Articulating Challenges of Hybrid Crafting for the Case of Interactive Silversmith Practice

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ABSTRACT
As interactive objects get embedded into different cultural contexts and take on more varied material forms, the relationship between interaction design and crafting practices in the physical domain is becoming increasingly interwoven. In this paper, we present an explorative project that involved intense collaborations between the areas of interaction design and silversmith practice. A main focus of the investigation concerned ways of surfacing conductive metals in interactive artefacts through the making of small, three-dimensional, and close-to-skin sensors. We reflect on insights made during this process, focusing on the challenges of combining the two knowledge areas on a level of materials, tools and techniques. In particular, we discuss qualities that silversmith crafting brings forth that can inform future directions of interaction design in terms of interaction gestalts, design values and hybrid crafting practices, more broadly.

Author Keywords
Hybrid crafting; interaction design; silversmith; metals.

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous;

INTRODUCTION
The research field of interaction design has recently seen a growing interest in how different so-called traditional crafting practices can inform the design of interactive technology, a theme grounded in perspectives on materiality of user experiences [13,65] and technology as design material [21,60]. Along this strand various physical crafting practices or materials have been of focal inquiry, such as leather crafting [56], glasswork [45], ceramics [41], paper crafting [30], or crafting with textiles [5,51]. Each of these studies point to historical and culturally rich perspectives that, in different ways, informed the making and thinking about interactive systems. Such combinations of interactive technology with physical making are referred to as *hybrid crafting* [14,15].

The work presented here contributes to this research space by reporting on an explorative research project in the intersection of silversmithing and interaction design. As a traditional craft, silversmithing is interesting to interaction design for a number of reasons. Firstly, due to their conductive properties, metals such as silver have a special position compared to other materials such as glass, ceramics or paper, in terms of interactive uses. Secondly, with the miniaturization of electronic components the design of interactive technology increasingly concerns relatively small physical objects, which is also a common focus in traditional silversmith practice. Thirdly, similar to glass or leather crafting, the established tools and practices of metalwork have long historical and cultural traditions as being relatively complex and performed primarily by professional craftspeople. When merged with electronics and interaction such practices may raise specific challenges in terms of hybrid crafting. We refer to this specific hybrid craft as *interactive silversmithing*.

Silversmithing in relation to interaction design is a relatively marginal research area, although there have been several previous studies related to jewellery in this domain [12,32,55,62,64,66]. While most previous explorations in this area have concentrated on aesthetic and cultural expressions, this paper will instead draw attention to challenges and possibilities in the concrete making of artefacts that combine metal crafting with electronic and interactive behaviour.

We will present an explorative interaction design project conducted during one-year long research collaboration with the professional silversmith artist Emma Rapp (3rd author). Throughout this year we engaged in practical design work at the silversmith studio, studying the intersection of the involved practices on a fundamental level of materials, tools, techniques and interaction gestalts, which refer to the experiential qualities of interaction design [27]. The main results will be presented in the form of insights and challenges that emerged throughout the project. We end with a broader discussion on the topic of interactive silversmith practice, focusing on some of the underlying value clashes that affected this project. In particular, we

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reflect on how the project gradually evolved into a character of slow, explorative tinkering; how this also shaped the interactive gestalt of the crafted outcomes; and finally, how we foresee new possibilities for designers as new tools and techniques will emerge in this domain.

BACKGROUND

One of the first scholars to bring attention to the notion of craft in the domain of interactive technology was Malcolm McCullough with his book Abstracting Craft: The Practiced Digital Hand, of 1998 [29]. Although that work focused primarily on aspects of crafting with media expressions displayed on screens, it also highlighted how bodily aspects such as hand-eye coordination and physical parts of an interface such as a computer mouse, are also fundamental to design practices in such partially intangible domains. The word *craft,* according to McCullough, refers to *'a specialized skill or dexterity in the manual arts'* and as a verb, *to craft* means to participate skilfully in some small-scale process ([29], *p.20,21*). Other definitions of craft also stress the skills needed in order to engage with materials [42] or the process of 'thinking' through the hands [33]. Yet a number of scholars are referring to crafting as an everyday practice, rather than crafting as a practice done only by experienced craftspeople [15,38,42]. In that context crafting has been used to describe any process of making such as knitting, or other DIY practices that entail a personal fabrication of artefacts [37,50]. Thus, when using the word 'crafting' instead of 'making' several aspects are usually highlighted. Those are related to a particular set of skills practised and applied by a person in a small-scale making process rather than mass production of goods, and with a visual presence and link to art [1,16,46].

In interaction design, the word crafting can be used not only for describing a making process that results in a physical interactive artefact, but also for the crafting of computer code or interactive media expressions [3,17,26,29]. When the crafting process and its result include both physical and computational elements, these forms of making are referred to as 'hybrid crafting', 'hybrid fabrication' or 'digital craftsmanship' [8,15,19,67]. The definition provided by Golsteijn *et al.* of hybrid crafting is: *"*[the] *everyday creative practices of using combinations of physical and digital materials, techniques or tools, to make interactive physical-digital creations"* ([15]*, p.594*).

Some of the most well-known examples of hybrid crafting can be found in the field of wearable technology, such as technologies embedded into clothes, accessories or jewellery (e.g. [25,39,52]). Examples of artefacts in this domain range from interactive accessories for health or sports contexts [28,34] to more conceptual design explorations focusing on decorative, performative or artistic expressions [9,23]. In particular, for the domain of interactive silversmithing, several early projects related to interactive jewellery were conducted around one decade ago. A general theme of these works concerned conceptual designs around bodily and social aspects, the wearer and his/her surroundings [22], or questioning assumptions in regards to everyday technologies [7,31]. Interactive jewellery has also been studied from a artistic perspective, in relation to personal attachment to objects and people [63,64].

Since these early explorations, significant technological developments have radically changed the possibilities of realising more sophisticated interactive artefacts. The recent advancements in more energy-efficient wireless protocols such as Bluetooth Low Energy (BLE), in addition to the miniaturization of electronic components, provide new possibilities in regards to mobile and wireless designs, e.g. in the forms of so-called Proxessories [47], being interactive accessories that work in close interplay with other interactive devices. Such recent advancements allow for a new design space to emerge at the intersection of interaction design and the design of small and mobile wearable artefacts. Looking at commercial products, apart from the most ubiquitous example of smartwatches, there are now many wireless accessories ranging from Apple's EarPods to wearable devices such as Cuff [68], Ringly [69], or Bellabeat LEAF [70], which are elaborately designed almost as exclusive jewellery items.

Recently, several scholars are looking at this field from a conceptual interaction design research perspective. For example Tsaknaki *et al.* [55], who discussed how the intersection of jewellery and interaction design can provide a fruitful space for re-thinking the design space of interactive accessories by questioning some of the clichés often associated with this domain. Others have investigated the intersection of interaction design and jewellery crafting in relation to socio-cultural values [62], or through more concrete design examples (e.g. [12,32]). These studies highlight in different ways the need to draw more attention towards the concrete aspects of crafting, materials and culture, in relation to interaction design.

The interrelation between materials and making in interaction design has been studied from several perspectives, such as through the concept of *Inspirational Bits* [49], as a way to expose, and get familiar with the properties of specific technologies, when designing interactive systems. Another great inspiration to the present study is the Kit-of-No-Parts, introduced by Perner-Wilson *et al.* [36], showing how sensors can be made concretely using conductive textile materials. As they mention, exploring different techniques for making textile sensors can allow for more "*transparent and expressive designs*" ([36], *p.66*). Additionally, the notion of *computational composites*, introduced by Vallgårda and Redström [59] highlights the interplay between physical matter and computation. More recent studies are looking at the intersection of programming and crafting, for example through the practice of *material programming* [57], or expanded explorations of the notion of *bricolage* [58], pointing to how material knowledge and resources very concretely may shape design thinking and -practices.

AN EXPLORATIVE STUDY AT A SILVERSMITH STUDIO

The study presented here was part of a long-term research project called Arts & Crafts, investigating crafting practices with historical traditions in relation to contemporary interaction design practices. It was also part of a larger regional initiative focused on innovative practices within the cultural sector, called Innovativ Kultur. In this context we got the opportunity to engage in a one-year collaborative study together with the local silversmith artist Emma Rapp.

Emma is trained as, works as, and defines herself as a silversmith artist. However, before we rush into generalisations, we would like to acknowledge that craftspeople in the area of silversmithery approach their artistry in very different and often highly specialised ways. A practitioner in this field may, for instance, focus on fabrication of standardised objects by extensive use of high-tech tools, or making fine design of utilitarian objects such as bowls or cutlery, or specialise in restoration or alteration of existing objects, e.g. adjusting the size of old rings or repairing broken necklaces. With a creative training in fine metal arts from the early 2000s, the practice of Emma is characterised by the making of conceptually loaded artworks in the form of jewellery or decorative artefacts by using tools and techniques taught in a classic silversmith education. Like many other silversmith artists, she does sometimes integrate other materials in her designs apart from metals, such as glass beads, seashells or wood. Since her exchange studies in Japan, an important influence has also concerned the Japanese philosophy of Wabi-Sabi, which is related to imperfection, simplicity and nature [40]. An example of her earlier work entitled ‘Religion Envy’, concerned symbolic meanings of jewellery items within contemporary atheist communities and cultures. Much of her recent work takes the form of jewellery items or artworks presented in exhibition settings, inspired by simple objects found in nature. At the beginning of this project she had no prior experience of either interaction design or electronics, but was highly intrigued by the topic and had a very active role in formulating the project as a whole.

The other main participant in this study was the first author, who worked close to the silversmith throughout the project. Apart from being a researcher in the domain of interaction design, the first author has also a background in product and textile design, and prior to this project had some very basic experience of silversmithing from related workshops. Involved in this project were two more interaction design researchers, one specialising towards electronics and the other in physical interaction design.

Methodological Approach

During a full year the first author was paying regular visits to the silversmith studio (Figure 1), located in the downtown area of Stockholm. These visits were on average twice per week, during which practical work was conducted between three to eight hours at the studio. The studio hosts several crucial tools and equipment for the silversmith practice such as soldering torch, anvils, bolts, or rolling mills for flattening metallic sheets, which could not be moved and carried to a different physical space. To be able to make interactive prototypes various tools and technologies were brought to this space, including different types of prototyping boards, a multimeter, batteries, soldering iron, small sensors and actuators, cables, e-textiles and conductive threads of different kinds, laptop and smartphone with various software programs installed for interactive experiments.

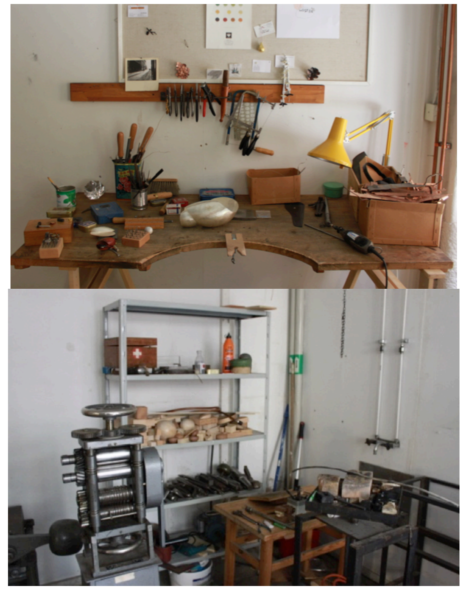

Figure 1. The silversmith studio: a) The desk where most work is conducted, b) a room with specialized equipment and tools for occasional use.

In this setting, the first and third authors engaged collaboratively in various explorations either on an artefact simultaneously or on different artefacts, side by side. Following a research-through-design methodological approach [10,48], the focus of the practical work was to explore the intersection of interaction design and silversmith practice on a fundamental level. This included the exploration of possible combinations of the different types of materials involved in regards to their properties, but also the observation and reflection on the particular hybrid crafting process and its emerging challenges, more broadly. As an explorative research project, the main intention with this study was to learn through hands-on experimentation at a level of tools, materials and techniques in this intersection. These explorations were conducted both from an engineering- and from an artistic perspective, involving the making of electronic circuits and software programming on the one hand, and how to combine these to artistic silversmithery, on the other. These two directions were explored in parallel and in close interplay, by following an explorative and highly collaborative design process.

Therefore, the goal of the practical work was not to produce a specific product or even to address a specific design challenge, although several conceptual design ideas were taken into consideration. As the practical work evolved, we focused on the making of simple prototypes and tangible artefacts, such as sensors. The making of concrete artefacts was an important part of this study, since when following a design and practice-based research methodology the actual designed outcomes become the key means in constructing knowledge [24]. Apart from the tangible artefacts that were produced we collected data from the practical work in the form of video recordings, photos, sketches and field notes. Those revealed how the hybrid crafting process evolved over time and were analyzed based on emerging themes that highlighted juxtapositions between the interaction design and the silversmith practice.

TOPICS ADDRESSED IN EXPLORATIONS

After the full year of the project had passed with numerous hours of practical design work each week in the studio, our developed artefacts consisted of a series of small-scale probes, a handful of beautiful but non-interactive mock-up designs, a number of partly completed or broken experiments, and a larger number of simple input components. Several of the artefacts we spent many hours sketching, discussing, making and embedding with electronic components had turned out as dead ends. The parts that in the end actually did work had also taken substantial time to complete, especially in regards to their relatively simplistic functionality. However, we arrived at interesting findings in regards to the making process and possible interactive gestalts at the intersection of interaction design and silversmith practice. Below we discuss our main insights in terms of:

- Basic material manipulations: Joining and shaping
- The design of simple sensors
- Hiding and surfacing the electronics

Basic Material Manipulations: Joining and Shaping

One of the primary motivations for the project was that silver is highly conductive, which is a central property of materials used to make sensors in physical computing. Metallic compounds are also part of cables, circuit boards and other electronic components, in order for electrical current to pass through. Thus, metal being present in both practices became a resource for studying ways of designing interactive artefacts that incorporate elements of silversmith practice. We imagined that the intersection of silversmith practice and interaction design could become increasingly relevant for future directions of augmenting jewellery and other accessories with interactive elements. Much of our explorations thereby were focused on a 'proto-level', meaning that we explored the making of simple sensors by testing and combining different materials, and most importantly observing and reflecting on the actual making process.

Quite similar to how electronic components are connected together or to a circuit board, *soldering* is well known and also fundamental in silversmith practice. However, we quickly learned that it is done in a rather different way than what is taught in an electronics class. Soldering in physical computing is relatively standardized compared to soldering in silversmith practice, in which there are substantial differences in the actual techniques and tools depending on the type of metals to be soldered, and for what purpose. On the contrary, when soldering electronic components there is mainly one type of metal used, the solder, and the parts that need to be combined are most often pre-manufactured, or designed for such purpose. The main tool used for soldering in silversmithery is called a *soldering torch* (Figure 2a), which is similar to a soldering iron, but based on a gas flame instead of an electrically heated tip. Apart from heating the pieces of metal to be joined and melting the solder for the same purpose, the soldering torch is also used for heating a metallic surface in order to make it soft and malleable and therefore possible to bend, shape or deform. Thus, even though the fundamental idea behind soldering is common to electronics and silversmithing, a main difference between the two is that the soldering torch has a strong flame that reaches high temperatures over a larger area. Using a soldering torch on electronic components would normally not work well, since electronic components are sensitive to the exposure on high temperatures, as cables may melt, circuits can be damaged, and soldered connections can be de-soldered. This posed very concrete challenges when we had to alternate silver crafting with the

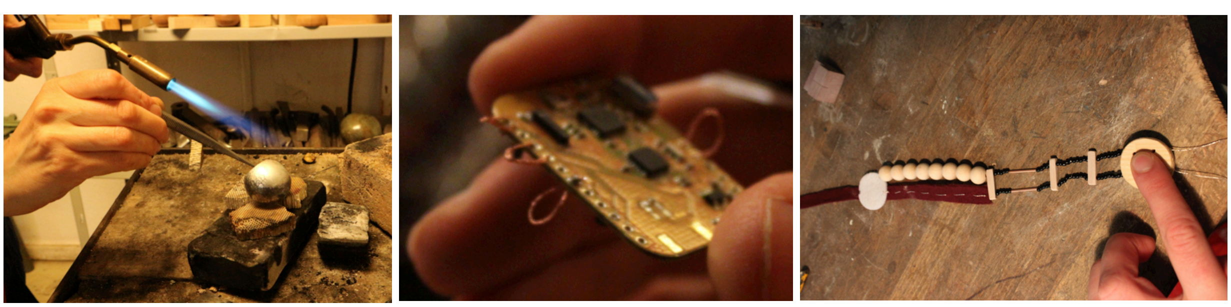

Figure 2. a) The soldering torch used in silversmithing for soldering metals, b) the customized Arduino-compatible rFlea circuit board with loops of conductive thread for quick connections, and c) a prototype necklace with an embedded potentiometer and a button.

making of a circuit on the same artefact, to connect cables, test different types of sensors, or fix connections.

Apart from soldering, another way of connecting metals in silversmithery is to use small rings to connect two metallic elements. Two small holes are drilled on both surfaces and another small metallic stick, later bended to the shape of a ring, passes through both holes. This is similar to the way a chain is made out of bended metallic rings. Although this technique is common in silversmith practice, it does not align with typical ways of making electronic circuits, since it does not guarantee a permanent connection and may cause temporary gaps e.g. when the object is lying flat on a table. However, inspired by this technique we tested ways of incorporating loops of conductive thread or metallic rings to the input/output pins of the circuit boards used in our explorations. This provided the possibility to connect metallic chains or conductive thread that we used as cables directly to the board and therefore make ‘plug and play’ solutions for the particular context (Figure 2b). Another technique for connecting metallic parts in silversmithing is to simply ‘stitch’ together the metals, similar to how flat surfaces of textile or leather are sewn for making three dimensional forms, as described in [56]. However, compared to e.g. textile crafting, the shaping of metallic objects is characterised by rather harsh treatments, using strong forces, such as hammering, drilling, and melting or softening the metals in high temperatures, combined with small-scale manipulations and activities upon these objects.

We also tested different combinations of highly conductive metals with non-conductive materials such as leather, organic matter or wood, in order to shield off and make functioning designs. For instance we explored the use of thin copper and silver sheets for coating materials such as wood, seashells, leather, and even dried leafs (Figure 6b), threading glass or wooden beads to shield off copper threads (Figure 2c), and ways of embedding metallic sections into solid wood (Figure 4) [11]. We also experimented concretely with how to connect components to a breadboard or circuit boards by making new ‘plug and play’ components out of jewellery hooks or silver pins.

The Design of Simple Sensors

Early on in the process we did several small-scale explorations using different types of actuators, including an interactive accessory made of wood that incorporated LEDs, a series of speakers embedded in various metallic shapes, and servo motors embedded into bracelets [53]. However, as the project evolved, the main direction of the work took the form of exploring the conductive and resistive properties of different materials, for making simple, nice looking and robust sensors.

Our research process resulted in several versions of buttons, switches and potentiometers as small artefacts that could be used as beads, pins or jewellery objects (e.g. Figure 2c). Rather than as complete products, we imagined such types of sensors to communicate wirelessly to a mobile device, such as a smartphone or a laptop and to trigger events on the remote device. For example when taking the forms of beads they could be part of a necklace or a bracelet, or when taking the form of a physical button they could work as a stand-alone accessory or as part of a garment. By making such simple sensors we explored subtle interaction gestures such as turning, sliding, stroking and light touching with the fingertips, compared to the touch screen interactions that dominate most current engagement with technology. Apart from actual making and sketching, *hands-only scenarios* [6], became an important resource in the process, in showing and experiencing design ideas, before reaching a prototype level of design concepts.

Specifically, this is reflected in the decision to focus on the making of varied types of small input sensors that could be worn or placed close to the body, and that would be triggered by close to skin interaction. Similar to how people who wear jewellery may habitually fiddle and twiddle with them in different ways, such as stroking an earring or sliding the beads of a necklace along the necklace cord, we saw an interesting space when it came to designing small interactive or responsive artefacts that could allow such types of subtle, hidden and in some sense even implicit modes of interactions. In terms of interactive function, the sensors were designed as components similar to any common physical button or switch, with the difference that they incorporate elements of silversmith practice and materials of which buttons are not usually made.

The buttons in Figure 3 are each based around a coin-size Bluetooth Low Energy (BLE) module from BlueRadios embedded inside the cavity of each button. They can be used as wireless controls of smart devices, a phone or a laptop. As depicted in Figure 3, conductive thread is used to

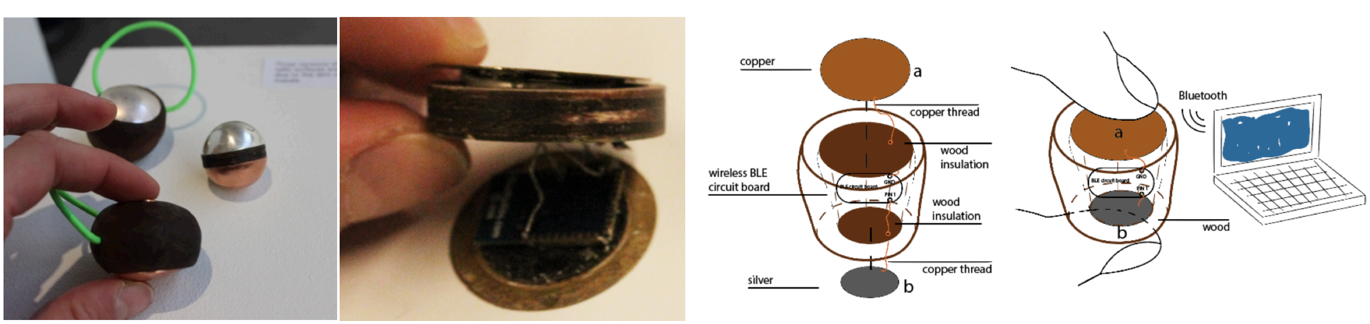

Figure 3. Variations of a wireless button made of copper, silver, wood and a BLE module. When both metallic surfaces are touched at the same time with bare skin, the circuit is closed and the button can trigger an action to a remote device.

connect each metallic plate surfaced on the button, to the metallic plates embedded on the BLE module (Pin Number and Ground). In that way, when touching the silver and copper surfaces simultaneously, an action is triggered. Similarly, an action would be triggered, or the state of the button would change, if one metallic surface is already in contact with bare skin and the same person touches the other. However, a challenge here was to create a cavity on the wood that it would be deep and long enough in order to host the BLE module, without affecting the radio signal transmitted from the module to a mobile phone or a laptop. The less the distance between the two metallic plates surfaced on the wood, the less space is available for the radio signals to be transmitted outside the module and reach the connected device. During an exhibition at the silversmith studio we demoed a wireless version of such a button (Figure 5a), in which the 'touch action' was mapped to changing the colour of a laptop screen, along with sending some extra information (proximity to the connected device and surrounding temperature). But it could just as well have been used for posting a notification, answering a call, or switching on a smart light, quite similar to the Flic button [71].

An example of another design is depicted in Figure 4. The main body of this touch button consists of wood and two silver inlays at its surface are connected to the copper tubes that penetrate the wood from both sides. When the two separated conductive threads that pass through the tubes are connected to a circuit board, the button is ready to be used. When simultaneously touching the two silver surfaces the circuit will 'close', triggering any event that has been mapped to this action. Figures 3 and 4 show how to concretely make buttons of the type we designed in this project.

Hiding and Surfacing the Electronics

A main question that emerged at the beginning of the study, and which continued to be a strong theme of discussion throughout the practical work, concerned what types of interaction gestalts to explore when combining silversmith practice with interaction design. Two alternative approaches were utilised to foreground the silversmith crafting in our study, which we here refer to as *hiding* versus *surfacing* the electronics.

The practice of giving shape to a metallic object most often includes hammering and/or melting metals in high temperatures, which may seriously damage any fragile electronic components involved. One way of overcoming such constraints was to make shapes and forms out of copper or silver in a way that would be possible to integrate or connect with the electronic components at a later stage. Similar to how most consumer electronic products are designed in which the electronic components are *hidden* and protected under a surface of a physical material such as plastic, glass or metal, the silversmith made several mock-up casings from copper, silver and wood, exploring alternative physical forms that could serve such a purpose (Figure 5b). This approach was one way of converging both practices and allowed us to find ways of overcoming problems in working simultaneously on the same artefact. One main goal while sketching and crafting such physical casings to protect and host electronic components was that they should provide access to the electronic components, in order to support practices of repair and maintenance. For example, some of the casings were designed as small boxes, possible to open and close with a small hinge. Others had more complicated shapes, as in the case of a silver spiral casing made for a speaker in a way that the cable of the speaker follows the spiral curvatures, making direct use of the acoustic properties of silver.

One core challenge we had to face was how to integrate circuit boards into complete designs, since existing circuit boards for prototyping purposes were not designed specifically for the context of silversmith crafting. Along this line we started thinking and sketching on possible imagined designs of circuit boards for the particular context, similar to how LilyPad Arduino [4] was designed for working with e-textiles. For the scope of this project however, and since the design of circuit boards was beyond our research focus, these explorations remained at a level of low-fidelity probes or sketches, mainly in regards to their physical form. In most of our explorations we used the rFlea [47], a wireless and customized Arduino-compatible prototyping board small enough to embed into designs of various shapes, and at the same time possible to connect remotely and program to interface with a smartphone. As described above, some designs also used more basic BLE modules. At the beginning of the project we also made use of the Aniomagic Chiclets, which unfortunately was discontinued during the time of this project.

Hosting electronic components and especially circuit boards inside metallic cases might seem an irrational design exploration, since electronics can malfunction or behave

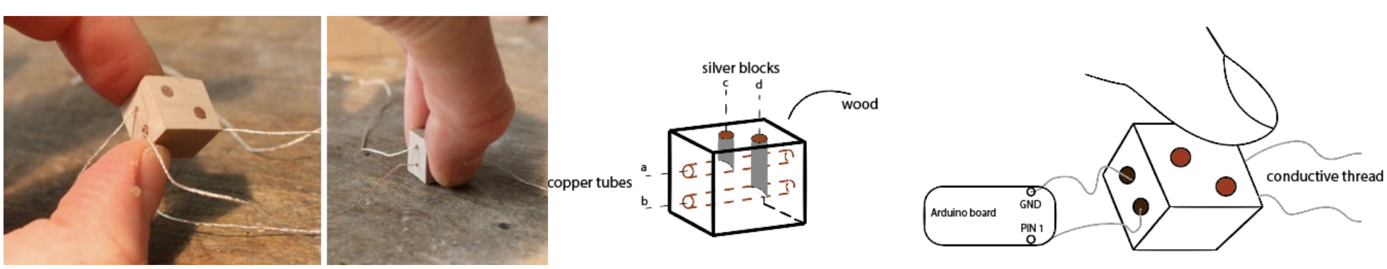

Figure 4. Wooden bead with copper and silver elements that functions as a button: when touching both silver surfaces at the same time with bare skin the circuit 'closes' and the state of the button changes.

unexpectedly if they come in contact with metals. Such malfunctions include short-circuits, permanent damage of electronics or loss of wireless communication. This was a challenge underlying the full spectrum of our practical explorations, as we had to cope with both the advantage of the conductive properties of metals, but at the same time also with the disadvantage of the same property. In order to tackle such problems we used physical materials such as wood, glass beads, yarns and leather for covering, shielding and protecting metallic areas or electronic parts (e.g. Figure 5c). This posed many challenges and was further complicated also because throughout the practical work we tried to use mainly craft materials and avoid the use of plastic or rubber coatings or glue for our designs.

The other approach followed, which we call *surfacing the electronics*, describes the design decisions taken when making sensors. In these examples, metal (copper or silver) became both the touch-sensitive input interface for triggering an action or interacting with something, but also the actual material used for making a decorative surface, as described in the section 'The Design of Simple Sensors'. In these cases, a silver or copper surface became both a material for interaction design and for silversmith crafting. Indeed, this is in no way unique to our project, as the design of physical controls always has both functional and aesthetic features. However, bringing interactive features to crafted metallic objects added important dimensions to our explorations. What would otherwise be considered only part of the 'electronics' here became the sensor's visual and tactile surface, and thus a very distinct feature of its aesthetic appearance: the electronics, through the metals, *surfaced* on the artefacts.

DISCUSSION

We realised that one additional motivation behind this study, apart from studying the intersection of silversmithing and interaction design from a hybrid crafting perspective, was to explore another aesthetic and ideological viewpoint other than the one communicated by the design of most electronic gadgets today. The choice to study silversmithing was partly made because this crafting practice has strong cultural and historical significance; it carries particular values, and at the same time is very distinct from interaction design. This is especially since the craft of silversmithing often deals with pure aesthetic, rather than utilitarian values such as efficiency and functionality, which are more dominant in interaction design. This new territory provided a ground for reflection on the values and ideals that are predominant in the domain of interaction research, more broadly.

The explorations and insights presented above led to several meta-reflections concerning value conflicts from working in the intersection between artistic silversmithery, product design and interactive technology. Below we briefly discuss three high-level themes that emerged from this study and were repeatedly brought to discussion. Each theme points to a shift in focus on how we addressed our explorations:

- From actuated expressions to sensors
- From rapid to slow prototyping
- From professional crafting to becoming beginners

From Actuated Expressions to Sensors

The first topic we want to bring to discussion concerns our shift in focus from expressive properties of interactive technology by incorporating actuators such as led lights, speakers and even motors, to finally focusing almost entirely on the design and making of sensors. We could, for instance, have explored designs that would incorporate a small screen in interactive amulets or alternative designs for a smartwatch, since this direction is more aligned to the visual aesthetics and the expressive role of jewellery. A main reason for not following those routes was not that we saw them as less promising in terms of resulting design concepts or interactions, but rather that we wanted to stay as close as possible to the material realm and to its particular qualities. Therefore, we made an active choice to focus this project specifically on the design of input components and to explore the space of screen-less, as compared to the predominant screen-based interactions. Similar to [5,36] who studied textile crafting in relation to interaction design, we were driven by the properties of silversmith materials in our case, in combination with computational materials. We looked at their particular properties in terms of crafting, but also in terms of visual, tactile and conductive properties. Moreover, we found it a relatively unexplored dimension of the domain of interactive jewellery, which previously had put more emphasis on interaction, focusing on actuators and expressions [12,22,62].

Figure 5. a) A wireless version of a button, demoed in the silversmith studio, in which the touch action was mapped to changing the colour of a laptop screen, b) form study of physical shapes crafted as casings for hosting electronic components of interactive objects, and c) an example of exploring the use of leather for shielding electronics and conductive areas.

Looking at the intersections of silversmith crafting and interaction design without previous knowledge on how these practices could be combined, required a focus on the actual material level of both practices, which led us to the making of small-scale artefacts with rather simple interactive properties. The concrete material explorations also had a central role in the designed artefacts on a conceptual level. The concrete hands-on experiences helped informing ways of making interactive components but also ways to interact with such components. Specifically, we reflected on the subtle bodily movements and expressions performed, but also on how the body is experienced, during this hybrid crafting process. Here, we mean both the careful manipulation and handling of electronic components for soldering, connecting cables or sensors, stitching and threading pearls on conductive thread, but also the more general actions performed by silversmiths. For example, the focus needed for connecting two pieces of metal or two cables, the bending of the body forwards while combining materials or giving form to an object (Figure 6a), or the careful handling of tools such as pliers. Since working with electronic components in physical computing involves the use of small components that are most often fragile and sensitive to handle, it became necessary to pay attention to details and treat this group of materials with delicacy. Thus, the direction of making small-scale sensors was not only aligned to the small-scale manipulations and interactions performed with electronic components, but also to the crafting of tiny objects and elaborate details in the specific crafts practice of the silversmith studio we worked in. We were also intrigued by the direction of looking closely at this level of interactions, since most often our own experience with physical and tangible interaction design had been focusing on larger gestures and manipulations, for example, with controls that are clearly visible and involve larger movements or bodily gestures.

Additionally, the process of exploring the concrete ways of making a simple sensor such as a button or a switch, required us to think in terms of more varied shapes and dimensions for interaction. In particular, the actual materials used – silver, copper, wood – in combination with the tools and the techniques of the silversmith practice, led us to the making of three-dimensional forms and shapes. This provided a ground for reflecting on possible designs for input sensors, and how they could be given more varied forms – and consequently what types of gestures and hand manipulations such input objects could allow. In terms of interaction design, the small and three dimensional shapes became a different design space compared to sketching or designing two-dimensional flat surfaces, or screens for interaction, for example, which materials such as textiles, leather or paper are more aligned to. This was a direct influence from working in a silversmith studio and adapting our previous knowledge of making sensors from other materials, such as e-textiles, to the needs and characteristics of this particular crafting practice.

A distinct feature of most of the sensors and probes made in this project was the lack of explicit output on the object itself, which made them ‘calm’ and in a sense non-intrusive. However, the lack of clear feedback on these objects also led to a certain ambiguity, since there is no direct indication in regards to whether an action is triggered, or even if they are switched on, or not. This would likely not be acceptable in most scenarios, especially where manipulations would be distant or detached from the device in which the output is manifested. An important reflection in regards to this was that if electronically responsive devices can be given any form, or will be designed with more varied types of materials or shapes, it does in the end become difficult to know not just how to interact with them, or what the effect of such interaction would be, but also if the object is at all interactive or not. Still, this direction may open a space for alternative types of remote controls, such as using accessories or proxessories [47] with embedded sensors. Possible functions could be to play games on a smartphone, or to control or trigger very basic functions such as a music player. It could also be used for emotional expressivity, or for further exploring and reflecting on the design of *uncomfortable interactions* [2]. The touch-sensitive sensors explored here could potentially allow for a broader range of felt and intimate interactions (e.g. [18,35,43,44]). For instance, the texture and tactile properties of physical materials such as copper, silver or of different types of wood, could provide attractive close to skin interactions, for which the felt tactile experience will be central.

From Rapid to Slow Prototyping

A main reflection from this project, in terms of value clashes was the perception of time underlying our practical work at the studio. We realised that the amount of work embedded in the process could be seen, from a silversmith perspective, as a source of vocational pride. The careful and elaborate work invested into making a single artefact is in a sense what customers pay for, when they buy a hand crafted item by a professional craftsperson, rather than a mass fabricated object with otherwise similar features. This speaks to different types of ideals compared to rapid prototyping and interaction/industrial design in general. But it also reflects a clash between the two practices in regards to the ‘preciousness’ embedded in both the actual process and the artefacts resulting from a silversmithing process, being fine jewellery or a set of silver utensils, more broadly.

Apart from the actual craft practice, the silversmith materials used in this study brought attention to both the metals embedded in electronic components that are hidden in most designs, but they also relate to artefacts that are treated as precious, such as fine jewellery. An interactive object made of silver, or a delicate button crafted from copper and wood for example, challenge common ways of designing or adopting electronic products. At the same time a silversmith crafts perspective on the design of interactive products highlights notions of planned obsolescence and gadget consumerism. Such a perspective could allow for discussing electronic devices and technology from a critical perspective, as " *things that promote engagement versus things that promote just consumption"* ([61], *p.178*). However, as mentioned in [55] we should be careful not to make assumptions based on clishé images of jewellery, a domain that is indeed also loaded by expensive consumerist values on the one hand, but also with practices of cheap personalised, fashionable and traditional folklore objects, on the other.

Participating in concrete making while embracing values embedded in silversmith practice partially collided with ideals from interaction design, where we were used to much more rapid processes and more or less instant results. Our collaborative workflow slowly adjusted to the pace of the silversmith and finally much time was spent planning in advance, sketching, testing and adjusting before proceeding to the actual making of an artefact. In this respect, the way the work in the silversmith studio was organised was in many ways similar to how interaction designers are advised to sketch and prototype thoroughly before the actual implementation. However, such an approach also contradicts, to some extent, other methods that strongly influence interaction design practice today, such as agile development processes, where it is necessary and expected that designers generate something interactive that can be fine tuned and adjusted over time. A concrete insight was that making something 'quick and dirty' by using materials such as silver, and the tools and techniques the silversmith used, was almost impossible.

A feature of interactive technologies, including software as well as electronics, is that they can normally be adjusted and extended after they have reached a stage of functioning design. Cables can be replaced, different types of sensors can be added and software can be re-appropriated for new purposes. Interactive artefacts are commonly expected to be updated or improved over time, which has been previously discussed as a state of being unfinished [54]. A silversmith object is fine-tuned and adjusted extensively during a crafting process, however, as discussed above, the nature of crafting with these materials meant that metallic objects, once connected to electronics, could not easily be re-shaped again.

The mere preciousness of materials, such as silver, also had direct implications for the design process. Although the craftsperson can melt or deform a spare part and start over by reshaping it for another design, there is an implicit principle not to waste material. This is more acceptable when working with materials such as filaments for 3D printers, cardboard, or other materials commonly used when making physical mock-ups and prototypes in interaction design. The process also needed to be well planned in advance for aesthetic reasons, since adding extra material on a later stage of the process can be very difficult, especially when already connected to electronic components. The aim towards resourceful use of materials was reflected, for instance, in boxes in the studio, which were full of parts from previous experiments, broken pieces, spare sheets of copper or silver, or old jewellery, all saved for future designs. Before picking a brand new silver or copper sheet for a new design, the boxes were always searched for parts that could be used or re-appropriated. This reflects a 'bricolage' approach to the making process, similar to what has been observed in other crafting practices, including interaction design [58]. This resourceful use of materials was also utilised with the electronic components and took on an active role in shaping our tangible outcomes.

From Professional Crafting to Becoming Beginners

The slowness of the overall process became a tool for reflecting on the intersection of our different practices, which had to meet in-between. The meeting point, we realised, was not just an attempt to combine two distinct disciplines, but rather to find a meaningful collaboration between a highly artistic approach to silversmithing, which in our case was also a highly individual practice, and a practice of explorative, and to a large degree collaborative practice of interaction design research. Thus, instead of just bringing two areas of expertise together this intersection was uncharted territory for both parties, where both became beginners. Throughout the full year of the project two participants representing the practices of silversmithing and interaction design research attempted to build a common ground for collaboration by contributing each with their own separate domain of expertise. This is reflected partly in 'strategies' invented during the explorations, but also in the development of a shared language in regards to materials,

Figure 6. a) The bodily movements performed in silversmith practice informed our focus on designing sensors, b) experiment with single-use button made from copper-coated autumn leaf and copper thread embedded in hemp yarn, and c) example of sketches on how to protect electronics with non-conductive materials and ideas to integrate simple buttons in designs.

tools and techniques, in order to bring both practices closer. One example is the crafting techniques of surfacing or hiding the electronics described earlier, which provided a way to build a common understanding on the properties of both interaction gestalts and silversmith crafting.

Both the interaction design researcher and the silversmith artist had to approach the same artefact from their own perspective, choosing which properties of it would come to the foreground for the particular context. The interaction design researcher tended to take on an engineering perspective, focusing more on the conductive properties of a silver surface, for example, how it could become part of a computational composite or how to connect it to a circuit board. At the same time, the silversmith focused on how to give form and shape the same metallic surface and how to combine it with other materials such as wood, for hiding or protecting the electronic components.

As the project progressed, the collaboration evolved into a form of vivid experimentation, or tinkering [20]. In that sense, crafting no longer felt like an appropriate term to describe the explored practice. This was partly due to the lack of specific skills, tools and techniques for working in this particular domain, but also due to the clash of values and ideals. Consequently, it was not the distinct design or crafts principles that met, but the actual process took the form of a rather exploratory research in the form of material exploration. This was especially the case since our particular collaboration involved a silversmith, whose practice was more aligned towards conceptual and artistic works, rather than the making of utility objects. Our project thus evolved as an exploration along artistic crafting and exploratory interaction design research. This resulted both in stretching the boundaries of the principles involved, while reflecting conceptually on the two distinct domains. Perhaps the most extreme example can be seen in the discursive design exploration of Figure 6b, where, as a note both towards planned obsolescence and imagined durability of silversmith crafted artefacts, a single use button is made from a copper-coated autumn leaf.

In general, we saw that the intersection of silversmithing and physical interaction design has a potential to be further developed as a separate practice, especially in regards to the growing field of designing wearable and mobile accessories. The conductive properties of metals place them ‘close’ to the electronic materials from one perspective, but at the same time constitute them a very challenging matter for interaction design, due to the possible problems they might create to circuits. We believe, however, that new tools and practices may emerge in the future, which will hopefully simplify future explorations in this domain, to focus more on fully functioning designs and systems. Similar to the domain of e-textiles and soft electronics, new resources may be designed specifically for prototyping and designing interactive silversmith items. However, contrary to interactive textile designs, the challenges and difficulties we encountered were not primarily about incorporating conductive elements, but rather finding ways of using the conductive properties of metals as a resource, rather than an obstacle for making hybrid designs. Specifically, in a future practice of what could be potentially named *interactive silversmithing*, or *e-silversmithing* it will be crucial to develop solutions for shielding, covering or protecting electronic components from metals by making combinations with non-conductive matter, or materials with higher resistance. More broadly, the metallic foundation of silversmith crafting, down to the level of electrical conductance, highlights how, from a perspective of interaction design, material properties become fundamental when exploring particular crafting practices focused on physical materials.

CONCLUSION

In this paper we presented a design research study at the intersection of silversmith crafting and interaction design that took place at a silversmith studio. We provided reflections and insights focusing specifically on some of the challenges of combining the two areas of expertise in regards to material manipulations. In terms of tools and techniques, the process highlighted several practical challenges of working with fragile electronic components together with the practice of giving form to metals in silversmithing. We also identified breakdowns during the process, derived from techniques, but also by clashes in values between the two distinct practices. These were overcome by a mutual influence on each other’s way of working and approaching the interactive materials and technologies. In terms of interaction gestalts, the silversmith practice directed the work towards the explorations of small, three-dimensional, and close-to-skin sensors that emphasised the conductive properties of different materials. This can be seen as a way of surfacing the electronics in the interactive experiences. Another direction of our explorations was towards ways of hosting electronic components inside casings made of metals or wood, and silversmith techniques. Finally, since both the involved experts became beginners to this hybrid making practice, it had more the character of explorative tinkering and testing or material exploration, rather than a proper crafting exploration. We believe that these intersections and identified challenges provide a fertile ground for reflecting and questioning the fundamentals of what a so-called hybrid crafting practice actually may entail. Our hope is that from an interaction design perspective, this direction could also raise a broader cultural grounding by creating new framings and understandings of interactive products and digital media in relation to crafts.

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