593-642-4. URL `http://doi.acm.org/10.1145/1240866.1240941`.

[74] Zimmerman, John, Forlizzi, Jodi, and Evenson, Shelley. Research through design as a method for interaction design research in hci. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '07, pages 493–502, New York, NY, USA, 2007. ACM. ISBN 978-1-59593-593-9. URL `http://doi.acm.org/10.1145/1240624.1240704`.

[75] Zimmerman, John, Stolterman, Erik, and Forlizzi, Jodi. An analysis and critique of Research through Design. In *Proceedings of the 8th ACM Conference on Designing Interactive Systems - DIS '10*, page 310, New York, New York, USA, August 2010. ACM Press. ISBN 9781450301039. URL `http://dl.acm.org/citation.cfm?id=1858171.1858228`.

Part II

Paper Reprints

Paper 1: The LEGA: A Device for Leaving and Finding Tactile Traces

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The Lega: A Device for Leaving and Finding Tactile Traces

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ABSTRACT

This paper describes experiences from development and deployment of the Lega, a hand held device for physical sharing of experiences during an art exhibition. Touching and moving the device in different ways creates a tactile trace that can be experienced by others through their own device. The system was successfully deployed at an art exhibition for two months where user studies were performed. Here we present some general observations regarding the systems performance and discuss issues that we encountered.

Author Keywords

Tactile interaction, gestural interaction, individual and social use

ACM Classification Keywords

H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

General Terms

Design

INTRODUCTION

This paper presents the Lega, a hand held device that lets visitors to an art hall share their experiences via physical traces that are created through bodily means of interaction. The Lega has an ovoid form that fits into the palm of your hand and has a soft surface that encourages tactile and gestural interaction. By touching and moving their device in various ways users create expressions of their experience that are left at their approximate location. There they can be discovered and experienced as vibration and light patterns by others in the group. Our intention was to create an experience reminiscent of someone drawing in your palm.

The design draws on experience oriented HCI research where there has been an increasing number of attempts to map out interaction qualities such as pliability [4] and suppleness [3] and the challenges related to designing for them. They all recognize the fact that experiences arise in use and depend on a combination of hardware, software and design elements. This holistic view makes the task of designing a system challenging as you constantly have to juggle several interdependent factors. Matters become even more complex when taking the view that representative use experiences are not likely to arise, and are therefore difficult to evaluate, until there is a sufficiently polished prototype available. When working with novel hardware and form factors this could in essence mean having to develop several more or less completed devices before design goals are reached.

There is a substantial body of work on the use of tactile information for non-visual information display [see e.g., 1] and input [see e.g., 5]. Our own work has been less focused on the use of tactile input/output for information transfer purposes but has rather focused on the experiential qualities afforded by tactile interaction. In that sense it bears greater resemblance to tactile messaging systems such as Share2Talk [2] which supports sharing of sensations between users.

While having a strong identity of its own, the Lega concept builds on experiences from *eMoto* [7] and *FriendSense* [6], two earlier prototypes developed within our group. In particular it shares the focus on communication and interaction within groups of friends, but also its focus on bodily interaction, with those earlier prototypes.

Here we discuss how hardware, software and infrastructure constraints together with ethnographic findings contributed in forming the design space out of which the Lega evolved.

DESIGNING THE LEGA

The Lega, named after the Swedish word for a place in the woods where you can see that an animal has slept, was developed in an iterative process that continued throughout the deployment at the art hall. Early users during the two months of the deployment at the art exhibition thus used a slightly different system compared to later users.

The annual Vårsalongen event at Liljevalchs exhibits professional and amateur art selected by a jury from anonymously submitted pieces. Each year around 250 pieces are exhibited for a period of two months. The event is visited by ~ 40.000 visitors each year and has a long-standing tradition of stirring up emotion and engagement from both visitors and media. The ethnographic study we made on-site during Vårsalongen 2009, as well as the art halls own statistics, showed that most visitors visit the

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exhibition in small groups of 2-5 people, with some larger organized tours taking place during evenings and weekends. For our purposes this was a perfect match between our interest in emotional and bodily communication of experiences among friends, and an emotionally evocative event visited mainly by small groups of friends.

The starting point for the design of the system was an ethnographically inspired study of art exhibition visitors and the way they experience and communicate about art through their bodily gestures. As an outcome of that study, we developed an approach to more explicitly taking bodily experiences as inspiration for design. In order to allow for creative linking between ethnographic findings of bodily practices and design, we developed a set of *body act* cards that were used in idea generation and prototyping. The cards are developed to carry experiential qualities from ethnography to design, providing details about movement, touch, gesture, spatiality and so forth, while still opening up for the creativity and interpretation necessary in productive design work.

Much of the design work was conducted within the premises of the art hall allowing ideas and concepts to be tried out in-situ. The design team, of about 15 people, consisted of interaction designers, industrial designers, hardware, sensor and software engineers, as well as HCI-specialists. In using the body cards in design we started out by giving the design team a presentation of the situations in the video material out of which they were derived and collaboratively analysed short snippets of video. This gave the team a first understanding of the setting and the phenomena of specific interest that had been identified. We presented the body cards and how these related to our studies. The design process consisted of a number of design exercises, lo-fi prototyping, and efforts to imagine the experience of users. The key inspiration for the idea that led up to the Lega was the *dancing eyes, fingers, and bodies* and *urge-to-touch* cards. The first card builds on observations of how visitors used the physical space to split up, re-gather, and invite each other to share experiences. The second card builds on observation on the substantial interactional work visitors did to experience the physical and material qualities of the art and the role this played in sharing, seeing, feeling, and imagining the art together with other visitors.

The design process itself started on site at Liljevalchs with a five day workshop that resulted in early implementations of several different concepts. Later several of those were merged to form the Lega concept. Over the course of the following months we involved art hall staff in testing and discussing prototypes as the concept was gradually refined. We also held weekly “build fests” for the design team where features and ideas that we had been working on during the week were tested and discussed, and where we decided what to focus on until the next build fest.

We also returned to Liljevalchs for testing prototypes with art hall staff on two occasions before the Vårsalongen event and received valuable feedback. Finally for three weeks before the event we gained free access to the art hall for testing and deploying the system while the exhibition was being set up.

Figure 1. Exploded view of a Lega showing it's layers

Construction

Throughout the design process careful attention was paid to the visual and tactile qualities of the device. We wanted its shape and visual appearance to invite users to pick it up and touch it. The Lega has an ovoid shape that is designed to fit comfortably into a users palm. Users can carry it in one or both hands while walking through the exhibition or let it hang by its strap. The ovoid shape also makes the device orient itself naturally in a users palm although it is possible to hold it comfortably in a variety of ways (see Figure 2, top left).

The device consists of two pieces, a top and a bottom part. The bottom part is a four layer structure (see Figure 1) consisting of a hard inner shell made from plastic, housing and protecting most of the electronics, covered by two layers of 4mm memory foam, and topped with cloth. The foam layers make the surface soft and pliable so that users to some extent can “squeeze” the device, while the cloth layer affords a soft silky surface that invites tactile interaction.

In between the foam layers eight vibrators catering for tactile feedback are embedded (see Figure 2, bottom left and right). Vibrators can be turned on and off – and their intensity can be set – individually to create various patterns of vibration. Vibrators fill a second function as electrodes for the non-contact capacitive touch sensor circuit that provides the means for tactile input. In addition a thin metallic foil to improve the sensitivity of the touch sensor also covers each vibrator used in this capacity. The foil is thin enough to not interfere with the overall tactile quality of the device.

The top part houses a servo-powered button that is used to alter the depth of the indentation on top of the device. Through a simple modification we were able to read the state of the servo's internal potentiometer thereby enabling it to also function as a sensor, telling us when the button was pushed. A single layer of cloth to create a seamless appearance covers the whole top, including the button. In addition the thin cloth layer allows light from the multi colored LEDs inside the device to shine through.

Figure 2. An assembled Lega, the inner shell, vibrator placement, and touch sensor placement.

Infrastructure

Positioning in the system relied on an infrastructure consisting of small, networked, sensor nodes placed around the art hall (See Figure 3). Each node corresponded to a rough location that usually covered more than one art piece. At regular intervals each node would broadcast its ID using a low transmission power to limit the range of the signal. Measuring the signal strength of all ID transmissions that their Lega could pick up and choosing the strongest one would then determine a visitor's position in the art hall. When a visitor left a trace it was uploaded to the infrastructure node "closest" to their position where it could be picked up by others. The art hall consists of 12 rooms and a lobby that are used for exhibiting art works. Each room was covered by 2-3 beacons creating an equal amount of "places" in the room.

Figure 3. Deployment of infrastructure beacons at the exhibition.

Usage

Lega devices are used in groups of 2-5 people. Each person gets their own Lega and moves around the exhibition freely. To make it possible to identify the source of a trace each device is associated with a color that is shown when a trace is found. The Lega constantly records signals from touch sensors and accelerometers. When the indentation on top of the Lega is pressed a trace based on how the Lega has been moved and touched for the past five seconds is transmitted to the infrastructure. This causes the servo-powered button to move down increasing the depth of the indentation, symbolically creating a "lega". Once the trace has been transmitted to the infrastructure the button resumes its original position. By changing how they move and touch their device different expressions can be created. Currently traces are based on how energetic the movement of the Lega has been and the rate of change in touch sensor activation.

Figure 4. Lega devices being used at the art exhibition

When a trace is found by another user the button again moves down to indicate that there is a trace present. At the same time LED patterns light up to show which of the other users left the trace (see Figure 4). When found, traces are experienced as vibration patterns that attempt to capture the characteristics of actions taken to create a trace. Note that traces have no inherent meaning. They are ambiguous by design to allow for a wide range of interpretations. Instead users make sense of them based on their knowledge about the person that left them, e.g. their likes and dislikes and ways of expressing themselves.

DISCUSSION

Over the two months that the exhibition lasted we performed extensive user studies using a wide range of methods. Here we present early findings along two themes that were crucial for users experiences and future technical development: the individual experience of traces, and how positioning of traces in the art hall played out in the practical circumstances of daily visits.

Experiencing vibrations. Our intention with the Lega was to create an experience reminiscent of someone drawing in your palm using a grid of vibrators. While developing the Lega we made interaction tests that convinced us that this would be possible. However, as we later found out users sometimes had difficulty distinguishing between characteristics of patterns other than their intensity of vibration. Due to the construction of the device vibrations easily propagate through the hard inner shell like vibrations that travel through human bone [1]. This makes it difficult to distinguish exactly where vibrations are coming from. A solution to the problem is to take advantage of this “flaw” and make vibration patterns more distinct by basing them more on intensity and rhythm rather than individual vibrator activations. Another is to find a transducer technology more suited for the intended experience as suggested by reviewers of this paper.

Positioning and people. The positioning scheme that was used is quite coarse. Due to the nature of radio communication this would on occasion result in more distant nodes being selected as the closest one For our design an approximate location was sufficient but when a trace was, as happened sometimes, left in a different room it was of course confusing for users.

On the other hand something we believed could be an issue actually turned out to work in our favor. As the exhibition would at times be quite crowded we worried that transmissions from the infrastructure would be absorbed by the mass of visitors. However, in the end this turned out to be an advantage instead as it further localized the range of broadcasts thereby making positioning more consistent.

Another issue became apparent when group size became larger or when users were very active in leaving traces. In such situations the exhibition would be flooded with traces causing the Legas to constantly find traces and replay them. As an effect it diminished the sense users had of finding something valuable left behind for them. One workaround for this would be to instead let users scan for traces when they want them, or to notify them in some more unobtrusive way that there are traces to be experienced.

CONCLUDING REMARKS

In many respects the Lega design was successful. It successfully merged hardware, software and design elements to create a system that is evocative of the type of experiences that were sought. However, it also emphasized the need for thorough exploration of the qualities of the components that go into the design at an early stage in the design process. For instance, although the vibrator grid was tried out at an early stage, the way in which vibrations were experienced changed dramatically once it was mounted on the hard shell of the Lega device. The challenge in designing systems such as the Lega involves not only exploring experiences provided by different technologies, but also finding ways of keeping those experiences intact throughout the development process.

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REFERENCES

1. Brewster, S. and Brown, L.M., Tactons: structured tactile messages for non-visual information display. in *Proceedings of the fifth conference on Australasian user interface - Volume 28*, Australian Computer Society, Inc. (2004), 15-23.
2. Brown, L.M., Sellen, A., Krishna, R. and Harper, R., Exploring the potential of audio-tactile messaging for remote interpersonal communication. in *Proceedings of the 27th international conference on Human factors in computing systems*, ACM (2009), 1527-1530.
3. Isbister, K. and Höök, K., On being supple: in search of rigor without rigidity in meeting new design and evaluation challenges for HCI practitioners. in *Proceedings of the 27th international conference on Human factors in computing systems*, ACM (2009), 2233-2242.
4. Löwgren, J. Inspirational Patterns for Embodied Interaction. *Knowledge, Technology & Policy*, *20* (3). 165-177.
5. Murray-Smith, R., Williamson, J., Hughes, S. and Quaade, T., Stane: synthesized surfaces for tactile input. in *Proceeding of the twenty-sixth annual SIGCHI conference on Human factors in computing systems*, ACM (2008), 1299-1302.
6. Sundström, P., Jaensson, T., Höök, K. and Pommeranz, A., Probing the potential of non-verbal group communication. in *Proceedings of the ACM 2009 international conference on Supporting group work*, ACM (2009), 351-360.
7. Sundström, P., Ståhl, A. and Höök, K. In situ informants exploring an emotional mobile messaging system in their everyday practice. *Int. J. Hum.-Comput. Stud.*, *65* (4). 388-403.

Paper 2: An Extension of Computer Engineering Methods for Interdisciplinary Design

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An Extension of Computer Engineering Methods for Interdisciplinary Design

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***Abstract*—This is a case study that focuses on design methods developed by a computer engineer engaged in an interdisciplinary design project with a classic designer. Of interest is how the computer engineer initially found the task of achieving the shared design goals to be almost impossible, primarily due to the differences between the codified design methods of the engineer, and the tacit knowledge based methods of the designer. The study describes how the engineer developed new design realization skills enabling him to reconcile these differences in a way that allow the tacit knowledge of the designer to influence the codified engineering process in a repeatable way. These methods referred to as "dreaming" and "mirroring" represent a potentially learnable extension to the classic engineering design realization process.**

Keywords-interdisciplinary design; engineering processes; product realization

I. INTRODUCTION

This paper describes a case study that was undertaken in order to understand how a set of traditional computer engineering design methods can be formally expanded to facilitate interdisciplinary design realization. From a computer engineering point of view, the importance of such an understanding lies in the ability to consistently realize new information technology (IT) artifacts that derive significant value from non-IT sources, such as classic design, art, fashion design and related areas. Products like these that combine a broad range of skills including art, science, engineering and humanities are referred to here as those that result from interdisciplinary design methods. Although many examples of successful products designed by interdisciplinary teams exist, it remains difficult to consistently practice or teach interdisciplinary skills.

This paper contributes to the field of interdisciplinary product design methods by studying and understanding how an IT engineer was able to expand his repertoire of design skills to include exploiting the efforts of a classic designer, and do it in potentially a learnable and repeatable way. The contribution is made by expanding the engineering design phase of the classic spiral product development loop [1]. Of particular interest here is that this study takes the approach that successful interdisciplinary design require new skills that enhance a contributor's existing area of expertise. This is contrary to the assumption that a successful interdisciplinary designer must master trade skills outside of their area of expertise or that a successful interdisciplinary design process is one that is completely new. In other words, a successful designer of interdisciplinary products becomes more skilled in their own field.

The vehicle for this study was a new mobile communication device called the Lega [2]. Communicating mobile devices are excellent candidates for interdisciplinary design, as they can incorporate a wide variety of technologies, styles and use models intended to promote human communication and interaction. The influence of classic design, art and fashion are especially interesting as they represent potentially lucrative market opportunities. The Lega device hardware was realized as an interdisciplinary effort involving a computer engineer having a traditional engineering educational background, and a classic designer trained in industrial design and the fine arts. This study specifically looks at what influential factors from the classic designer resulted in changes and especially additions to the computer engineer's design realization process. The study specifically looks at actions that can be turned into learnable and repeatable methods useful for engineers across a wide range of interactions with classic designers.

II. PRIOR WORK

When discussing interdisciplinary design, it is important to distinguish between innovation and realization as both can involve interdisciplinary effort. Innovation deals with methods to identify the right product or service to provide to a customer, and large numbers of books have been written on various innovation techniques. Commonly known techniques are interdisciplinary in nature, and involve methods such as brainstorming, role playing, sketching and scenario generation [3], and design-driven innovation [4]. Realization is the processes by which the physical product or service is actually designed and built, and how to do this as an engineer in an interdisciplinary environment is the focus of this study. Interdisciplinary design as part of the engineering process and methods to teach such design skills are needed because product factors influenced by classic design not only play a significant role in the market acceptance of many ICT devices and services, but are increasingly driving new product ideas that are proving to have very unique business and humanistic values. High profile examples of these are seen in products such as fashion influenced mobile devices and ICT enhanced clothing [5], and new services exploiting a wide range of sensed context and new forms of human interaction such as online social networking. However, merging classic design with computer engineering to realize new products is a difficult undertaking because of the differences in the way the two disciplines articulate design goals. Design goals in projects involving classic design, art, and social and behavioural paradigms are represented by tacit knowledge, where realization processes are characterized by observation, practice, and direct experience. In contrast, ICT product realization characterized by engineering paradigms is represented by codified information readily expressed and transferred as numbers. Formal product realization processes that combine the two paradigms do not exist [6], which makes successful interdisciplinary realization of such products a very time consuming process, and one where success is largely a matter of serendipity. This is directly due to the differences that exist in how goals are realized between engineering and design, and the lack of method to be able to describe and enable the link between the two.

This study addresses this lack of method in computer engineering by looking at how design processes can be extended to provide new tools for design realization in an interdisciplinary environment. Engineering design processes are generally part of an entire product development process of which there can be several kinds depending on the type of product being developed [1]. IT devices frequently follow a version of these called a spiral development process which is shown in figure 1. The term "spiral" is derived from a characteristic of the entire process which allows for the engineering design, build and test phases of the product to undergo an iterative loop to evaluate and refine early versions or prototypes of the final product. This study recognizes that the ability to contribute to interdisciplinary design does not imply that a person has all skills. Computer engineers are not expected to become classic designers. What is of interest here is how to influence, adapt and enhance processes as they relate to product realization, and take steps towards formalizing methods that can be part of a program of instruction, and made a permanent part of an engineers set of tools. Evidence that supports the idea that interdisciplinary design results in changes to the engineering process exists, for example in a study involving the Hewlett Packard and Swatch companies [7]. It is important to stress that these enhancements affect the output of the classic product development process by influencing the engineering design step, which is represented by a single box in figure 1. In other words, the novelty is at a finer granularity than the entire realization loop itself.

III. DESIGN DESCRIPTION AND GOALS

The task undertaken in this study was to design a new wireless communication device that could support touch based interaction among groups of friends in an art exhibition. The device called a Lega is shown in Figures 2 and 3. The name of the device is a Swedish word used to describe a place in the woods where, from marks or other traces left behind, one can see that an animal has slept there. The Lega device is touch, motion, and location sensitive. Users nonverbally express experiences, impressions or reactions of art works in the exhibition with the Lega by stroking it and gesturing with it. These impressions or traces are "left behind" by wirelessly uploading them to a server. Communication with others in the user's group occurs when these traces are "found" based on proximity to a work of art in the exhibit. When found, traces are experienced as vibration patterns that roughly correspond to the actions taken to create a trace. At the same time LED patterns light up to show which of the other users left the trace. Tactile user interaction, both as input through touch and as output through vibrations, were a key factor of the design. A full description of the design can be found in [2]. The need for classical and industrial design skills in the project came from the requirement that the Lega device be easily hand held, and also have a shape, size, and be made of materials that would encourage users to touch and move it with minimal constraints. Color, surface texture and density were all parts of the design. Contained in the device are motion sensors, tactile actuators, illumination devices, radios, and other IT components which require the computer engineer's skills. The interdisciplinary aspect of the design is apparent from the requirement that materials, textures, sensors and actuators work together and complement each other in such a way that the Lega device's use experience is valuable, unique, and is itself a work of art.

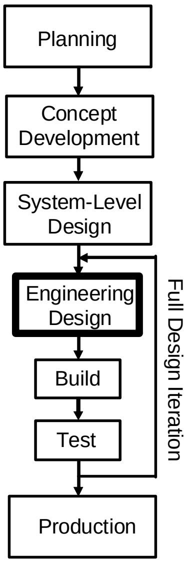

Figure 1: Classic spiral product development process

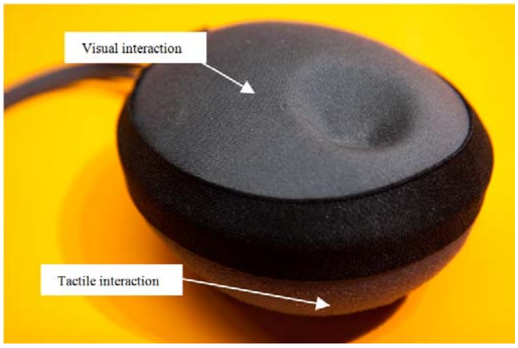

Figure 2: The hand held Lega device

Figure 3: The Lega device in use

Realization of the physical Lega device object was a shared effort involving a computer engineer and a classic designer. The computer engineer is a doctoral student with several years of embedded computing design experience, but no industrial or classic design experience at all. The classic designer has training in both industrial design and the fine arts, and currently runs a successful design consultancy business. However, the classic designer has no experience with any form of computer engineering. This study was used to determine what, from the perspective of the computer engineer, was new or changed in his own design realization methods that were caused directly or indirectly by the industrial designer during the shared design task.

IV. PROCESS FROM THE COMPUTER ENGINEERING PERSPECTIVE

The realization of the Lega device spanned two calendar months. At the start of the Lega design, neither the computer engineer nor the classic designer had ever worked with each other before. Although the innovation leading to the concept and use model of the Lega system had been defined in a larger brainstorming event, no details of the device's actual embodiment were known in advance. It was only known to be something that a user could carry and touch. At the beginning of the design phase the computer engineer had no real idea of what the Lega actually was. Aspects of functionality were known, and so the engineer proceeded with the design in a traditional way by looking for design metrics and proposing technologies to satisfy them. The process did not work. At this early phase, the engineer could not understand or make sense of the classic designer's processes, the output of which seemed to be not realizable or impossible. From the point of view of the engineer, the designer was just "dreaming" with no connection to reality. As the engineer discussed technology with the designer, he was expected to deploy the technology in the context of the dreams, which to the engineer did not seem possible because they violated his codified rules of design. This made the early realization situation worse because the engineer started to feel that he was little more than a "slave" to the designer. The designer was generating design ideas that the engineer viewed as nonsensical, but he was expected to realize them anyway. Overall the engineer felt that he was not part of the interdisciplinary design process.

At this point towards the middle phase of the design time line the engineer began to take steps in order to have some kind of influence on the design. What significantly marked this part of the design is that the engineer stopped talking about technology in the process with the designer. Instead, he joined into the design process with the designer, but not in a way where he tried to become a classic designer himself. Instead he endeavored to learn how to contribute to what he saw as the designer's "dreaming" through a process of active listening. This involved learning how to listen to the dreams and in turn how to begin a process of dreaming bounded by his competence. By doing this the impression of being a slave disappeared, and he felt that by a combination of active listening and dreaming he was finally contributing to the design process without trying to be an industrial or classic designer. This is new to the engineer as this process does not involve codified design metrics yet, and no specific technology is discussed.

In the later phase of the design time line the engineer evolved a process of how to convert the dreams into design metrics. The engineer would create a subset of metrics by using the dreams to instantiate small pieces of technology. This was done either by using a CAD drawing, or by actually building a small amount of hardware. The engineer then used this instantiation to "mirror" the reality of the design dream back to the designer. By becoming a design mirror, the engineer learned a new process tool that serves as a form of design visualization for the designer. At that point the designer could understand the impact and limitations of the technology on the design. This would initiate another wave of dreaming, and the process of dreaming and mirroring continued until all the engineering metrics were known and the design could move on to the build and test phases of the development process leading toward a full prototype. The engineer felt that from his point of view he now had two new design processes that he did not possess before the start of the interdisciplinary design effort. These design processes are the steps of *dreaming* and *mirroring* and they directly alter the engineering design process used by the engineer. The enhanced design process as part of the classic development process is shown in figure 4.

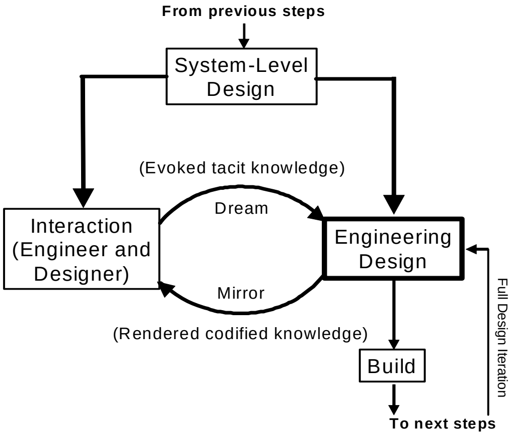

Figure 4: Engineering with dreaming and mirroring steps

V. Process Discussion

Through these new engineering skills of dreaming and mirroring the engineer now has both the ability to contribute to the interdisciplinary design in a way consistent with the processes of the designer, and also in a way that has impact on the design itself and leads to engineering design metrics. From the point of view of the engineer, in order to effectively contribute to and have influence in an interdisciplinary design project, the engineer must be involved in the design process from the beginning, even if the engineer doesn’t initially understand it. By learning to actively listen and become assimilated into the designer’s dreaming process the engineer will in turn learn how to dream. As a form of tacit knowledge, dreaming is learned by doing. The engineer learns how to dream from participating in the act of dreaming directly with the designer. This is consistent with and accommodating toward what Utterback et al [8] describe as a dreaming process that characterizes how a classic designer will begin a new project. By adopting a complementary method for dreaming within the context of computer engineering, the engineer stops being confused by the process, is able to exploit the skills of the designer, and begins to effectively contribute.

Learning to dream is only part of the extended engineering process. Because the designer could not see the meaning of technology as an engineer, the designer could not understand what was or was not possible to realize. Thus at the beginning of the design process the ideas of what the product represented was very different between the engineer and the designer. From the engineering viewpoint, this was resolved through the process of mirroring. This is an effective method for engineers in interdisciplinary design realization because of the role that visualization plays in the process of classic designers. Utterback also supports this by explaining that in classic design, visualization elicits “a rich variety of tacit knowledge from participants”. By mirroring the dreaming phases in the design through visualizing bits of codified technology, the engineer evoked tacit knowledge from the designer in response, thus establishing a coherent link between codified and tacit knowledge in the final realization. Finally, these new methods are not a departure from the traditional IT product design, build and test loop. Instead these methods occur as tools used in the engineer’s design process. They are new skills enabling the engineer to convince and communicate accurately in an interdisciplinary design setting.

VI. Conclusions

This work is the start of a larger effort to extend engineering processes to accommodate interdisciplinary design. The next step is to devise mechanisms for how the dreaming and mirroring processes can be taught and learned as engineering skills. It is also important to extend these ideas further into more aspects of design that contribute to products like the Lega device that enhance communication. This is a rich area for interdisciplinary design, which can combine the application of IT with components such as textures, colors, form and style. This may involve extensions to the processes of dreaming and mirroring, or the evolution of completely new methods that could extend all parts of the traditional product development process. It may also turn out that new and different process steps are needed to translate between all different disciplines used in future interdisciplinary design realization efforts. More work will be needed to discover what these process steps are.

References

[1] Karl T. Ulrich., Steven D. Eppinger, “Product Design and Development,” Third Edition, McGraw-Hill/Irwin ISBN 007-247146-8, 2003.

[2] Jarmo Laaksolahti, Jordi Solsona Belenguer, Marcus Lundén, Anna Karlsson Anna, Jacob Tholander, “The LEGA: A Device for Leaving and Finding Tactile Traces,” Accepted for publication at the Fifth International conference on Tangible, Embedded and Embodied Interaction, TEI '11, January 23, 2011, Funchal, Portugal.

[3] Willian Buxton, “Sketching User Experiences: Getting the Design Right and the Right Design,” Morgan Kaufmann, ISBN 978-0-12-374037-3, 2007.

[4] Roberto Verganti, “Design-Driven Innovation: Changing the Rules of Competition By Radically Innovating What Things Mean,” Harvard Business School Publishing, ISBN 978-1-4221-2482-6, 2009.

[5] Savine Seymour, “Fashionable Technology: The Intersection of Design, Fashion, Science, and Technology,” Springer-Verlag/Wien, ISBN 978-3-211-79591-0, 2009.

[6] Henry Chesbrough, Jim Spohrer, “A Research Manifesto for Services Science, Communications of the ACM,” Vol. 49, No. 7, pp 35-40, July 2006.

[7] Mark T. Smith., “Reconciling ICT and Wearable Design: Ten Lessons from Working with Swatch,” Proceedings of the ISWC07 Workshop on the Role of Design in Wearable Computing, held in conjunction with the IEEE International Symposium on Wearable Computers, October 13 2007, Boston MA, USA.

[8] James Utterback, Bengt-Arne Vedin, Eduardo Alvarez, Sten Ekman, Susan Walsh Sanderson, Bruce Tether, Roberto Verganti, “Design Inspired Innovation,” World Scientific Publishing, ISBN 981-256-695-3, 2006.

Paper 3: Inspirational Bits — Towards a shared understanding of the digital material

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Inspirational Bits
Towards a shared understanding of the digital material

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ABSTRACT
In any design process, a medium's properties need to be considered. This is nothing new in design. Still we find that in HCI and interactive systems design the properties of a technology are often glossed over. That is, technologies are black-boxed without much thought given to how their distinctive properties open up design possibilities. In this paper we describe what we call *inspirational bits* as a way to become more familiar with the design material in HCI, the digital material. We describe inspirational bits as quick and dirty but fully working systems in both hardware and software built with the aim of exposing one or several of the dynamic properties of a digital material. We also show how they provide a means of sharing design knowledge across the members of a multi-disciplined design team.

Author Keywords
Digital materials, Design, Design materials, Design approach, Multi-disciplined design teams, Bluetooth, RFID, Accelerometers, Wireless sensor networks, Sensor nodes, Radio communication, Radio signal strength

ACM Classification Keywords
Design Methods, Prototyping, Interaction Design

General Terms
Design

INTRODUCTION
As a research group tasked with designing interactive systems, we are made up of an eclectic assortment of differently skilled individuals - a multi-disciplined arrangement that now arguably typifies a significant proportion of R&D groups in HCI. Not only do our members consist of the prerequisite software engineers and interaction designers. We also have people skilled in hardware, experimental psychology, qualitative fieldwork and even choreography.

Assembled in this way, one issue the group regularly faces is how to work, collectively, to imagine new interaction possibilities and different applications of emerging technology. Too often we find ourselves reverting to the established sub-divisions of social science, design and engineering, and conforming to a design approach where insights into users' experiences are applied to drive design and development. We may use lab-based or in-the-field studies of people's activities to inform an interactive system's design, or use evaluations of working prototypes to shape new design iterations. However, the actual building of the technical systems, even when iterative, is bracketed off.

Although this approach will be familiar to many and recognized as one that has produced valuable outcomes, we have found it troubling on two counts. First, it feels that much of the emphasis at the early stages of design exploration is placed on what users do and, consequently, attention is directed away from exploring and thinking imaginatively about the technologies. Often the technologies are chosen to solve a user need or support some experience before thoroughly examining their distinctive properties and how they might open up the design possibilities. In effect, the technologies are treated as black boxes, configured to enable predefined interaction scenarios.

Second, we find it leads to a largely linear and one-directional form of communication within our group. At best, the ideas used to open up the design possibilities flow from the studies of users to those who build the interactive systems. The actual implementation of a system remains closed; as a group, we rarely get a sense of the technologies until they are an integral part of a working prototype. Thus, there is little discussion between the skill sets in the group about what the properties of the technologies are and, again, whether they might open up new possibilities. In short, there are few chances in the design process to simply explore the technology, collaboratively.

In this paper, we present our recent and ongoing efforts to address these two concerns. We describe an approach to interactive systems design using *inspirational bits* that aims to foreground technologies as design materials early on in the design process. We see the approach as complimenting the design strategies many of us in HCI have become

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familiar with and, importantly, encouraging dialogue within multi-skilled interaction design teams. What we hope to convey in reporting our own experiences is that inspirational bits might be seen as a generally applicable method, relevant to groups involved in interactive systems design other than ours.

BACKGROUND

To address what we have felt to be our group's lack of collaborative experimentation with technology, we have in a number of recent projects attempted various strategies to expose and experiment with the properties of technologies. That is, we have sought to identify some of the defining features of a technology and then informally experiment with their configurations. We have found this technological un-blackboxing, if you will, has provided us with a richer set of possibilities when designing interactive systems; in effect, exposing the properties of the technology has opened us up to discovering new and in some cases unexpected directions for our designs.

A recent example is a project in which we used wireless, motion sensors to capture and display the emotional character of a community's physical movements [16]. Initially, we had hoped to use the radio signals from the sensor devices to triangulate location and then visually display the physical proximity between people alongside a visualization of their movements. However, we found this location detection to be far too unreliable because of the manner in which radio signals travel. Instead, through a series of experiments with radio and the sensors, we found we were able to detect and reliably communicate concurrent movements between people. This allowed us to cluster common kinds of movements and visually present them to the users, enabling them to interpret both the kinds of emotions being physically expressed and the prevalence of the expression in real-time.

One lesson we drew from this project was that in starting with a particular end goal in mind we found ourselves thwarted by the particular constraints of radio transceivers - constraints that only became apparent as we sought, unsuccessfully to determine location and physical proximity. Instead of viewing these constraints as a barrier to progress, however, we decided to take a different starting point. In short, we chose to think of the constraints as basic properties of the technology and to purposefully exploit them. Rather than stick to a predefined design and user experience to be achieved with a chosen technology, the system emerged by starting with a treatment of the technology as a material, alongside the other factors shaping the work. The final design came about because we eventually allowed the properties of the technology to play a stronger role in shaping the outcome and be a formative resource driving the overall design process.

On the face of it, such a process may seem unremarkable. Yet, what has struck us in looking back is how this particular treatment of technology as a design resource is not something we have really pursued with deliberate intent, nor regularly brought up in shared discussions among the interdisciplinary members of our design team. Indeed, in our experience the default position has often been to think of the technology as a means to solve a defined problem such as detecting location. It has been only when we have started getting our hands dirty, so to speak, that we have found ourselves tweaking the underpinnings of a technology and almost accidently arriving at some promising possibility. Consequently, such an exercise has not been pursued as a systematic component, where it is deliberately used as a resource for expanding or *"opening up the play of possibilities for design*" (to borrow a phase from another context [2]).

In articulating this, we want to be careful to distinguish our reflections from the conventional forms of techno-centric innovation that HCI has made it its business to address. We see this re-centering of technological concerns as remaining very closely tied to user and design concerns, and human centered/experience-oriented design, specifically. However, in bringing together the user, design and technological concerns, what we aim to explore in this paper is whether we might start from different points of entry – and in this particular instance, from the material and architectural properties of the technology (cf [5], [6]).

RELATED WORK

Most of us will readily accept that algorithms, databases, hardware, communication standards, etc. have their own limitations and possibilities. Embedded in each are properties that are more or less fixed, even though the possibilities for combining them are almost endless [11]. Also, development work rarely starts from scratch; instead, we build using existing libraries, established communication protocols etc. each with their own pre-defined properties.

In this vein, Vallgårda and Redström talk of *computational composites*, alloys made up of a combination of digital material that impose particular properties [18]. Thus, they explain that it is almost impossible to work with the digital material in its most raw form, at the granularity where technology *"handles only voltage according to stored sequences of (practically) discrete voltage levels and maybe input streams likewise of (practically) discrete voltage levels"* (p. 516). Components such as accelerometers, short-range communications etc. build on top of this basic level, and, in turn, become subsumed into yet more abstract interactive systems, such as PCs, mobile phones, etc. Because of this layering of technology, what we find in HCI and interactive systems design is that the particular properties of low-level technologies are often glossed over.

This appears to stand in stark contrast to the techniques and approaches that permeate studio-based and creative design practices [3]. Through sketches, mock-ups and early prototyping, traditionally schooled designers engage in a *conversation with materials* [15]. In the formation of a new idea the materials are worked with is such a way that they start to *talk back*, revealing new opportunities and challenges. It seems, however, that computing technology is a more complicated material for many designers to work with [8]. It is a material that evolves over both space and time [7]. It is not enough to touch and feel this material in any given moment and thereby get to know its properties and potentials; instead; the digital material has to reveal itself and its dynamic qualities when put together into a running system.

One popular approach to supporting developers and designers building interactive systems has been to work on so-called support tools. Yet, most of these systems aim to support designers in the processes of visualizing and refining an interactive system's design (e.g. [9], [13]), not to handle and explore the digital material. There are also a range of systems that enable designers to rapidly reconfigure the construction of their designs, such as varying the color, form and overall build of an object, and also visualize previous versions of a design (e.g. [17]), but still this does not provide access to the full range of possibilities the digital material might offer. The designer remains, in some fashion, removed from the actual technology.

The range of *plug and play* building block solutions provide an alternative, hands-on approach to building systems and, in doing so, go some way towards solving the immediacy problem. These systems, such as Phidgets[1] and Arduino[2], let the amateur hardware developer/maker handle and come to understand more of the digital material's potentials, making the material more open to what Schön refers to as *reflection in action* [15]. But, they still compartmentalize and blackbox basic building blocks such as RFID, Bluetooth, accelerometers, etc. Arguably, this is intended in their design and the basis of their success.

In the following, we thus present a strategy or approach to support the creative and collaborative experimentation with technologies that are usually embedded and thus taken for granted in the design process. As we have suggested, this approach has emerged through our own varied experiences of designing interactive systems in a multi-disciplined group. For example, it builds on our efforts to learn from designers and their use of sketches, storyboards and mock-ups to open up a design space and how they find inspiration in a range of new design ideas. It also draws on the attempts we have made to design *hand in hand* with the digital material [16]. It has been informed too by the increasing number of experiences we have had with hardware kits such as Arduino and Phidgets. Rather than using the kits to build specific solutions, however, our experiences have been centered on getting to know the workings of the technologies and their peculiar properties. Last but not least, it hinges on our processes of engaging all members/disciplines of our group in the generative stages of design thinking.

For the purposes of this paper, the phrase we have adopted to articulate this roughly circumscribed and still evolving approach is inspirational bits. Our idea is for an inspirational bit to offer the basic elements of a technology in a shape that allows all members of a design team to *look* at it, *feel* it and experience it over time and space - exposing all or some of the properties of the technology as a material. The inspirational bits approach thus involves the design team's attempts to work with and handle the technology; exposing its parts, and figuring out how it really works. To communicate the properties of the material to the design team, a fun and inspirational application of the technology is then used. The examples we present are made up of a range of quick and dirty games as we had the idea that the incentives people naturally have to understand the rules of a game would be helpful in conveying technological limitations and properties.

More specifically, this paper describes how we started out to explore Bluetooth as a design material and how we used the feedback we received in our continuous work refining the approach as well as going on to build bits using RFID, accelerometers, and wireless sensor networks. It also describes a two-days workshop to which we invited designers from both research and industry to introduce them to the idea of using inspirational bits in design. From this workshop, we describe how the feedback from one of the more experienced designers has helped us to be clearer about what we want the inspirational bits to be.

INITIAL EXPLORATIONS

Something that contributed early on to this idea of inspirational bits was an exploration we undertook into Bluetooth. Bluetooth was chosen as a technology for a number of reasons. Broadly, we were attracted to the ubiquity of Bluetooth and its status as a standard for wireless, short-range data communication. We felt this provided us with a technology that is often seen as a closed system or black box with numerous taken for granted properties. Again, the intention was not to solve a specific problem using Bluetooth or to achieve some predefined endpoint. It was rather to see whether a focused investigation into Bluetooth, as a design medium, might open us up to anything different and/or unexpected—that is, to find what could be inspirational in this technology.

One thing we found interesting was how a Bluetooth device cannot search and listen at the same time. One device needs to be searching and one needs to be listening for two devices to find each other. Incidentally, this is a property of Bluetooth that is problematic when it comes to peer-to-peer connectivity as both systems may be searching or listening at the same time and therefore not find each other (as in e.g. the MobiTip system [14]). BluePete is an inspirational bit we have built that aims to expose this material property of

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[1] www.phidgets.com

[2] www.arduino.cc

Figure 1. BluePete; on the left a device having him and on the right a device about to get him (being this close)

Bluetooth and also in order to show how it can be played with that the Bluetooth technology needs two clients to be in different modes in order for them to find each other. In this quickly implemented game searching devices "carry" BluePete and listening devices are in danger of "catching" him, which can happen when the two devices are close enough, see Figure 1. Playing this game allows a design team to experiment with the relationship between proximity, connectivity and exchange (e.g. sneaking up on someone, physically hold on to them or taking their phone). Playing the game also allow all parties of an multi-disciplined design team to think of new ways of exploiting these Bluetooth properties and other scenarios where the properties might add to the experience of a system's design.

BTScore is another of our Bluetooth bits. The BTScore bit reveals the Bluetooth devices that are nearby and of what kind they are, e.g., headsets, printers, mobile phones, etc. The bit thereby helps to explain what information one Bluetooth device will send to another, such as device class, services provided and more, and thus reveals a property that might be used for the purposes of design. In BTScore a device's class number allocates a predefined point value when a connection is made with it. To increase their scores users thus have to run around looking for potential Bluetooth devices to connect to. Coincidently, the device class numbering scheme for Bluetooth devices works well with this game design as rare devices tend to have a higher number than common devices, such as 7936 for an Bluetooth Arduino board versus 512 for a smart phone. The bit, then, conveys something of the practical details and the real-world workings of the Bluetooth protocol and, specifically, how devices differentiate themselves through connections and communication.

These examples hopefully capture some of the key ideas we think to be of value in the inspirational bits approach. First and foremost they illustrate the understanding of the material one can get from using them. They show too how this can be achieved with quick and simple systems. For example, BTScore was built in a day or two and relies on a crude graphical interface to convey details about the device class numbering in Bluetooth. Also by presenting the two examples, we hope they capture the experimental quality of the approach. It should be clear that different features of the technology led to different strategies for exposing and working creatively with the properties and constraints. In this way the approach is seen as open-ended and relatively unstructured. Again, the aim is to be generative and to let the material's properties serve as a guide in this creative process.

BITS EXPOSURE

To introduce other designers and researchers to the inspirational bits approach and to get their perspectives on working with technologies as design materials we have presented our Bluetooth bits at two workshops: the Materialities workshop[3] at the Designing Interactive Systems conference 2010 and at the Artifacts workshop[4] at CHI 2010. At both workshops we received very positive feedback. Broadly, the responses suggested the approach was seen as valuable in helping to understand technologies as a medium for design and in generating new design ideas.

At the Artifacts workshop the Bluetooth bits were the starting point for a design exercise; the workshop participants, having used the bits, were told to brainstorm around Bluetooth technology and develop design sketches. In total, a broad range of ideas was generated. Here though we wish to focus on the workshop participants' impressions of using inspirational bits to inspire design. One overall impression was how the ideas that came about seemed to be more grounded in the material. This in comparison to ideas that came out of a similar exercise in the workshop using inspirational pictures of various kinds.

We have also used the Bluetooth bits as a starting point for a design project in the Affective Interaction course given at Stockholm University. Here, the students showed a fascination with the bits. They said they liked how the technology had been transformed into experiences, and how it was the experiences—in this case of Bluetooth, such as the experiences of hunting or being pushed something—that inspired them. However, the students reported struggling to develop their own designs recounting how it was one thing to understand and another to recreate/make use of the bits.

This latter result, in particular, got us thinking about the principal intention of the bits approach. It had never been our intention that the bits would explain how to work with the material; our aim was to use inspirational bits to promote a greater familiarity with the technology and to communicate this knowledge within the design team. In contrast to plug and play toolkits, such as Arduino and Phidgets, we hoped for users of the bits not to become individually accomplished system engineers. Rather, we intended for the design team itself to mark out time to build and come to understand some provided bits and then communicate this knowledge to all members of the team

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[3] http://sites.google.com/site/materialitiesdis2010/

[4] http://people.cs.vt.edu/~swahid/chi2010-artifacts/

and subsequently use this knowledge in the design process. We also imagined this to be a cumulative process where teams and individuals in the teams retained skills and knowledge around particular technologies and their bits.

GOING BROAD

With this early indication that we were on to something useful and something design teams possibly want, we decided to expand our exploration to include other digital materials. In the following, we describe our application of the inspirational bits approach using RFID, accelerometers, and wireless sensor networks, further detailing the approach as well as showing how it has evolved. For each technology we first give a short summary of some of the characteristics and properties of the technology and then mention just a few of the bits we built using the technology. Each section ends with a summary of the bits discussed and what property they aim to convey. The presented examples have been chosen, in part to convey the diversity of bits that can come from working with quite different digital materials and how such a diversity can be the source of creativity. Our hope is the range and variety of bits may help to communicate the underlying notion of this work, that the digital material really is a *material*, and a material we need to consider in design like any other.

RFID

Radio Frequency Identification (RFID) is a material that has been experimented with in the past (e.g. [12]). In the work we present, however, the distinctive intention has been to consider what happens when the technology's properties are exposed in the design process and to design teams.

RFID is a technology that uses radio waves for sending and reading information at a distance. This communication occurs between a reader and a tag. The angle of a tag's antenna with respect to the reader's antenna is critical for a tag to be read. The diZe is an inspirational bit that was designed to convey this property. This bit is a board game that consists of a high frequency RFID reader with a very large antenna and a dice with pockets on each side, see Figure 2. In this bit, the reader's antenna defines the area of the game board. A player chooses one of the pockets of the dice for a RFID tag and then throws the dice onto the board. This only gives the tag a one-in-three chance of being read. Because of the direction of the magnetic flow that the reader's antenna creates, current will be induced only when the antenna's tag is perpendicular to the magnetic flow. With these properties in mind, the game can be introduced as it is or in a context chosen for a design task specifically.

RFID might not be as complex as a design material as perhaps some of the other materials presented in this paper. But the diZe in a very good way exemplifies how a bit does not need to be complex. How a bit, in fact, can be something very simple. Through something as easy as varying the size of a familiar technology can make its workings intelligible but also open it up for new ways of thinking about its use. But also how a deeper knowledge in materials offers us the possibility of twisting and tweaking the underpinnings of that material to open up for more innovative ideas. But, in order to be inspirational the question is, if this bit is enough? We will return to this question later in the paper, but what we see here is a possible difference between bits that are designed to explain and bits that are meant to inspire. What we see though is that it may be a range of bits that is in fact what is needed to fully understand the range of possibilities of a material.

Another slightly more complicated bit we developed using the large RFID antenna is our strategic game, inteRFere. This is a two-player game where each player has a set of three tags and must role them in such a way that their tag is the last one read. The game is designed to demonstrate the properties of antenna interference, variations in magnetic field strength and that readers can only communicate with one tag at the time. For example, this bit reveals how two tags on top of one another can cause interference and also that there is an inverse relationship between magnetic field strength and the distance between the tag's and reader's antennae.

To emphasize the diversity of the bits we have built, before continuing we also want to briefly mention BendID. BendID is a game that aims to break away from the conventions of handheld technologies and, in the case of RFID, the common assumption of one-tag-per-user. In

Figure 2. The diZe – a playful presentation of the reading angle of RFID; BendID – a bit where the user wears tags over her whole body; A mechanical model of an accelerometer showing how gravity always is a factor

BendID each user has tags placed over her body. When a game master calls a specific body part the aim is to be the first player to have that body part read without stepping out of a small circle on the floor, where the reader is placed, see Figure 2.

To summarize:

- diZe – demonstrates how the relationship between the tag's and reader's antennae is critical;
- InteRFere – demonstrates the properties of antenna interference, variations in the magnetic field and how a reader can only communicate with one tag at a time; and
- BendID – plays with the conventions of hand held technologies, in this case with several RFID tags distributed over the body.

The Accelerometer

The accelerometer is a sensor that measures change of velocity (acceleration) relative to freefall (or zero gravity) and transforms this measure into a proportional electric signal. The device is usually attached to an object, the acceleration of which one wants to measure.

To visualize the basic mechanics of an accelerometer and also to show how gravity continuously acts on the acceleration that is measured, we found that we needed something as basic as a mechanical model. This model consists of a transparent tube, a mechanical spring and a small weight. One end of the spring is attached to the top of the tube, and the other is attached to the weight. When the tube is moved, the displacement of the weight corresponds to the acceleration that is affecting it. With this tube we wanted to show how it really is acceleration and not movement that an accelerometer captures, something one would think is obvious, but as the accelerometer is used very often to capture movements and also does so rather well [16] the misunderstanding is common. Our test tube, so to speak, also illustrates how accelerometer measurements are always influenced by gravity, as it reveals that when turned towards the ground an effect is apparent even though it is being held perfectly still (see Figure 2). A combination of three such test tubes visualizes the same characteristics of a three-dimensional accelerometer.

Another interesting property we found was how accelerometers in fact sense movement slightly differently, even when moved together. This is a typical issue that can become frustrating in a design situation if it is exact data that is wanted/needed. With our WaveRave bit we aim to show how this can be a design feature. WaveRave is a multiplayer game where the aim is to follow the movements of a leader as closely as possible. To make this game a full body exercise, the accelerometers are attached to the players' chests rather than held in the hand, where it is easier to control the accelerometer using small hand gestures. Players must thus "follow" the physical movements of the leader as best they can. Scores are continuously updated depending on the similarity between a player's accelerometer readings and the leader's. However, imperfect measurements and imperfectly calibrated devices add an extra dimension to the pleasure of playing this game. Players' devices can also be attached differently than that of the leader. For example, by turning the leader's device up-side down, players are forced to perform movements that are inverted to that of the leader.

To summarize:

- The mechanical model - visualizes the basic mechanics of an accelerometer and how gravity always acts on the measured acceleration; and
- WaveRave – shows how imperfect devices can be inspiration to a game and in a way the game feature.

Wireless Sensor Networks

Wireless sensor networks consist of sensor nodes that can communicate and share data with each other in various ways. Each sensor node is a small electronic system containing a transceiver, a microcontroller and different kinds of sensors. For the following bits we have been working with sensor nodes communicating over radio. More specifically, we have been working with electromagnetic radiation, radio waves that propagate in space and travel at the speed of light.

In several of our previous designs we have encountered problems with wireless sensor networks and radio (e.g. [16]). The fact is that radio signal strength is currently one of the most common ways to perform outdoor and indoor positioning. This works relatively well outdoors, but indoors the technology is susceptible to interference from many sources. For this reason, we have found radio particularly hard to think through and design with in the multi-disciplined teams we have worked in. In short, the very immaterial characteristics of this material accentuate the problems; even though the sensors can be seen and their use can be discussed in various scenarios, it is not always easy to see/feel how the radio communication works, and why it is so hard to calculate distance and position (indoors). Therefore, in starting our design exploration into sensor networks, we first set out to try to make this problem more visible, more material.

We built two bits for this purpose, one turning the radio signal strength into sound and one into graphics. The sound bit, RadioSound, consists of two sensor nodes where one is equipped with a small speaker emitting a single tone. The tone increases with the signal strength between the two nodes. Using these sensor nodes one can walk around in the environment noting how the volume changes as the signal is affected by other materials, walls and furniture. Using this bit one can also hear how the signal strength is greatly affected by the human body. In order to also explain how the signal strength measurement is difficult to measure for fast moving and moving sensor nodes, we also decided to build a bit using a graphical representation of the radio signal strength. In this second bit, that later evolved into the GoldRush game, the size of a graphical circle visualizes signal strength. As the circle sometimes disappears, completely, this graphical representation very clearly shows the fluctuations in the signal strength measurement when a node is moving quickly in relation to a receiver node and how a signal stabilizes when holding it still. Also the circle flickers more if the two nodes are far apart.

As one of the intentions with the bits is to turn limitations into possibilities, we explored using these thought of limitations of the radio material as possible features. In GoldRush, for example, a sensor node is hidden, and then looked for by the game's players using a combination of another sensor node and the graphical representation described above. This hide-and-seek game is made more challenging by giving the four players their own sensor nodes and graphical representations of the hidden node. This demands that players cooperate by, for instance, asking others to stand back not to lessen the interference cause by their bodies or sharing their individual graphical representations to find the hidden sensor node faster.

Playing with this bit, we also found that we could use the flickering of the circle as an indicator of whether a sensor node was moving slow or fast. This we used in a second game, Gymkhana, in which the aim is, initially, to move as fast as possible to disturb the signal reception as much as possible and thereby gain points. Players then aim to limit the amount of points they lose by moving between a set of distributed sensor nodes, undetected.

To summarize:

- RadioSound – visualizes the radio signal strength between sensors and how it is affected by the environment and the human body;
- GoldRush – turns the difficulty of using radio signal strength for positioning into a game feature; and
- Gymkhana – visualizes and plays with how the measurement of radio signal strength is different/difficult to measure correctly when there is a lot of movement in the room.

WORKSHOP @ MOBILE LIFE

Our most recent activity targeted at exploring the inspirational bits process has centered on a workshop in which we wanted to get feedback about both the bits and the approach as a whole.

In August 2010 we invited our colleagues and partners at the Mobile Life centre to a two-day workshop where we allowed everyone to experience and learn more about the materials we had worked with so far. Approximately twenty designers and researchers took part in this event. To allow everyone to handle, experience and play with the bits, we divided them into three smaller groups and gave each group time to work with the RFID hardware, accelerometers, and sensor nodes. Each material session lasted for approximately two hours. The first day each group got two such material sessions and one the day after. The second day we also gave each group a design exercise to find out if they felt they could apply what they had learnt.

For this paper, we have asked one of the workshop participants, Anna Karlsson from BORIS design studio[5] in Hong Kong for her thoughts on the idea of using inspirational bits in design and also on the workshop in general. We chose to solicit feedback from Anna for a number of reasons. One important reason was that she does not usually work as a researcher but rather as a professional designer in an international design firm. With her extensive experience in doing design and also working both in multi-disciplined design teams and in collaboration with other stakeholders in a design process we regarded Anna a good person to ask for feedback. Anna has also worked with us on a number of occasions on different projects, and held the role of design research consultant with us. We present Anna's feedback, below, not as a formal evaluation of the idea of using inspirational bits in design, but instead as a means to convey how the idea was responded to in practice, and also as a resource to better articulate our own ideas on this matter.

Below, we have chosen to focus on three themes Anna raised in her feedback: *the idea in general*, *a categorization of the bits*, and *a template for constructing bits*.

The idea in general

First a quote from Anna's feedback to the general idea:

"The inspirational bits approach is about play; it is a positive way to approach a technology. During the play you will learn certain things about the material and the learnings are something you will bring with you to the next step in the design process. Keeping the bits intact could though have the opposite effect for the design team, the team can get stuck on the initial ideas and not be able to move on to the next step. It is therefore important as I see it to point out that after experiencing the bits they should be broken down into their basic material parts; these are what you can use as the foundation for innovation.

The inspirational bits approach is a good way to start a complex project, it helps the team to get a better idea of the material's properties, possibilities and limitations and it also lays the ground for more equal discussions within the group. This is maybe one of the most important aspects you can get from using the inspirational bits approach.

The inspirational bits can also help the design process to become less linear. By integrating construction and production at the start of product development, this cross disciplinary way of working creates a common platform of knowledge for the whole team."

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[5] www.borisdesignstudio.com

A categorization of the bits

In her feedback, Anna also explained how she experienced the bits to be quite different to each other and was therefore compelled to categorize them. She explained how a categorization of the bits would help her and others decide what category of bits that should be used in different projects, or different phases of a project. This is something we had started to contemplate ourselves. We had begun to categorize the bits in terms of whether they served some explanatory role or whether a particular property served as inspiration. From this in mind, we found Anna's feedback as an outsider to the approach to be particularly interesting. In effect, we have found it to provide a useful counter-position to our own.

Anna's categorization consists of four categories; *core bits*, *educational bits*, *boundary bits* and *beyond bits*.

Core Bits - "Give it to me in one sentence or 3 secs"

These are bits that can be described in one sentence or quickly grasped in three seconds, Anna explains. An example of such bit is the oversized mechanical model of the accelerometer.

"Using these bits the approach is similar to a design method where you establish the very basics of things as a way to inspire innovation. It is similar to the task of designing a chair where one had to explain what a chair is in one sentence, a sentence that really grasps the concept of a chair. One such sentence could be: 'A horizontal plane big enough for one person to sit'. This explanation opens up for innovation rather than frames you in an idea of what a chair is. The core bits as I see them are about explaining technology in that very same way and thus opening up for innovation."

Educational Bits - "Explain it to me, I am an idiot"

Anna explains how these are bits that share a focus on learning, they convey the basics of a technology. The fewer aspects of the material that are highlighted the better and the easier the bit is to grasp. There should be no value *vis-à-vis* a final design when creating an educational bit. An example of an educational bit is the diZe. The level of complexity in this bit is low, it is immediately or very quickly understood.

Boundary Bits - "Show me the Limits"

The boundary bits are about highlighting a downside to the technology. They serve to break pre-defined ideas about a material and to start group discussions. An example of such a bit is the RadioSound bit.

"The boundary bits are similar to the educational bits as the defining characteristic is learning. The boundary bits are powerful in the way that the whole team gets a full understanding of the limitations of a material before proceeding with a design conceptualization. Another great advantage of the boundary bits is the time that could be saved in the development process of a new service or product: 'show me the limits so that I can avoid traps.'"

Beyond Bits - "Turn the limitation into a feature"

The last of Anna's four categories she calls "beyond bits". This category she explains are bits that are very creative and can trigger a lot of spin-off ideas. They thus tackle the limitations of a material and turn them into features. A good example here is the Gymkhana bit.

"To summarize the first three categories, they are all about understanding a technology, here refereed to as the material. These bits should be built and explained by those who know the material well. The fourth category is slightly different and could be used as the subsequent phase, after presenting bits in the first three categories. The beyond bits could work as a good kickoff in the concept design phase in a development project where the developers get together with the rest of the team to take things one step further. The beyond bits are about making use of the things the design team all learnt from the earlier bits."

We are very grateful to Anna for giving us this extensive feedback; it has helped us to be clearer about what we want the bits to be. We find her categorization useful because it captures the diverse role bits can play at various levels of applicability and complexity; we see how some are more inspirational and others better explain the basic elements of a material. Anna's categorization scheme offers an approachable way of understanding the bits in these terms.

We also agree with Anna that the bits need to be picked apart before using them in design, and that some of them might fit better than others in a specific project and in specific stages in the design process. We are slightly more cautious, however, about Anna's next suggestion, which is about defining the purpose of the bits *a priori*. If we tried to shape the approach into something more structured, we feel we might sacrifice what we see as a fundamental aspect of the approach; that is, its dynamic and open approach to experiencing and exploring technologies and design materials.

A template for constructing bits

What Anna suggests is a template for how to construct bits, a helping guide in creating them. Anna described how she wanted the different types of bits to be well defined. She says: *"before building a bit it should be clear what purpose the bit should have. Should its purpose be to highlight a problem or show a specific characteristic? The template should work as a guideline and checklist but also as an inspirational trigger for developers."*

As a response to this suggestion we want to point out how the digital materials in fact are very different from each other. One can think of the processes of uncovering materials as very structured, where a designer/engineer simply thinks of and builds one bit at a time. And also that the first bits that appear to him or her are the most simple bits and that they, throughout the process, become more complex. Our impression, however, is that it should be quite the opposite. In fact, it is most often in what Anna refers to as the beyond bits, her last category, that we start this kind of process and it is in fact through building these more playful and perhaps more “designed” bits that we begin to understand the material better and begin to pin down the more basic properties of the material. For this to happen it is essential, though, that the process is kept explorative and open ended. It is not that there is a specific set of bits to find. What bits there will be depend on who in the design team participates in the process, the potential limitations/directions, previous experiences and more. In these terms, it is most beneficial if the process can be unconstrained for a short period of time. And, also as Anna suggests, the bits can always be picked apart later on and not all bits need to be used. Most important is that someone in the design team gets to develop a deeper knowledge of the material, or perhaps expands her previous knowledge of that material, and is able to better communicate some of this knowledge to the rest of the design team—something we in fact believe we accomplished in the workshop Anna attended.

CONCLUSION

Inspirational Bits

In summary, the work we report on above has, hopefully, conveyed our experiences with technologies as materials—what we refer to as inspirational bits. We also hope the paper has painted a clearer picture of what we think inspirational bits to be. In short, we see the inspirational bits as a rough way of seeing the technology that allows us to *look* at it, *feel* it and experience it over time and space, exposing all or some of the properties of a material. As we have come to understand them, inspirational bits can be used as one of the initial steps in a design process, making them similar to a technology-driven design process or to Ljungblad’s and Holmquist‘s work on grounded innovation [10] (alt. 1 in Figure 3). In addition, they can also be used to inform a design team about the properties of the materials that might be used in a project (alt. 2 in Figure 3). In any case, we see inspirational bits as something to be used in the early stages of a design process or as early as possible. Also, importantly, we do not see them being used in the first stages of a potential prototype that is to be extended into a full-blown system. Nor do we see them as narrowing down options as in the case of structured methods or design patterns [1]. Rather, they provide a way to produce quick and dirty but fully working sketches with the primary aim of exposing the properties of the material. We have also found that it helps to work with inspirational bits in a playful way to open up the possibilities of a material and not focus as much on its limitations.

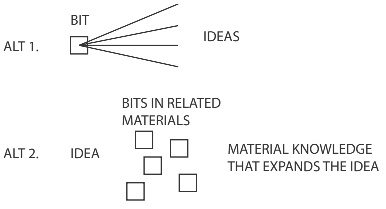

Figure 3. A schematic diagram for how/when the inspirational bits idea can be used, and what for

However, inspirational bits should be quick to build. While building the first bit in a material may take longer time, most of the digital materials are very adaptable and from our experience the second and third bit will take much less time to build. This also means that using these or other inspirational bits in a design workshop they can to some extent be changed there and then to fit with ideas the design team come up with while using them. The idea is to move some of the time and effort we in a design situation at some point anyway will have to spend getting to know materials, to the more early stages of a design process when it can have an effect on the overall idea. By doing so we also believe the total amount of time it takes to build interactive systems in fact will be shorter, in that we will stay away from fighting our material and instead working with it working out the design concept.

Moreover, taking a longer-term perspective, we see the approach having an impact on the longer lasting skills and expertise within a design team. Thus technologies would not need to be repetitively subject to the same investigation, but rather the materials might be added to and taken from a growing repository of bits.

General themes

To conclude, we want to foreground several themes we believe have some general importance to interactive systems design:

Technologies as design materials

Overall, we think there is value in treating a technology as a material in the design process. In our examples, we hope to have shown that unpacking a technology like Bluetooth and exposing at least some of its properties, we can produce some productive tools for a design process.

Design inspiration

We also hope to have shown that there is inspiration to be found in exploring the properties of a technology. Critically, we believe the approach we have taken differentiates itself from a techno-centric perspective. As opposed to the technology driving a design (and, as frequently happens, the resulting solution “looking for a problem”), we have shown that exposing a technology’s properties can open up design possibilities and inspire a space for creative thinking. In short, working with a technology as a material does not just limit you to solving problems, it can also be a source of creative inspiration.

Constructive limitations

We think a *technology-as-material* approach provides inspiration because it encourages a constructive view of the technology’s limitations or constraints. When technologies are used to solve user-defined problems or achieve technology-defined criteria, their limitations or constraints are usually seen as things to be overcome or worked around. In our examples, we have hopefully shown that the limitations of a few digital materials can be regarded as constructive properties that can inspire design ideas.

Material sketches

We hope the work above illustrates the value of open-ended prototyping or sketching around a technology. In much the same way as Fallman [4] and Buxton [3] describe sketching in design, sketching we see that using technology-as-material opens up the creative options. We find it is also a way to expose the properties of a technology that are frequently overlooked or taken for granted.

System descriptions

Finally, while we recognise the publishing constraints most research is subject to, we feel that a design community could benefit from system descriptions that were more explicit about the properties of the technologies used and how/if they severed as building blocks in the design process?

In sum, then, we believe we have provided some details about Bluetooth, RFID, accelerometers and wireless sensor networks as design materials and also raised some general themes broadly relevant to the interaction design community. Our implications are modest in so far as we recognise the sources of creativity and inspiration in design are many and varied. Nevertheless, we hope to have contributed somewhat to, as Vallgårda and Sokoler express it, a "*better understanding of the space of possibilities*." ([19], p. 4152).

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REFERENCES

1. Alexander, C., Ishikawa, S., et al. (1977) A Pattern Language, New York: Oxford University Press.
2. Anderson, R. J. (1994). Representations and requirements: the value of ethnography in system design. Human-Computer Interaction, 9(1), 151-182.
3. Buxton, B. (2007) Sketching User Experiences - Getting the Design Right and the Right Design. Morgan Kaufmann.
4. Fallman, D. (2003) Design-oriented human-computer interaction. CHI'03, Ft. Lauderdale, Florida, USA.
5. Gellersen, H. et al. (2005) UbiPhysics: Designing for physically integrated interaction. Ubicomp'05, Tokyo, Japan.
6. Greenberg, S. and Buxton, B. (2008). Usability evaluation considered harmful (some of the time). CHI'08. Florence, Italy.
7. Hallnäs, L. and Redström, J. (2006). Interaction Design - Foundations, Experiments, The Interactive Institute, The Swedish School of Textiles, and University College of Borås.
8. Kursat Ozenc, F. et al. (2010) How to support designers in getting hold of the immaterial material of software. Proceedings of the 28th international conference on Human factors in computing systems. Atlanta, Georgia, USA, ACM.
9. Landay, J. and Myers, B. (2001). "Sketching Interfaces: Toward More Human Interface Design." Computer 34(3): 56-64.
10. Ljungblad, S. and Holmquist, L. E. (2007). Transfer Scenarios: Grounding Innovation with Marginal Practices. CHI 2007, San Jose, CA, USA.
11. Löwgren, J. and Stolterman, E. (2004). Thoughtful Interaction Design: A Design Perspective on Information Technology, The MIT Press.
12. Marquardt, N., Taylor, A., et al. (2010) Rethinking RFID: awareness and control for interaction with RFID systems. Proceedings of the 28th international conference on Human factors in computing systems. Atlanta, Georgia, USA, ACM.
13. Richard C. et al. (2008) K-Sketch: A "Kinetic" Sketch Pad for Novice Animators. In Proc. of CHI, ACM Press, 413--422.
14. Rudström, Å. Höök, K. and Svensson, M. (2005). Social positioning: Designing the Seams between Social, Physical and Digital Space. HCII'05, Las Vegas, USA.
15. Schön, D. A. (1983). The Reflective Practitioner: How professionals think in action. London, Temple Smith.
16. Sundström, P. and Höök, K. (2010) Hand in hand with the material: designing for suppleness. Proceedings of the 28th international conference on Human factors in computing systems. Atlanta, Georgia, USA, ACM.
17. Terry, M. and Mynatt, E. (2002) Recognizing Creative Needs in User Interface Design. In Proc. of C&C, ACM Press, 38--44.
18. Vallgårda, A. and Redström, J. (2007). Computational composites. Proceedings of the SIGCHI conference on Human factors in computing systems. San Jose, California, USA, ACM.
19. Vallgårda, A. and Sokoler, T. (2009). A material focus: exploring properties of computational composites. Proceedings of the 27th international conference extended abstracts on Human factors in computing systems. Boston, MA, USA, ACM.

Paper 4: Immaterial Materials: Designing with Radio

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Immaterial Materials: Designing with Radio

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ABSTRACT

Designing with digital materials is sometimes challenging due to material properties that are for all practical purposes invisible. Here we present our work on exploring one such material, radio, and how we have worked with making radio a more tangible and accessible design material for multidisciplinary design teams to work with. Starting from an account of a previous project of ours, the LEGA project, we describe a design situation involving radio that exemplifies some of the challenges that working with radio can involve. We thereafter describe how we have used the *Inspirational Bits* approach to further investigate the peculiarities of radio as an immaterial design material and what possibilities it holds for interactive systems design.

Author Keywords

Design, Design Material, Radio communication

ACM Classification Keywords

H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

General Terms

Design, Experimentation.

INTRODUCTION

Design in the digital realm is faced with particular challenges, as properties of involved technologies are often hard to observe and thus experiment with. In some cases such properties are for all practical purposes invisible.

An example of such a technology is radio communication, which exhibits behavior that does not match our intuitive, albeit somewhat naive, understanding of how it works. For instance, most of us have no doubt wondered at the mystery of how radio devices can fail to communicate despite being separated by a very short distance, or how one device can communicate with another but not the other way around. Often such failures are blamed on the technology itself (e.g. a bad transceiver), when in fact they may be a result of the way in which radio waves naturally propagate. However, as we have no way of directly sensing radio waves we are left in the dark about what is actually going on. This property of radio waves makes it challenging to design applications that rely on wireless communication.

Misconceptions and lack of knowledge about wireless communication is widespread. Even in research communities devoted to the topic overly simplistic assumptions are made and wrong simulation models are used [7]. For instance, protocols for wireless networks have usually been created for static networks. With devices increasingly becoming mobile such protocols fall short as mobility poses very different demands on the network and turns many assumptions on their head [3].

As various forms of radio communication (e.g. Bluetooth, ZigBee, Wi-Fi networks etc.) increasingly come into play when designing digital artifacts, in particular in mobile device and service design, finding ways for designers and developers to understand and work with this invisible material becomes important. The current evolution of an Internet of Things [17] consisting of billions of connected, and interconnected, objects/devices in our everyday life will further necessitate such a development.

In addition creating connections between devices is only one possible use of radio. Familiar examples of other kinds of use include microwave ovens for heating food, radar for keeping track of air and sea traffic, AM and FM radio for broadcasting news and entertainment, and so forth. Hence, instead of a technology limited to point-to-point connections the view we take is that of radio as a digital design material that can be shaped and molded to fit a wide variety of purposes, much like more traditional materials such as clay or paint.

Here we use a previous project of ours, the LEGA project [8], to outline some specific issues we have had when working with radio in the design of interactive systems. The paper then continues to present how we have learnt from the LEGA project and constructed what we in a previous paper of ours refer to as *Inspirational Bits* [15] as a tool for working with radio in design situations. Inspirational Bits are quick and dirty designs developed with the single aim of exposing the properties of digital materials, here radio, in a way that all members of an interdisciplinary design team can understand and use. Bits are not meant to be early iterations of a prototype but rather, as the name indicates, are meant to be "one bit" designs that highlight particular

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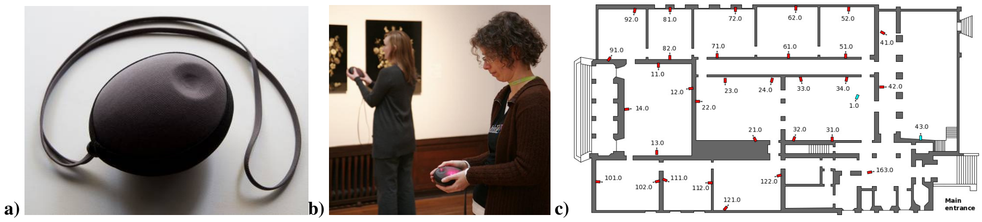

Figure 1. a) A close up of the LEGA b) The LEGA in an art exhibition c) Map of the exhibition with the infrastructure nodes

properties of a design material and point out possibilities for design. Here we present six of the Inspirational Bits we have developed to make radio as a design material less immaterial, both for ourselves and others, in future projects.

A CASE STUDY OF RADIO DESIGN – THE LEGA

The LEGA is a hand held device that allows visitors to an art hall to share their experiences via physical traces that are created through gesture and touch. The device was created for the Vårsalongen event at Liljevalchs art hall in Stockholm, Sweden, which exhibits professional and amateur art selected by a jury from anonymously submitted pieces. Each year around 250 pieces are exhibited for a period of two months. The event is visited by approximately 40.000 visitors each year and has a long-standing tradition of stirring up emotion and engagement from both visitors and media.

The LEGA device has an ovoid form that fits into the palm of your hand and has a soft surface that encourages tactile and gestural interaction, see Figure 1a. By touching and moving their device in various ways users create expressions, or traces, of their experience that are left at their approximate location. There they can be discovered and experienced as vibration and light patterns by others in the group (see Figure 1b) passing by that location in the exhibition space.

The LEGA makes use of radio in several ways. First and foremost radio is the basis for the positioning system that was used to determine the location of LEGAs and traces. The system relies on an infrastructure of radio devices that at regular intervals transmit their id number using low transmission power. From the radio signal strength of received beacons and number of beacons received in a time slot, LEGAs can acquire an approximate location. In total 31 infrastructure devices, corresponding to an equal amount of locations, were placed around the art hall (Figure 1c). Secondly radio is used to transmit trace data between the LEGAs and the infrastructure where it is stored. When a trace is left it is transmitted to the infrastructure node that corresponds to the location of the LEGA leaving the trace. When a LEGA acquires a new location any traces that are stored on the infrastructure node are transmitted back to the LEGA.

In our work with the LEGA system we encountered several difficulties while working with radio. Firstly, due to the immateriality of radio communication it was occasionally very hard for the design team to understand what was going on. For instance, traces would seemingly be lost, or found at locations where no traces could have been left which made it very hard to verify that the system was functioning properly. Finding an explanation to these behaviors required lengthy investigations and extensive experimentation. For instance, we found that some infrastructure devices were placed in spots where their transmissions could be heard through walls accounting for the mysteriously appearing traces, or radio traffic congestion preventing traces from being sent or received by LEGAs, accounting for the lost traces. The latter was a consequence of the way the protocol handled transmitting to all nodes in range in a power saving network. In the end we were able to overcome most of the peculiar behavior by moving around the infrastructure devices to more suitable locations, adjusting their transmission power, and rethinking a basic communication principle, from push to pull, to avoid congestion and overhearing [9]. However, even finding the source of the problems required a substantial effort, which could have been avoided, if we would have had access to better tools for exploring such issues at an earlier stage in the design process.

During our work we also encountered behaviors caused by the nature of radio waves that worked to our benefit. A prime example of such behavior was due to the absorption of radio waves by human bodies. One of the worries we initially had was that transmissions from the infrastructure beacons would not reach far enough. Hence, we started out by placing them on ledges high up (about 5 meters) in the art hall to avoid obstacles. This turned for the beacons to be heard in locations up to three rooms away. When we instead moved them down about half a meter the positioning system suddenly worked substantially better. While we were initially confounded by this we soon found out that by placing the beacons at a height where the crowd visiting the exhibition would actually absorb radio waves, we prevented transmissions from leaking to adjoining rooms and thus made the locations more exact. From a strictly technical point of view this behavior could have been foreseen, but from a design point of view it was not until we actually encountered it that we could understand it, and see the usefulness of it. Here the immateriality of radio, and lack of tools for exploring it, prevented us from recognizing an opportunity for design at an earlier stage of the process.

The LEGA device was realized as a multidisciplinary design effort involving a wide range of competences such as industrial design, hardware and software engineering, as well as a HCI design. This combination of competences is necessary to build a system such as the LEGA. However, it also posed us with unique challenges in making sure that the whole design team understood the challenges of working with radio during the LEGA design process. The issues we encountered were problematic to get a grip on even for those in the design team that were best equipped to do so, the engineers. For others, such as industrial and interaction designers, it was near impossible. As a result it was hard for them to take such things into consideration in their design work.

It is rare, although not unheard of [2] to find people skilled in both the kind of creative design and engineering that are required in order to innovate, design and develop systems such as the LEGA. In addition, systems such as the LEGA are very hard, if not impossible, to fully design without trying them out and experience them in practice.

What became apparent in the LEGA design process was that in order to work out and realize systems of this level of complexity, designers and engineers need to find better ways of communicating and working together, that takes into consideration the varying areas of expertise that team members have. Designers on the one hand need to develop ways to express their creative thinking in an understandable form to non-designers [10] and engineers on the other hand need to find ways to illustrate and explain properties and behaviors of digital materials such as radio for non-engineers in a way that turns them into resources for design. Sculptors sometimes claim that they are only bringing out what is already present in the material they are working with. In the same way digital design materials need to come alive for designers so that they can bring out the designs and interactions that lie dormant in the material.

As the engineers of the multidisciplinary design team working out the LEGA design we encountered these challenges first hand. We found the behavior of radio especially problematic to explain and also sometimes understand ourselves. Even though we all could see the infrastructure devices and discuss them by acting out various scenarios, parts of the design team still found it hard to understand how the radio communication worked, and why it was so hard to use the radio signal strength to calculate distance and position, or even how this could be done in the first place. Therefore, when later starting our design exploration – or uncovering of – radio using the Inspirational Bits approach we first set out to make the issue of using radio and RSS as a means to indoor positioning more understandable. But first, some basic facts about radio.

BASIC FACTS ABOUT RADIO

Radio waves are electromagnetic waves that can be used for information transfer by modulating the waves, i.e. changing some basic properties of the waves such as the amplitude, frequency or phase, to encode information. Radio waves are transmitted by applying an oscillating electrical current to an antenna. Receiving antennas transform it back into an oscillating electrical current that can be decoded to reveal the sent information.

In this paper, radio communication in the microwave spectrum (centered around 2.4 GHz) is the main focus. This frequency band is used by communication technologies such as Bluetooth and ZigBee, as well as many consumer devices using proprietary communication protocol stacks. The microwave spectrum is popular as it is open for use in almost the entire world, in contrast to other spectrums that require special permits to use. However, to some extent, the results and insights reported in this paper also holds true for other spectrums and technologies communicating via radio.

Radio Signal Strength, Absorption, Reflection and Asymmetric links

One fundamental metric of radio waves that we already have mentioned is the received signal strength (RSS). This is a metric in decibel (dBm) for how strong a signal is at the receiver. RSS decreases with distance and is therefore sometimes used for indoor positioning as the Global Positioning System (GPS) signals cannot reach there. However, as the RSS also decreases with environmental factors, such as the existence of attenuating materials, such positioning is not always reliable. For radio waves in the microwave spectrum, the frequency corresponds to the resonance frequency of water, thus anything containing water will be particularly good at absorbing radio waves (which incidentally is the basis for how an ordinary microwave oven functions). An average person contains 45-60 % water and thereby functions as an excellent attenuator, but also other materials are attenuators. Metals are generally reflectors and instead reflect radio waves, which causes reflections that at the receiver can cause a decoding to fail as multiple waves arrive with slight variations in phase and amplitude, causing destructive interference. The effects of this superposition of radio waves, is commonly called *multipath phenomena*. Sometimes multipath can however improve communication as when adding up all the different paths being in the same phase, the signal becomes stronger.

A counter-intuitive observation due to such phenomena is *asymmetric links*, where communication does not work both

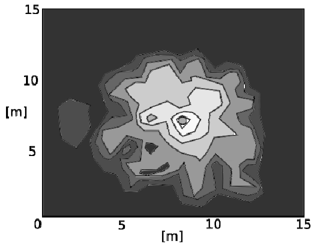

Figure 2. Heatmap showing the probability of receiving a packet from a device positioned in the center. Note that it does not look like a uniform disc. After results acquired experimentally by Ganesan et al[4].

ways. Device A can hear device B, but not the other way around. This is repeatedly seen in real world deployments and experiments [4]. Radio links also exhibit burst properties. The probability of successfully receiving a transmission is dependant on how many transmissions were successful or unsuccessful just before it [14]. The reason for this is in part unknown, but a suggested cause is the almost ubiquitous 802.11b wireless networks, where signals are on the order of 1000 times stronger than the typical ZigBee device.

Due to multipath phenomena and reflecting/attenuating materials the probability of receiving a packet – the combination of a message and metadata – will not just depend on distance to the transmitter. Figure 2 shows a map of the probability of receiving a packet from an experiment conducted in an open parking lot. It clearly shows the irregular and volatile nature of wireless communication. In addition the reception landscape shown in Figure 2 is highly dynamic, shifting over time as conditions change.

Because of this, packet loss is something that has to be taken into account. One way to do this is to wait for an answer that it was received. If this acknowledgement (ACK) is not received within a set period of time, a retransmission will occur. After a number of unsuccessful retransmissions the application will be notified of the failure and can for example try sending to another device or show an error message. This is called a *reliable transmission*. The opposite is a *best effort transmission* where ACKs are not used and the sender will not know if the receiver has received a package sent.

Network Communication and Topologies

A set of devices communicating via radio forms a wireless network. In such networks there is a logical structure for how the devices coordinate communication with each other, called a network topology. The choice of topology, e.g. ring, star, mesh or bus, is done either implicitly as it sometimes comes with the choice of technology such as Bluetooth or ZigBee, or explicitly if another abstraction layer is put on top of the technology. Topologies differ for example in latency, physical layout, message passing order and how and how well they cope with transmission failures. For instance, in the ring topology, each device is connected to one device in the forward direction and one in the backward direction. A message is sent in one direction (e.g. clock wise), and changes direction if a failure is detected. The star topology has a master device in the center and slaves surrounding it. Slaves cannot send directly to another slave, but the message must always pass the master. This makes it more robust to failures as long as it is not the master that fails.

Lifetime is another crucial factor for devices communicating via radio as it consumes a lot of energy. A common way to preserve energy is to shut down the radio for as much as possible. Some applications only have their radio on for about 1 % of the time. In order to transmit to a neighbor that sleeps, one way is to repeatedly transmit the same information or a wake up packet until the receiver hears it when it periodically wakes up to listen. Because of this, sending to all neighbors in range can be more costly than sending to one single neighbor [10], and it also adds to congestion in the wireless medium, blocking others from transmitting as well as causing interference.

Many of the above properties of radio communication may be common knowledge to researchers, designers and engineers working in the field of ubiquitous computing. But it is when that is not the case, when radio communication is assumed by some to be just a wireless equivalent of wired communication that we in interactive systems design teams sometimes start to get problems. In the following, and with an eye on design, we take a more detailed look at these underlying features of radio and how we can come to a shared understanding of these properties, when working out interactive systems designs in multidisciplinary design teams.

RADIO AS A DESIGN MATERIAL

Through sketches, mock-ups and early prototyping, designers engage in a "*conversation with their materials*" [12]. In the formation of new ideas materials start to "*talk back*", revealing design opportunities and challenges. Digital materials— including both hardware and software— are however sometimes complicated for designers to work with [9]. An important aspect of digital materials, differentiating them from other materials, is that they typically have a temporal aspect to them. Over time properties reveal themselves and change in interaction, providing new and sometimes unforeseen use experiences [5]. Thus, it is not enough to experience digital materials at any given moment to grasp their properties and design potentials; instead such dynamic qualities only reveal themselves when put to use. More often than not they have to be assembled as part of running systems for properties to take on form and substance, and especially so for materials as immaterial as radio.

There are many examples of projects where radio communication has been used as a design material in one way or the other. Chandrasekaran and colleagues [1] used RSS from GSM cell towers to approximate vehicular speed for road traffic congestion monitoring. Kim and colleagues used the identity of cell towers and wireless access points, snooped from radio beacons, for discovering locations that users visited [6]. Rose and Welsh [11] placed wireless sniffers across a city landscape to snoop on beacons and traffic in order to detect and measure usage, traffic, mobility and more. The Yourban project[1] at the Institute of Design at Oslo School of Architecture and Design has worked on several prototypes specifically addressing the immateriality of radio. For instance, "Light painting Wi-Fi" where they visualize Wi-Fi radio signals in the streets of a city or "Ghost in the field" where a radiation pattern from a RFID antenna is visualized. These last two examples have been made by designers using radio as a design material and source of inspiration.

But, as previously said, it is not always that one person alone is skilled in both creative design and explorative engineering, nor are collaborations between designers and engineers always easy and productive. Many times the immaterial aspects of a design material such as radio are hard to discuss and come to grips with and this is when we need methods and tools for how to communicate between competences in order to come up with cool innovative ideas for design and also set them to life. In order to help those who engage in design with digital technologies, we thus need to consider how we can systematically and critically expose dynamic qualities of digital materials in ways that make sense to designers, HCI-experts and other non-expert members of multidisciplinary design teams.

With this in mind, and as a first step in this direction, we in a previous paper of ours introduced the *Inspirational Bits* approach [15] as a way for engineers and developers to "*unfold the design space"* by experimenting with digital materials.

RADIO USING THE INSPIRATIONAL BITS APPROACH

In total we built six Inspirational Bits that explored various aspects of radio ranging from network topologies to RSS. For our work we have used the Tmote Sky[2] sensor node, which is a popular platform in the research community. It has an 8 MHz microcontroller, a 2.4 GHz short-range radio transceiver, a 1 MB flash memory and environmental sensors (light, humidity, temperature). In addition, we have used a very similar platform, the Sentilla JCreate[3] sensor node that, instead of environmental sensors, has a three-axis accelerometer, a set of LEDs and comes in a casing comfortable to hold in the hand. Both platforms/sensor nodes are shown in Figure 3.

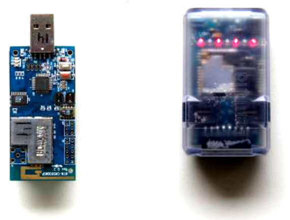

Figure 3. The wireless sensor nodes used for the bits described in this paper: to the left the Tmote Sky sensor node, and to the right the Sentilla JCreate sensor node.

Bits on Radio, RSS and Positioning

Not only in the LEGA project but in several of our previous designs (e.g. [16]) we have encountered problems with wireless sensor networks, radio communication and using RSS as a means to indoor positioning. Therefore, in starting our design exploration of radio, we first set out to try to make immaterial properties of the radio signals more 'material' and thereby easier to grasp. We built three bits for this purpose, one turning the RSS into sound, a second trying to explain the difficulties of using signal strength as a means to indoor positioning, and a third that shows how the absorbing properties of the human body, can be turned into a game feature rather than being a limitation.

Our first bit, RadioSound, turns the RSS into sound and thereby 'materializes' how the signal strength is affected by the environment and the human body. RadioSound consists of two sensor nodes: one is a JCreate node that is equipped with a small speaker emitting a single tone, while the other is a constantly transmitting Tmote Sky sensor node. The pitch of the emitted tone increases with the signal strength between the two nodes. Using these sensor nodes one can walk around in the environment noting how the tone changes as the signal is affected by other materials such as walls, furniture and especially metal and human bodies.

In order to explain how the signal strength measurement is very unstable due to changes in the environment or fast movement of the nodes, we decided to build a second bit this time using a graphical representation of the RSS. In this second bit, that we later turned into our GoldRush game (explained below), the size of a graphical circle visualizes the signal strength measurement, where fluctuations or instability in the signal strength can be observed as the circle disappears completely when there is no signal at all and comes back again when the signal stabilizes. Using this bit one will see how the circle disappears when a node is moving too fast or the surrounding environment is changing or moving (people and furniture), and how the signal then

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[1] www.yourban.no

[2] http://www.moteiv.com

[3] http://www.sentilla.com/

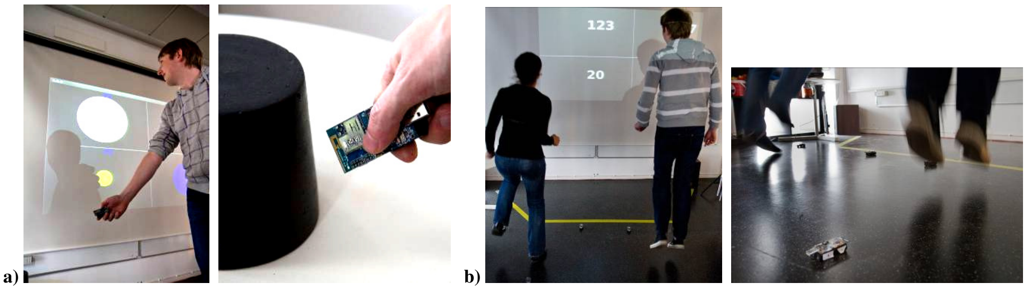

Figure 4. a) Gold Rush bit, interface and Tmote sky node used for seeking b) The Gymkhana bit, two players playing the game

again stabilizes when holding it still for a while. Also the circle flickers more if the transmitter node and the moving node are far apart, as they then are more affected by the environment.

GoldRush explains the difficulties of using the RSS as a means to indoor positioning by letting the inconsistency in this usage of radio be the game feature itself. In Gold Rush, one hidden Tmote Sky sensor node is set to constantly transmit. Four users are then set to look for the transmitter by walking around with a Tmote Sky sensor node that listens for the signal. The RSS of each player is shown as above using a circular shape displayed on the wall, see Figure 4a. By playing the game four users at a time they need to understand the concept of how their body and movement make the RSS fluctuate. In order to get a more stable RSS it is better if no one is moving in the room. Here users can choose to either cooperate, ask each other to stay still for a second and get a stable RSS reading, or move about thereby diminishing the chances for other players to get a stable reading.

Playing with this bit we also got the idea of using the body itself as the moving part, and let a set of positioned sensor nodes ‘measure’ the amount of movement between them, see Figure 4b. , by measuring how the signal is absorbed and disturbed by moving bodies. This turned into the Gymkhana game, where the idea is to first move as fast as possible to disturb the radio signal and thereby gain points, and then not lose those points by acting out a set of full body movements without disturbing the radio signal. Up to four Tmote Sky sensor nodes are placed on the floor or on some stable furniture around the body of the player, and they transmit continuously to each other, which makes the body of the participant become an obstacle for the signal. The more users move their bodies, the more the signal is disturbed. Gymkhana is intended to make the user understand how her body affects the radio signal but also how limitations of this material themselves can be used as possibilities for design.

In summary the most important aspects of radio that were explored by these Inspirational Bits were:

- RadioSound – turns the RSS into sound and thereby ‘materializes’ how the signal strength is affected by the environment and the human body
- GoldRush – explains the difficulties of using the radio signal strength as a means to indoor positioning by letting the inconsistency in this usage of radio be the game feature itself
- Gymkhana – is meant to make the user further understand how her body affects the radio signal, but also how previously thought of limitations of this material can be used in themselves as possibilities for design.

Bits on Radio, Topologies and Communication

We also wanted to build a set of bits explaining how even something as the topology set up can be used as a in design. Network topologies are typically hidden from the user under layers of abstractions, though we felt there could be value in showing the topology explicitly; show how it works and how it in fact already does affect the user experience. For example, the slow speed at which Bluetooth connects is in part due to the network reorganizing as devices listen for neighbors and sets up a synchronous protocol. So to further explain the concept of topologies and to explain how they work and point in directions in which they can be used we built three inspirational bits: the ComNet bit, the RobustNet bit and the GeoNet bit.

ComNet (Figure 5a) shows how the packet passing order differs between network topologies and how that can affect the user experience. One JCreate sensor node per participant is used, first set up as a star and later a ring topology. One of the nodes injects a packet that is then automatically passed on in the topology. Every node keeps the packet for a while and then passes it on to the next node following the message path set by the topology. LEDs lit up indicate that the node has the packet, and only one node at a time can have it. At least three participants are needed, who

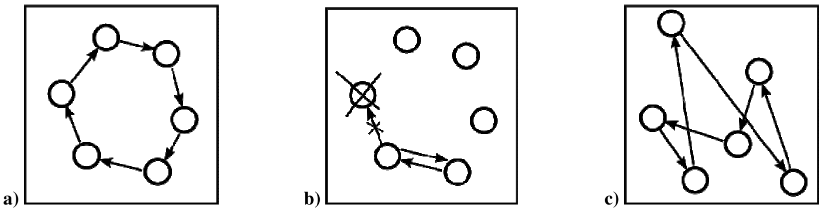

Figure 5. Illustrations of the topology bits in a ring topology setting a) ComNet, showing the message passing order b) RobustNet, showing how it handles a failed transmission c) GeoNet,showing that physical position can differ from logical

are given one sensor node each. To get the participants to further engage with the material and thereby better understand it we turned this into a game where the goal for the team was to, in the shortest possible time, physically move the message by moving the nodes from the starting point to a target area, approximately 50 meters away, and back again. The person having the packet is not allowed to move but has to wait for it to be transmitted to one of the other nodes, which then hopefully is closer to the target area. Which node that gets the packet depends on the packet passing order of the topology and the connectivity between nodes. To let the participants get the time to understand how the passing order works, the radio in the nodes was set to a maximum transmission range of approximately 10 meters. Using this bit in a star topology setting, one participant has to run more than the others as that participant has the master node and as mentioned, in the star topology, all packets always pass through the master. In the ring topology setting, the team has to figure out in which direction the packet is passed on so that they can move the packet forward towards the target area.

Our second bit on radio, topologies and communication, RobustNet (Figure 5b), shows how topologies differ in terms of robustness and what happens when something goes wrong. Here 'wrong' means that a communication fails due to e.g. a node running out of battery, is broken or moves out of transmission range. The same setup as in ComNet is used, but this time the participants are encouraged to keep extra long distances from each other to make the nodes lose connectivity as they are out of transmission range, to turn off their nodes, or to hide them. This was done to provoke more packet losses and (simulated) node failures while observing what happen with the network communication.

Finally, our GeoNet bit (Figure 5c) shows the difference between physical and logical positions in a network. This bit was not made as a game, but rather as a quick explanatory bit as the message it conveys is similar to the ComNet bit, but still different enough to justify a new bit. A topology might imply from its name that the devices should be placed in e.g. a ring, but that does not have to correspond to the actual placement of the nodes in the physical world, but merely how the nodes are addressed in a logical sense within the network. Yet again, the same setup as above is used. This bit was used right after the RobustNet bit, before participants gathered back and had a chance to organize themselves. They were then standing in random positions in the room. Their physical location is explicitly pointed out to them while the network is still working, making them aware of that the network is actually working fine and as a ring (or star) while they themselves are not standing in such a manner. The participants are then encouraged to position themselves in the corresponding physical locations (i.e. ring or star) so that the network becomes visible and apparent in how it passes packets around, lighting up LEDs on the node that has it. This distinction is simple but important to know when facing a choice between topologies indirectly through choice of radio technology.

These three inspirational bits can help both us and others to understand the concept of topologies and also show how something as 'immaterial' as how the nodes are set up to communicate can be used to unfold the design space. By using these bits ourselves we got a better understanding of what happens when a node for some reason fails. For instance, how it is that the star topology is more robust than the ring in case of failure, but also how fragile the star topology is when something happens to the master node.

Having this knowledge allows for more informed decisions, when prototyping or implementing various designs using radio, e.g. choosing ZigBee over Bluetooth because of network setup latency. Seeing how a star topology handles node failure also gives a better understanding for what can happen in e.g. Bluetooth networks. Finally, by making both designers and engineers working together in a multidisciplinary design team aware of these matters, designs that cope with various communication problems explicitly, or use such failures as a resource for something else, can be created.

In summary the most important aspects of radio that were explored by these Inspirational Bits were:

- ComNet – shows how the packet passing order differs between network topologies and how that can affect the user experience.

- RobustNet – shows how topologies differ in terms of robustness and what happens when something goes wrong.
- GeoNet – shows how, in wireless communication, the physical placement is different from the logical positions that stems from the topology, e.g. ring or star topologies

CONCLUDING REMARKS

In conclusion, we have presented our work on radio as a design material within the field of interactive systems design, and how we see from our work on the LEGA system and other projects that there needs to be a shared understanding about the radio material among all professionals working in this area in order to work better together and create more innovative designs. We have also argued for the need of better tools for turning immaterial materials such as radio into useful and understandable resources for designers and engineers alike. Here we have specifically focused on radio and the Inspirational Bits approach, but there are some efforts addressing the same issues albeit in a different vein (e.g. [13]) and of course many other materials.

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REFERENCES

1. Chandrasekaran, G., Vu, T., Varshavsky, A., Gruteser, M., Martin, R. P., Yang, J., and Chen, Y. (2010). Vehicular speed estimation using received signal strength from mobile phones. In Proc. of the 12th ACM international conference on Ubiquitous computing, Ubicomp '10, pp 237--240.
2. Dunne, A., and Raby, F. (2001). Design Noir: The Secret Life of Electronic Objects. Birkhäuser.
3. Dutta, P., and Culler, D. (2009). Mobility changes everything in low-power wireless sensornets. In Proc. of the 12th Workshop on Hot Topics in Operating Systems (HotOS-XII), Monte Verita, Switzerland.
4. Ganesan, D., Krishnamachari, B., Woo, A., Culler, D., Estrin, D., and Wicker, S. (2002). Complex Behavior at Scale: An Experimental Study of Low-Power Wireless Sensor Networks. In Technical Report UCLA/CSD-TR 02-0013, Computer Science Department, UCLA.
5. Hallnäs, L., and Redström, J. (2006). Interaction Design - Foundations, Experiments, The Interactive Institute, The Swedish School of Textiles, and University College of Borås.
6. Kim, D., H.,Hightower, J., Govindan, R., and Estrin, D. (2009). Discovering semantically meaningful places from pervasive RF-beacons. In Proc. of the 11th international conference on Ubiquitous computing, Ubicomp '09, pp 21--30.
7. Kotz, D., Newport, C., Gray, R. S., Liu, J., Yuan, Y. and Elliott, C. (2004). Experimental evaluation of wireless simulation assumptions. In Proc. of the 7th ACM international symposium on Modeling, analysis and simulation of wireless and mobile systems, MSWiM '04, pages 78-82, New York, NY, USA. ACM.
8. Laaksolahti, J., Tholander, J., Lundén, M., Solsona Belenguer, J., Karlsson, A.. and Jaensson, T. (2011). The LEGA: a device for leaving and finding tactile traces. In Proc. of the fifth international conference on Tangible, embedded, and embodied interaction, TEI '11, 193--196.
9. Lundén, M., and Dunkels, A. (2011) The Politecast Communication Primitive for Low-Power Wireless, ACM Computer Communication Review, April 2011.
10. Ozenc, F. K., Kim, M., Zimmerman, J., Oney, S. and Myers, B. (2010) How to support designers in getting hold of the immaterial material of software. Proc. of the 28th international conference on Human factors in computing systems. Atlanta, Georgia, USA, ACM.
11. Rose, I., and Welsh, M. (2010). Mapping the urban wireless landscape with Argos. In Proc. of the 8th ACM Conference on Embedded Networked Sensor Systems, SenSys '10, pp 323--336.
12. Schön, D. A. (1983). The Reflective Practitioner: How professionals think in action. London, Temple Smith.
13. Solsona, J., and Smith, M. (2011) An Extension of Computer Engineering Methods for Interdisciplinary Design. Workshop paper. Pervasive Computing, PerCom'11, Seattle WA, USA.
14. Srinivasan, K., Kazandjieva, M. A., Agarwal, S. and Levis, P. (2008). The beta-factor: measuring wireless link burstiness. In SenSys ’08: Proc. of the 6th ACM conference on Embedded network sensor systems, pages 29–42, New York, NY, USA. ACM.
15. Sundström, P., Taylor A., Grufberg, K., Wirström, N., Solsona Belenguer, J. and Lundén, M. (2011). Inspirational Bits - Towards a shared understanding of the digital material. CHI'11, May 7-11, Vancouver, BC.
16. Sundström, P., and K. Höök, (2010) Hand in hand with the material: designing for suppleness. Proc. of the 28th international conference on Human factors in computing systems. Atlanta, Georgia, USA, ACM.
17. Vasseur, J-P. and Dunkels, A. (2010). Interconnecting Smart Object with IP - The Next Internet. Morgan Kaufmann Publisher

Paper 5: Exploring the Design Space of Proxessories

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Exploring the Design Space of Proxessories

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ABSTRACT

In this paper we explore the design space in the intersection of proxemics and accessories. *Proxessories,* a combination of the words, describe systems designed to operate in close proximity of other devices and users to enhance, extend, or embellish interaction. Characteristics for Proxessories are that they share some material as well as technological characteristics: seamless wireless connectivity; low power computation and power consumption; sensor technologies and finally material aesthetics. Those attributes surface not only during usage, but also already in early stages of the design process, making them essential even in the earliest part of a design process. Proxessories extend, enhance, and support the interaction capabilities of existing mobile devices. As part of exploring this design space, we introduce a platform, SW and a HW-toolkit that is tailored to the specific technical requirements together with a handful of resulting design examples of actual *Proxe*ssories explorations. The platform was validated through the development of five different design exemplars. Each application illustrates different aspects of using the platform while simultaneously exploring the design space of Proxessories.

Author Keywords

Proxessories; IxD; Design; IoT; Prototyping; Aesthetics; Arduino.

ACM Classification Keywords

Design.

INTRODUCTION

Fueled by technological developments within the area of IoT, information technology is currently finding its way into an increasing number of arenas of life. For instance, smart homes, smart grids, and smart objects are becoming household words for an increasing number of people that live and interact with such technology on a daily basis. In addition to designs for instrumental purposes such as energy management the same technological development provides opportunities for novel designs catering for other kinds of use and use experiences, including entertainment and leisure use, and aesthetic experiences.

This paper presents our research exploring the design space in the intersection of proxemics and accessories. It revolves around prototyping activities in interaction design and in particular systems for exploring new and novel types of experience-centered and embodied interaction within the Internet of Things domain.

Proxessories are proximal accessories to common mobile devices, intended to enhance, extend, or embellish interaction with those devices or services running on them. Proxessories usually operate in the proximity of mobile devices and rely on sensor and actuator technologies as well as wireless connectivity to provide their services. Like accessories, they can be part of compositions or outfits that are intended for specific purposes or occasions. Hence, by changing Proxessories, you can alter the experience of interacting with a device in the same way that changing jewelry can alter the look of an outfit. Just as the right accessories can make an outfit feel complete, the right Proxessories can make interaction with a device or a service feel aesthetically complete.

Proxessories do not provide much value on their own, but when combined with wireless connectivity, mobile phones, tablets or smart watches they can provide appealing interactions. They become the tangible interaction accessories of our everyday gadgets. While Proxessories can enhance an interaction for instrumental purposes such as introducing a more efficient way of interaction, their main function is to embellish interaction for aesthetic or experiential purposes.

Heretofore, there has been a dearth of specific tools that support design-led explorations of the design space, especially sketching in hardware and early concept-development. In this paper, we will introduce two tools aiming to support such early design led prototyping activities. *rFlea* (see Figure 1 left) is a hardware platform that provides an easy-to-use and efficient base for prototyping in hardware using sensors, actuators and wireless connectivity. rFlea is complemented by Insbits Studio (see Figure 1 right), a browser-based prototyping tool that allows for rapid prototyping of ensembles of connected devices including rFleas, mobile phones, and other devices. Together, these tools provide support for exploring design possibilities and allow for functional or

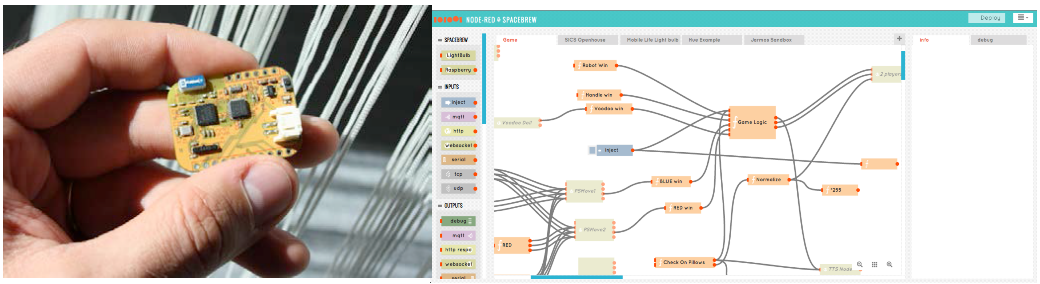

Figure 1: Left, rFlea board; right, Insbits

aesthetic considerations to be made already from the early prototyping stages.

In this paper, we will show how the prototyping platform was successfully used in the development of five different applications designed by interaction design students in different workshops. Each application illustrates different aspects of using the platform while exploring the design space of Proxessories.

RELATED WORK

In 1966, Hall coined the term proxemics as the study of the human use of space within the context of cultures [25]. Hall's most famous innovation in this area relates to the definition of the informal or personal spaces that surround individuals:

- Intimate space. The closest "bubble" of space surrounding a person. Entry into this space is acceptable only for the closest friends and intimates.
- Social and consultative spaces. The spaces in which people feel comfortable conducting routine social interactions with acquaintances as well as strangers.
- Public space. The area of space beyond which people will perceive interactions as impersonal and relatively anonymous.

The concept of proxemics thus relates distance with cultural context, but, what if we add a mix of people and digital artifacts? Greenberg et al. have used the term proxemics to as a way to define Proxemic Interactions [6]. They introduced the term proxemics to the Ubicomp research community and refer to it as Ubicomp proxemics, more specifically concerning inter-entity distance, where entities can be a mix of people, digital devices, and non-digital things. Furthermore they present a number of different dimensions to the distance in between those interactions: distance, orientation, movement, identity and location itself.

While the articulation of the Proxessories design space is outlined here, there are precedents in previous work. Examples of systems from the HCI-field with similar characteristics as Proxemics include The Stane [15] and The Shoogle System [24]. They are accessories to mobile phones that enable novel interactions, and both rely on sensors, novel materials, and wireless communication to provide their functionality. Furthermore, The Stane, is an interaction artifact that enables tactile interaction with the mobile phone and the user; its design, material and shape plays an important role in the final interaction, making the material qualities of the design an early design decision.

eMoto[20], by Sundström et al., is a system that includes a custom-made stylus that can be used with mobile phones. Its stylus extends the interaction with motion and temperature sensors to allow users to express themselves physically. By gesturing with the stylus, using pressure and movement, users can change the background of a text message to have colors, shapes and animations as a function of their physical movements. These messages could then be sent to other users to express various emotional content. The authors of the paper comment that eMoto in many ways was a success, but the actual shape of the extended stylus was a disappointment to them and users, as the stylus became quite large in order to include battery, wireless communication to the mobile, and sensors. Users were very unhappy with the shape of the eMoto and felt embarrassed to use it in public; these limitations of the technology led to a bad user experience [5].

A similar development can be seen in industry where there is a growing segment of systems typically found in settings like sports interactions, bio-sensor-enabled systems or interaction accessories for our phones and devices. Typical commercial examples include Estimote [26], Bluetooth beacons that connect to your phone; Flic [27], a Bluetooth button that can trigger functions in your phone: or, Fitbit [28], an activity and performance tracking bracelet.

Another related body of work related to proxemics can be found in Proxemics play [14]. Muller et al. combine playful interaction and interpersonal distance between players. They use the new wireless technologies to facilitate novel play experiences.

The HCI community has shown how novel tools and platforms open up various design spaces. One prominent example is the Lilipad Arduino [3] that introduced a novel way of combining electronics and various textile and artistic practices. By building on the Arduino platform [29], the LilyPad could tap into an existing and well-established community. In return, the Arduino community will expand as new domains and practitioners become involved.

Two of the domains that LilyPad had a direct impact on were e-Textiles and wearable computing, but more importantly the project opened up a design space that went beyond these domains by, for instance, crafting activities based on paper [16][13]. Other projects such as Amarino focuses on quick and accessible prototyping between an android device and an Arduino [10]. Similarly, there is a whole range of products like BLEduino [30], Blidgets [11] and DUL Radio [2] – platforms bridging the prototyping and wireless technologies to make design and explorations of accessories and IoT systems easier.

Yet another example from research is ActDresses [8], a proposed concept for exploring how actual use of accessories can influence a device and vice-versa. ActDresses is way of tapping into existing practices of dressing up interactive artifacts to make them more personal, like, for instance, dressing up robot toys or vacuum clearers. The idea is that clothes and accessories can have inbuilt identification tags that seamlessly alters the device's programmed behavior.

SUPPORTING PROXESOSORY DESIGN AND DEVELOPMENT

To support our exploration of Proxessories we developed a collection of tools. Having a prototyping platform provides a hands-on way for exploring Proxessories, but at the same time it is important to stress that it will likely not fulfill the entire spectrum of needs. An iterative process where the design space is gradually opened through iterations over both platform and interaction-design instances helps to see which needs stand out and absolute needs to be catered for in the platform. The resulting platform thus becomes something like a design platform since it more specifically supports interaction design practices tied to a particular design space.

The point of a prototyping platform is not necessarily to produce the final product but to enable the brainstorming and early prototyping. It needs to have the crucial properties and cater for the key experiential qualities to improve our design explorations. The collections of tools, what we will refer to as platform has been tailored the use of two programming languages, and those, that are supported by a large existing community (Arduino) or the most used (Javascript). On the other hand, the hardware has been designed to take advantage of low power technologies, and emphasize wireless communications, all integrated in a small-sized board. Figure 2 shows how all the elements are connected, the Arduino wireless board (rFlea) connects to existing mobiles phones, and, using its cloud connectivity, they bridge into the cloud prototyping tool (Insbits Studio). The next subsections will give more detail in each of the parts that form the platform.

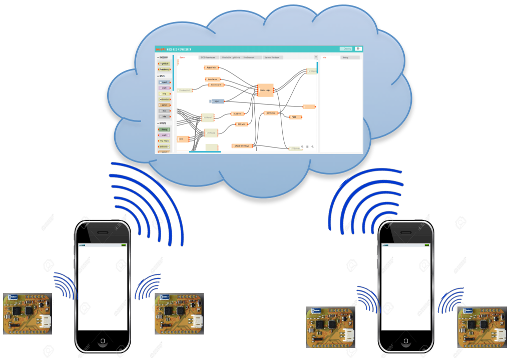

Figure 2. How the platform is connected

RFLEA: AN ARDUINO COMPATIBLE WIRELESS BOARD

We have built an Arduino compatible prototyping board, rFlea (see Figure 1, left), with wireless transceiver that allows us to talk directly to mobile phones, tablets and computers in general.

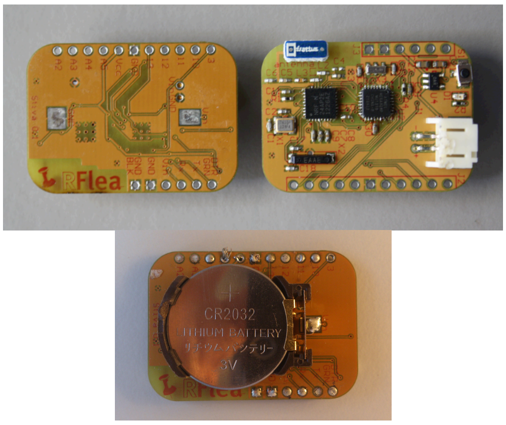

Figure 3. Close look at rFlea: The top left image shows the bottom view, including the two solder points for mounting a standard coin cell battery holder, and the top right view included the (optional) JST connector for connecting Li-Po batteries. The bottom picture shows rFlea with coin battery onboard.

A central aspect we considered while developing rFlea was the desired small form factor (see Figure 3). As can be seen in the analysis of the Proxessory design exemplars below, a key ideal was to reduce the size of the Arduino board. Balancing the tradeoffs between small size on the one hand and practical use (e.g., the number of pins that can be placed on the edges) on the other hand, we ended up with a layout of 25 times 35 mm with rounded corners.

Closely related to any considerations regarding size and form factor of the desired kind of prototypes and applications is power consumption, as, in any untethered working system power consumption practically translates to (battery) size. Thus, for rFlea we aimed for an ultra-low power (ULP) system that consumes as little energy as possible, with the ability to scale functionality and processing power (and thus energy consumption) on demand. This means we aimed for an implementation that provides fast processing and wireless connectivity when needed, while offering idle modes that consume at ultralow power levels systems, thus allowing rFlea to be deployed for long-time applications.

In order to provide a sustainable prototyping solution, we decided to base our design on the well-established Arduino platform. It is a standard that has proven to provide easy-entry access to physical prototyping with its combination of a standardized, yet extendable hardware platform and a simple integrated programming environment, with an ever-growing community that provides an incredible wealth of knowledge, information and sources in the form of e.g., code libraries and online documentation. Specifically, rFlea's range of functions is roughly based on the reference design of the Arduino Pro Mini [31], centered around an ATMEL ATMega 328p [32], with some necessary alterations due to the desired component size on the one hand and the requirements of interfacing with the wireless transceiver on the board (i.e., a reduced number of inputs and outputs in comparison to the Pro Mini) on the other.

The core-differentiating element of rFlea in contrast to any existing Arduino-based hardware is of course its incorporation of a wireless connectivity platform. rFlea provides this specific ultralow power technology in a way that is ready to use, by means of integrating the hardware as well as the software.

While simple examples can utilize the connectivity provided straightforward to, e.g., connect multiple rFleas, more comprehensive options are available in order to use the full potential of flexibility the wireless platform provides. This includes, among many others, options to create complex mesh networks on the fly, utilize signal strength to estimate distance between multiple rFleas, and create networks that dynamically adapt their transmission bandwidth in order to minimize power consumption.

Libraries and WebApp

To provide high connectivity to an rFlea board, libraries are available in two forms: Arduino libraries [33], JavaScript libraries [34] and a mobile app which handle all the connections and provide a Javascript environment to program, also known as webapp. The app has a web address where the creator can link to a webapp. Javascrip libraries are provided to handle all communications with an rFlea and make it fast and easy; no Android programming environment is needed as the webapp provided includes all interfaces to talk to the mobile phone hardware and wireless connections.

Insbits Studio

Insbits Studio is a visual dataflow, development platform that combines the power and flexibility of Node-RED [35] with the plug and play simplicity of Spacebrew [36]; both of which are open-source IoT visual programming platforms.

Insbits Studio, as seen in Figure 1 right, is a visual programming interface. The server is waiting for new artifacts to connect, where each artifact has a unique ID and can define outputs and inputs. New artifacts appear automatically in the top left corner (see Figure 4, left). For example, if we connect a new rFlea, with name "rFlea 59411" (see Figure 4 left) a box with that name will appear. Each box has the inputs on the left side (orange square) and outputs in the right side (orange circle). Once visible, we can drag and drop into the workspace (see Figure 4 right) and start connecting inputs with outputs and vice-versa from other boxes. Other boxes are available, like JS functions boxes, inputs generators, debugging, IoT protocols like mqtt or websockets in general.

Important features that we found useful in the construction of this tool are:

- Live animations of data arriving and moving through the connections.
- Unique ID for each object, so when it goes offline it keeps the connections and as soon it comes online the flow of data is recovered.
- Object oriented boxes.
- Compatibility with open-source programming platform.
- Only JavaScript used to connect to the server or manipulate code inside insbits Studio.

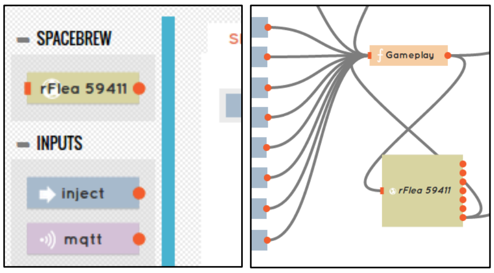

Figure 4. Left, tool bar with online artifacts. Right, input and output example.

The target user group is interaction designers who would like to quickly sketch out both interactive settings featuring any number of sensors and actuators. Moreover, for this case, it is important to point out that the design is focused around getting away from the often too abstract sensor/actuator model in favor of a more expressive format that can bring out more of the behavior of a thing or a device. Supporting this type of sketching activity would thus be the main defining design-characteristic for such a programming platform. Furthermore, we wanted it to be a modern platform that made use of the latest cloud- and web-based principles. In this way, what started as a small survey of existing systems, ended up becoming a mash-up project where different parts from different systems were stitched together to better support an actual interaction design process.

Insbits Studio was originally designed to support a small set of very simple sensors and actuators, but in the end, the project ended up supporting many more things, such as game controllers and other off-the-shelf components. This was a fortunate side-effect from mashing up two existing platforms that already had this functionality built in. The visual interface of Insbits Studio is at a first glance very similar to Node-RED. The main differences are that Node-Red does not have live feedback of data flowing and boxes, and only connections defined in the server can be effected, while Insbits Studio actively listens for connections. Another feature is that the artifacts define themselves through their boxes. In short, Spacebrew acts as the back-end server, while Node-RED generates the server side scripts that make up the logic between publishers and subscribers. Furthermore, each connector has been implemented so that it blinks when there is data available on the channel, similarly to that of Spacebrew. In its current version, any rewiring in the visual code graph is not in effect until it has been deployed through the deploy button.

All libraries and examples are open-source and available in GitHub together with instructions on how to install them and use them.

DESIGN EXPLORATIONS

Looking back at some of our own research, we have struggled when attempting to design interaction within the Proxessory design space. Our early explorations have often ended up being bulky, uncomfortable, and in many cases aesthetically unappealing. Because of this, it has sometimes been challenging to shape and probe the user experience.

To provide an example of this type of situation, let us have a look at a real design case from our own research. We were trying to design a sports app that would give feedback while running or skiing through vibrations on different parts of the body. The aim was to test in action different vibrators, in different places and patterns in a rapid manner. Using existing tools, we developed a test system that would be used in action. As expected the user portrayed in Figure 6 was not able to perform his sports freely, which in turn impacted the test and subsequent design iterations. As cables and soldering points tend to break due to bulkiness and body movement, we repeatedly experienced severe breakdowns of the system and interaction. In the end, it became almost impossible to test the things that we needed in order to advance the project unless we spent extra time making the system robust and usable.

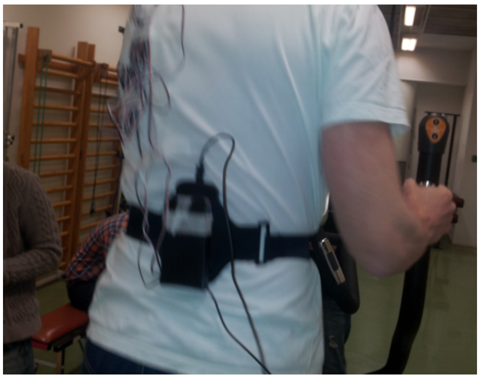

Figure 5. Interaction feedback in a sport system set up.

After several design projects that the authors of this paper have developed, we decided to develop a platform based on our experiences. In parallel to the design processes of developing a platform and testing them out in other interactive systems, there are a couple of projects where the rFlea platform co-evolved with the development of applications.

In the Metaphone project, an artistic paint installation that explores bodily relationships with machine aesthetics [19], we used an early version of the platform. The role of the platform at that time was less articulated, but an important outcome was that it enabled exploration of various accessories picking up on bio-sensor data (pulse, GSR (Galvanic Skin Response) and accelerometer-based movement data) that could be used to wirelessly connect with the machine. The platform allowed us to quickly build an accessory and connect it to the machine, see Figure 6. Because of this, the exploration became simpler and faster compared to the previous sports example, and in the end it affected how the artistic expression as a whole unfolded.

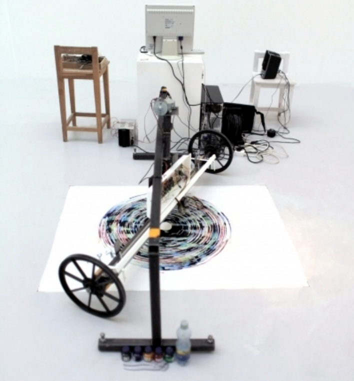

Figure 6. The Metaphone

As a second example of early design explorations, an early version of the platform was used in a studio session to enable hand-crafting electronic accessories [4], sensors and actuators using precious/natural materials e.g. wood, copper, silver, leather, wool, and seeds. For instance participants in this studio would explore how to craft interactive jewelry and in particular directly craft sensors only using various conductive and resistive materials (Figure 7). The platform allowed participants to quickly test the intended interaction using only their own mobile devices.

Figure 7. Hand-crafting electronic accessories.

To give examples of what interactions designers, students and other crafts people have done with the more complete and mature platform, in this paper we present five examples in more detail: the first four are student projects in a physical computer interaction course, while the last one is an interaction designer fast prototyping of an interactive light installation.

The Peripipe

The Peripipe [37] is a tangible remote control for a music player in the shape of an old crafted wooden smoking pipe, see Figure 8. The interaction is based on breath control, using sips and puffs as control commands. The Peripipe has an air pressure sensor and detects changes in air pressure, processes what air interaction is happening and wirelessly sends commands to a smartphone running a music player written in Javascript. Additionally, the Peripipe provides “fumeovisual” feedback, using color-illuminated smoke to display the system status.

This project was made by a group of five students. At the beginning, the students did not use rFlea as a prototyping platform. During the experimentation and test of different sensors and actuators, they successfully used an Arduino Uno (see Figure 9), where they could test and verify how the pressure sensor, the smoke generator and the LEDs would work together to provide the desired interaction. Approaching the concept of a smoking pipe as being a kind of Proxessory, they realized that is had to be wireless and the electronics inside including the battery had to fit in a very small place in order to keep the pipe in reasonable weight and shape and to not ruin the interaction experience. By the end of the project, after attempting to find available tools that could help them to fit all the system inside the pipe without having to redesign or add more work, they decided to use rFlea and Insbits Studio along with the specific Arduino framework and wireless libraries.

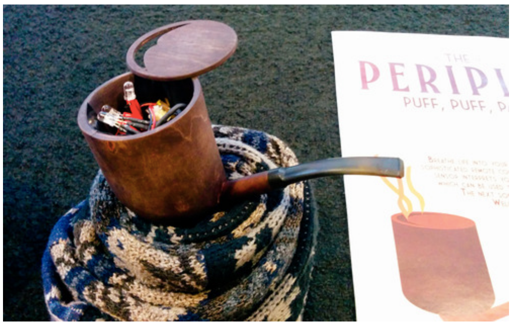

Figure 8. The Peripipe

This project shows the potency of rFlea in three ways. First, the Arduino compatibility allowed the design team to test sensors and actuators out of an Arduino Uno, and once these tests were finished, move all the work to an rFlea without adding much extra work to complicate and delay the building phase. Secondly, another aspect of rFlea that was highlighted by the students was the small size, robustness and all-in-one format with both microcontroller and wireless connectivity included. Finally, rFlea allowed working with media resources in the phone, for instance adding existing examples like Javascript code for playing music.

Figure 9. Left: early interaction sketches of The Peripe. Right: last prototype of the Peripipe

The Copernicus

Another student project that was realized in three days was called The Copernicus. In short, it is a pulse-controlled multiplayer game. It consists of a wristband with a light-based pulse sensor (see Figure 10). One or more players will play the game at the same time and also compete against each other. The goal is to reach a particular pulse-window – indicated by a green light – and, if the player manages to keep the pulse in that window for a certain time, the player wins, and a light sequence will appear. The losing player(s) will get a bright white blinking light. The game can then be externally reset, and a new goal pulse can be set.

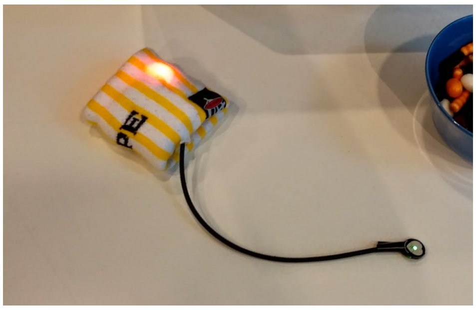

Figure 10. The Copernicus heart rate game

This project was sketched and then shifted into a functioning prototype and tested in about two days of work. It uses the advantages of Insbits studio where the game logic is programmed in the Insbits Studio in the cloud. Figure 11 shows all the game logic in a visual form. As the students made heavy use all the readymade libraries provided by rFlea, the mobile web app as well as the Javascript libraries, they were liberated to instead focus in the interaction and material aesthetics of the prototype. For example, they did not have to solve the connectivity between Copernicus, the mobile and the server.

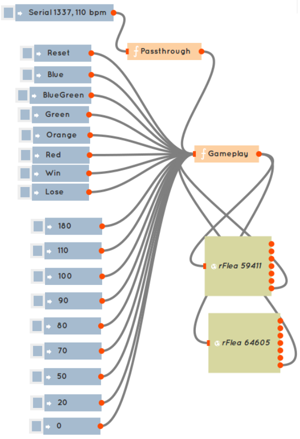

Figure 11. Game logic

Meya Bag

The Meya bag [38] (Figure 12) is a leather hand-bag that communicates wirelessly with your smartphones. It allows you to control certain functions of the mobile phone and react to incoming calls directly through the bag instead of having to pick up the smartphone [38]. By using clothing design to implement the material “feel” of the interaction combining it with an rFlea and conductive thread, the result became a functional fashion accessory. The bag has a snap metal button that acts as a switch, a padded ball winded inside with a tubular knit stretch sensor made of resistive yarn which can be used as a potentiometer by squeezing it. Finally the front face of the bag is filled with LEDs using conductive thread and a servomotor that generates movement in the fabric.

An app available for Android phones will seamlessly establish connectivity with the bag and enable its functions when worn. When the phone receives a call, the LEDs and motors will go on in a pulsating pattern to alert the owner, by squeezing the ball the call can be rejected without taking the phone out of the pocket, and finally, the snap metal switch can be used to set on or off the silent mode of the phone.

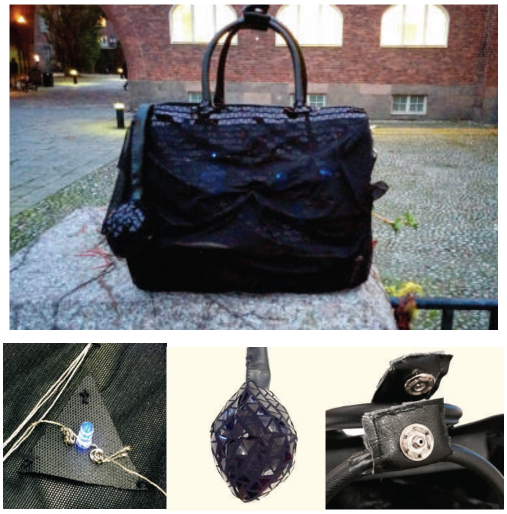

Figure 12. The Meya bag (top). Left: conductive thread to connect the leds. Center: squeeze ball made of conductive yarn. Right: switch made of snap button.

The Meya bag shows how an accessory can be turned into a Proxessory while tapping into the existing practice of accessorizing, developing the aesthetical expression and developing the dynamic interaction.

Memonile

The Memonile [39], is an accessory to a mobile phone that is worn around the neck like a necklace and wirelessly records notes, messages or drawings through its touch screen. Messages created on the Memonile can later be retrieved through an accompanying app in the mobile phone. The design exploration of the device revolved around having little or no feedback when pointing at the touch surface, and completely leaving out the visual element of the screen.

Figure 13. The Memonile

The Memonile (see Figure 13) is a small device built from hand-crafting and laser cutting materials (leather and wood) which, when combined with the technology, gives a very unique aesthetic expression.

The Memonile ended up being a fully working and operational demonstrator. The artifact together with all the software (mobile App) is not only complete, but actually provides the interaction outlined in the first conception of the idea. This was possible since the rFlea provided an all-in-one hardware solution, while the webapp together with the libraries allowed them to create an easy app that would talk to the Memonile. In this case, most of the effort was dedicated into crafting a distinctive look for the Memonile, instead of struggling with the technology and communication parts.

Space-Time Convolution

Space-Time Convolution is a playful artifact for visualizing and exploring human movement patterns in social spaces. The design consists of a set of portable, tennis ball sized spheres (Figure 14) that can be distributed in, a shared working space or an office building, for example. The spheres, made from transparent silicone, capture human movement in their close surroundings, developing an ad-hoc interpretation of what is going on through taking into account the variety of people walking by, their frequency of presence, the time spent in range, and so on. The complexity and dynamics of this local history is then expressed by means of the sphere illuminating in distinct, oscillating patterns. The design goal for this project was thus to find an aesthetic and temporal form that unfolds this spatiotemporal complexity while still replicating the blurry, somewhat unpredictable nature of movement in social spaces.

The system was deployed and explored in different surroundings, that is, in office environments, public events, and even in the control room of a thermal power plant. The "users" in these contexts were also equipped with unique identifiers that constantly transmitted using either rFlea boards powered from coin cell batteries or their own mobile phones running the webapp. The spheres on the other hand, consisted of battery-powered rFleas that continuously scanned for these identifiers and calculated the distance between them based on signal strength. The spheres would then change their lights in different pulsating patterns depending on the different parameters of the recent hours of human activity.

The main defining quality of the platform that came into play in this design case was its ability to provide wireless connectivity in a form factor small enough to fit the desired sphere shape. Moreover, rFlea allowed the spheres to work stand-alone, creating their own wireless infrastructure. In that way, rFlea allowed us to deploy tiny, coin, cell-powered wireless tokens, with months of battery life, to identify and monitor the proximity of people. This project emphasized the Arduino nature of the rFlea, as the interaction designers made use of their previous knowledge about Arduino programming to create an out-of-the-box, independent wireless infrastructure.

Figure 14. Space-Time Convolution light sphere deployed in the coffee area of an office space.

RESULTS AND DISCUSSION

Each of the five projects helped in illustrating the kind of support our tools provided for designing Proxessories. It becomes even more apparent when comparing to previous design experiences that some of the design teams had, where the design process broke down completely due to lack of proper tools that could realize the envisioned interaction.

Development of the platform was in itself a designerly process applied to an electrical engineering problem. The process contributed to our growing understanding of the characteristics of the design space itself as well as what kind of tools that might be helpful to support design efforts within it. The end result is a set of tools that provide better support for design led explorations of Proxessories.

Here we have presented five design cases that illustrate the kinds of support the tools provide for designing Proxessories, but also provide exemplars of what they could be. The selected cases are samples from a much larger collection of design cases that have used the tools. We would like to organize our discussion along themes that have been common in most if not all the cases: namely, materials and aesthetics, technical requirements, and interaction experience design.

Materials and Aesthetics

Aesthetics is important nowadays and so are material qualities. Sometimes materials and the corresponding skill-set for using these set the boundaries for what kind of designs that are being looked into from an arts and crafts perspective. Over the years we have seen people in the CHI community looking into various material practices, for example, old-school book binding [17], using leather [21], wood [18] or even silver-smithing [4] to name a few.

An important aspect from looking at the projects presented here is how the tools may work in favor of working with a particular set of materials. It seems somehow important that interactive technology does not get in the way of the crafting, but rather supports it, and possibly even pushes it further.

Moreover there are many new and – perhaps more significantly – affordable tools available to work with materials in new ways. Most recently, there have been examples like how laser-cutters and 3D printers have entered the scene and become widely used in industry as well as academia and maker-community contexts. An effect of having such tools as well as suitable technology like rFlea and Insbits Studio is that design practitioners will be able to afford spending time with materials that we have not very often combined with electronics before or demanding materials like glass, leather and bamboo. With such materials, comes other qualities like fragility, patina, reflection and suppleness, to name some that become both interesting and desirable, and in some cases enriches the design space in unforeseeable ways [22][23].

The result is that tools for making Proxessories enter fields and domains where traditional crafting practices need to be taken into account. By picking those and making them part of the tool and what it cater for, an active dialogue between them may emerge – creating a digital crafts movement [21][4].

Technical Requirements

Looking at the projects presented here, one of the more appreciated features was having something that was truly self-contained regarding low power and small electronic board size. This is certainly the case for all the presented examples. If one starts to design something that runs out of tethered power, it is often the case that the design will have to be appropriated around it. Starting with low-power and limited but contained supply in mind changes the outset of what is possible. High power consumption increases the size of the prototypes, as they require bigger batteries. Small form factor of the whole prototype has been an enabler in all presented projects in this paper.

One of the main outcomes of the Inspirational Bits project was the realization that interaction-designers often find themselves fighting their physical-digital material. For instance using Bluetooth in a design often turns into a struggle with the technology rather than a fruitful exploration of possible qualities in the interaction. Leaving such struggles behind and becoming truly *connection agnostic* is an important quality regarding the design space of Proxessories.

Reducing complexity of wireless connections through Arduino libraries, mobile phone apps and the effort to allow for a unification of programming languages (JavaScript) in the phone and in the cloud-based programming language, had a significant impact on the students to work to explore the design space. From early experiences, mobile phone programming has a steep learning curve. Using Javascript with libraries to control the wireless connections facilitates the interaction designers to focus on the tangible interaction and aesthetics of the prototype, not fight the technology.

Having things that are untethered enables “Things with satellites” as exemplified by the Meya Bag. Concepts such as these, pieces for thought or even directed attitudes, may in turn provide ways for directing research through design regarding tangible interaction. From this point of view, Proxessories may not provide any interaction themselves, but rather become truly ubiquitous by merely facilitating interaction. In the end it becomes a matter of actively choosing a proper stance for how to best engage with a particular design space. The design platform allows for a certain flow in the exploration in addition to providing “physical” characteristics.

Interaction Design for Experiences

Interaction designers often struggle with questions regarding, what their design will “feel” like and what novel experience[7] can be crafted? The field of HCI provides a wide range of methods for example, sketching in hardware, rapid prototyping, or lightweight ethnography to explore possible user-experiences. It becomes important that platforms and tools for Proxessories can be made to fit reasonably well with those existing already-established methods. That is not to say that new methods will not emerge along the road.

Providing grounding in what actually happens in the world and what people actually do is often the best stimulus to action and easily obtained. Many types of activities that are seemingly everyday activities , like, for instance, changing music (The PeriPipe), taking notes (Memonile), carrying a hand-bag (Meya Bag) or simply measuring the heart rate (playing The Copernicus) often provide us with a sufficient grounding to start the design process.

Accessorizing can be thought of as a generic activity that can be traced through the examples, one that provides an alternative to thinking about novel interfaces. Similarly Proximity expresses a sense of nearness, being close to, attached to or having a spatial relationship with something. To sum up, we have explored interaction design in the intersection of proxemics and accessories. We have named designs that inhabit this space Proxessories to indicate how they thrive in proximity to other devices and users, and their function as accessories to interaction. As such they are part of interactional ensembles or "outfits" that provide their value as a whole.

CONCLUSION

Proxessories are wireless, ultra-low powered devices with a small form factor. To facilitate our exploration of this design space we have continuously been developing a platform, rFlea and Insbits Studio, that can help us to better understand it. Furthermore, in parallel to developing the presented prototypes, the platform itself went through an iterative design process where we would try out new layouts using paper prototypes, mock-ups for shields, and others. Thus, the electrical engineering process was not only based on specifications, but rather driven by designerly ways of thinking and working. It is an explorative approach where one has to try out things in order to get a feeling for what works and not. In fact our process was one of tinkering rather than engineering due to its explorative nature [9][1]. We foresee an increasing demand for researchers who can bridge these two domains in our interdisciplinary field of interaction design.

The design tools provided in this paper are not meant to be the ultimate tools for designing Proxessories. Instead, they were themselves designed as yet another means to explore the Proxessories design space. Moreover, the tools were created using the most basic electronics, embedded programming, wireless technologies, mobile apps, cloud services technologies and visual programming interfaces that could be found. That said, each of these could be re-designed in ways that better articulate different aspects of the Proxessories design space or even expand others. From that perspective these tools and examples are intended to serve as *design exemplars* as described by Stolterman [39][11], that is – particular systems used in particular contexts.

After introducing rFlea and Insbits Studio as a constructive platform that aims to tackle those challenges, we provided several examples that demonstrated how students and practitioners successfully utilized our platform for the implementation of prototypical systems that utilize the crucial, desired characteristics of Proxessories, and at the same time explore the design space of Proxessories.

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REFERENCES

1. Jon Bird, Paul Marshall, and Yvonne Rogers. 2009. Low-fi skin vision: a case study in rapid prototyping a sensory substitution system. 55–64. Retrieved September 23, 2015 from http://dl.acm.org/citation.cfm?id=1671011.1671018

2. Martin Brynskov and Rasmus B. Lunding. 2012. Sketching sensor-based performances with DUL radio. *Proceedings of the Sixth International Conference on Tangible, Embedded and Embodied Interaction - TEI '12*, ACM Press, 363. http://doi.org/10.1145/2148131.2148218

3. Leah Buechley, Mike Eisenberg, Jaime Catchen, and Ali Crockett. 2008. The LilyPad Arduino. *Proceeding of the twenty-sixth annual CHI conference on Human factors in computing systems - CHI '08*, ACM Press, 423. http://doi.org/10.1145/1357054.1357123

4. Ylva Fernaeus, Martin Murer, Vasiliki Tsaknaki, and Jordi Solsona Belenguer. 2013. Handcrafting electronic accessories using "raw" materials. *Proceedings of the 8th International Conference on Tangible, Embedded and Embodied Interaction - TEI '14*, ACM Press, 369–372. http://doi.org/10.1145/2540930.2567906

5. Ylva Fernaeus and Petra Sundström. 2012. The material move how materials matter in interaction design research. *Proceedings of the Designing Interactive Systems Conference on - DIS '12*, ACM Press, 486. http://doi.org/10.1145/2317956.2318029

6. Saul Greenberg, Nicolai Marquardt, Till Ballendat, Rob Diaz-Marino, and Miaosen Wang. 2011. Proxemic interactions. *interactions* 18, 1: 42. http://doi.org/10.1145/1897239.1897250

7. Mattias Jacobsson, Ylva Fernaeus, and Rob Tieben. 2010. The look, the feel and the action. *Proceedings of the 8th ACM Conference on Designing Interactive Systems - DIS '10*, ACM Press, 132. http://doi.org/10.1145/1858171.1858196

8. Mattias Jacobsson. 2013. Tinkering with Interactive Materials : Studies, Concepts and Prototypes. Retrieved September 23, 2015 from http://www.diva-portal.org/smash/record.jsf?pid=diva2%3A668779&dswid=3027

9. Bonifaz Kaufmann and Leah Buechley. 2010. Amarino. *Proceedings of the 12th international conference on Human computer interaction with mobile devices and services - MobileHCI '10*, ACM Press, 291. http://doi.org/10.1145/1851600.1851652

10. Thomas Kubitza, Albrecht Schmidt, Norman Pohl, Daniela Petrelli, Tilman Dingler, and Nick Dulake. 2013. Tools and methods for creating interactive artifacts. *Proceedings of the 8th International Conference on Tangible, Embedded and Embodied Interaction - TEI '14*, ACM Press, 385–388. http://doi.org/10.1145/2540930.2568483

11. Youn-Kyung Lim, Erik Stolterman, and Josh Tenenberg. 2008. The anatomy of prototypes. *ACM Transactions on Computer-Human Interaction* 15, 2: 1–27. http://doi.org/10.1145/1375761.1375762

12. David A. Mellis, Sam Jacoby, Leah Buechley, Hannah Perner-Wilson, and Jie Qi. 2013. Microcontrollers as material. *Proceedings of the 7th International Conference on Tangible, Embedded and Embodied Interaction - TEI '13*, ACM Press, 83. http://doi.org/10.1145/2460625.2460638

13. Florian Mueller, Sophie Stellmach, Saul Greenberg, et al. 2014. Proxemics play. *Proceedings of the 2014 conference on Designing interactive systems - DIS '14*, ACM Press, 533–542. http://doi.org/10.1145/2598510.2598532

14. Roderick Murray-Smith, John Williamson, Stephen Hughes, Torben Quaade, and Steven Strachan. 2008. Rub the stane. *Proceeding of the twenty-sixth annual CHI conference extended abstracts on Human factors in computing systems - CHI '08*, ACM Press, 2355. http://doi.org/10.1145/1358628.1358683

15. Jie Qi and Leah Buechley. 2014. Sketching in circuits. *Proceedings of the 32nd annual ACM conference on Human factors in computing systems - CHI '14*, ACM Press, 1713–1722. http://doi.org/10.1145/2556288.2557391

16. Daniela K. Rosner and Alex S. Taylor. 2011. Antiquarian answers. *Proceedings of the 2011 annual conference on Human factors in computing systems - CHI '11*, ACM Press, 2665. http://doi.org/10.1145/1978942.1979332

17. Stefan Schneegass, Alireza Sahami Shirazi, Tanja Döring, David Schmid, and Albrecht Schmidt. 2014. NatCut. *Proceedings of the extended abstracts of the 32nd annual ACM conference on Human factors in computing systems - CHI EA '14*, ACM Press, 1441–1446. http://doi.org/10.1145/2559206.2581189

18. Vygandas Šimbelis, Anders Lundström, Kristina Höök, Jordi Solsona, and Vincent Lewandowski. 2014. Metaphone. *Proceedings of the 32nd annual ACM conference on Human factors in computing systems - CHI '14*, ACM Press, 1–10. http://doi.org/10.1145/2556288.2557152

19. Petra Sundström, Anna Ståhl, and Kristina Höök. 2007. In situ informants exploring an emotional mobile messaging system in their everyday practice. *International Journal of Human-Computer Studies* 65, 4: 388–403. http://doi.org/10.1016/j.ijhcs.2006.11.013

20. Vasiliki Tsaknaki, Ylva Fernaeus, and Mischa Schaub. 2014. Leather as a material for crafting interactive and physical artifacts. *Proceedings of the 2014 conference on Designing interactive systems - DIS '14*, ACM Press, 5–14. http://doi.org/10.1145/2598510.2598574

21. Anna Vallgårda and Ylva Fernaeus. 2015. Interaction Design as a Bricolage Practice. *Proceedings of the Ninth International Conference on Tangible, Embedded, and Embodied Interaction - TEI '14*, ACM Press, 173–180. http://doi.org/10.1145/2677199.2680594

22. Anna Vallgårda and Tomas Sokolar. 2010. Material computing. *Proceedings of the 12th ACM international conference adjunct papers on Ubiquitous computing - Ubicomp '10*, ACM Press, 383. http://doi.org/10.1145/1864431.1864447

23. John Williamson, Roderick Murray-Smith, and Stephen Hughes. 2007. Devices as interactive physical containers. *CHI '07 extended abstracts on Human factors in computing systems - CHI '07*, ACM Press, 2013. http://doi.org/10.1145/1240866.1240941

24. The Hidden Dimension (Anchor Books a Doubleday Anchor Book): Edward T. Hall: 9780385084765: Amazon.com: Books. Retrieved September 23, 2015 from http://www.amazon.com/Hidden-Dimension-Anchor-Books-Doubleday/dp/0385084765

25. Estimote Beacons — real world context for your apps. Retrieved September 23, 2015 from http://estimote.com/

26. Flic: The Wireless Smart Button. Retrieved September 23, 2015 from https://flic.io/

27. Fitbit Official Site for Activity Trackers & More. Retrieved September 25, 2015 from https://www.fitbit.com/se

28. Arduino - Home. Retrieved September 23, 2015 from https://www.arduino.cc/

29. BLEduino: Bluetooth 4.0 Made Easy. Retrieved September 23, 2015 from http://bleduino.cc/

30. Arduino - ArduinoBoardProMini. Retrieved September 25, 2015 from https://www.arduino.cc/en/Main/ArduinoBoardProMini

31. ATmega328P. Retrieved September 25, 2015 from http://www.atmel.com/devices/atmega328p.aspx

32. Flea_Arduino. Retrieved September 23, 2015 from https://github.com/MobileLifeCentre/rFlea_Arduino

33. rFlea_JavaScript. Retrieved September 23, 2015 from https://github.com/MobileLifeCentre/rFlea_JavaScript

34. Node-RED. Retrieved September 23, 2015 from http://nodered.org/

35. Spacebrew. Retrieved September 23, 2015 from http://docs.spacebrew.cc/

36. Proceedings of SIDeR 2015 - 11th Student Interaction Design Research Conference. Retrieved September 23, 2015 from http://www.sider2015.sdu.dk/proceedings/

37. MEYA – crafting an interactive bag with e-textile sensors and actuators. Retrieved September 23, 2015 from http://www.sider2015.sdu.dk/papers/38 MEYA %E2%80%93 Crafting an Interactive Bag with E-textile Sensors and Actuators.pdf

38. The Memonile. Retrieved September 23, 2015 from http://www.sider2015.sdu.dk/papers/35 The Memonile.pdf

39. The Nature of Design Practice and Implications for Interaction Design Research. Retrieved September 23, 2015 from http://www.ijdesign.org/ojs/index.php/IJDesign/article/view/240