Prototyping Tangible User Interfaces: Case Study of the Collaboration between Academia and Industry within the Design Process

Jolien De Ville[a], Jelle Saldien[a*], Peter Conradie[a] and Cesar Vandevelde[a]

[a]*Department of Industrial System and Product Design, Ghent University campus Kortrijk, Graaf Karel de Goedelaan 5, 8500 Kortrijk, Belgium*

(Received 31 August 2014)

In this paper, a platform is introduced for the creation of Tangible User Interfaces (TUIs). An interdisciplinary design approach is described with an emphasis on iterative prototyping enabling the involvement of a user as a key element for designing interactions. This includes the importance of (1) a network, (2) a new design method using project roadmaps and, (3) the availability of tools and platforms in an exploratory lab environment. A close collaboration between industry and academia made it possible to implement this approach with a total of 77 design cases. Students got to work on realistic design problems while companies can explore new ideas at low risk. We found that open design assignments lead to more creative results as opposed to well-defined cases. One of the general conclusions to obtain an optimal user experience is the importance of involving multiple stakeholders into the development process of TUIs through iterative prototyping of interactions. We define four prototyping phases within our approach.

We found this approach successful, with design cases that lead to new research, technologies and commercial products. Four specific cases are presented in more detail, while the general insights and guidelines can be used to improve future development of TUIs.

Keywords: design; education; human–computer interaction; laboratory; tangible user interfaces; methodology; interaction design; teaching; embodied interaction

1 Introduction

Recently more practitioners and academic researchers are adopting a User Experience (UX) centred approach to the design of interactive systems, emphasizing elements such as ‘fun’, ‘emotion’, ‘joy’ and ‘pride’ (Hassenzahl and Tractinsky 2006). Because of the limitations of traditional usability framework, focusing primarily on user cognition and user performance, we see this shift towards UX that highlights non-utilitarian aspects such as user affection, sensation, meaning and value of interactions in human-technology of everyday life (Law et al. 2009).

Simultaneously, changes are occurring in how we manipulate digital information. While traditional computer interfaces consisted out of a keyboard and a pointing device - typically a computer mouse (Wiberg and Robles 2010) - a shift is occurring where computers and interfaces are changing form to include a wide variety of input and output devices (Ullmer and Ishii 2000). These Tangible User Interfaces (TUIs) that are emerging could allow the *direct manipulation of bits* (Ishii 2008) facilitating a shift away from the desktop paradigm of computing. This change is also resulting in products that are interactive, connected to the internet, that adapt to our needs and respond to our behavior (Satyanarayanan 2001; Saha and Mukherjee 2003).

[*] Corresponding author. E-mail: Jelle.Saldien@ugent.be

Notably the shift towards interactivity of everyday products such as umbrellas, tables, lights, or kitchen appliances (Shaer and Hornecker 2009) presents challenges for the Small Medium Enterprises (SMEs) involved in the design and development of non-interactive durable goods. Additionally, when designing interactive products there is a need to design more than merely the functionality and usability of the product. During the UX design process more attention needs to be paid to emotions (e.g. pleasure, fun, frustration, boredom, etc.) that emerge during the interaction with the product.

Universities have traditionally played an important role as sources of new knowledge and technology (Agrawal 2001) through partnerships with the industry, while companies are also increasingly employing external Research and Development (R&D) organizations such as Universities to support innovation (Gassmann, Enkel, and Chesbrough 2010).

This presents an opportunity for SMEs who are interested in adapting their products to increase emphasis on UX, while also exploring how new modes of interaction can be achieved. Within this paper we present a case study following a three-year project named TIII (Tangible Intuitive Interactive Interfaces), where the aim was to create TUIs in close collaboration with local SMEs in Belgium. The project organised 77 design cases that resulted in TUI prototypes. Each design case followed a similar design approach using different techniques and technologies. In most cases a close collaboration with the industry took place.

The remainder of this paper is structured as follows: Section 2 will elaborate on the key concepts behind the project's platform: UX and the design of TUIs in the context of higher education and the link with the industry. In Section 3 we will present the structure of the TIII platform and the general results of all design cases. In section four we describe the cooperation between students and industry participants. Section five will examine four specific case studies, while Section six will present a discussion of the lessons learned.

2 Background

2.1 User Experience Design

Previously, interactive systems were primarily designed to improve performance or decrease errors. Recently, a new design paradigm, UX, has emerged that focuses more on hedonistic goals (Moczarny, de Villiers, and van Biljon 2012). This design approach does not exclude basic usability principles such as learnability or productivity, but sees the additional value of emotional experiences associated with product use (Hassenzahl and Tractinsky 2006) and has been adopted both by researchers of HCI and design practitioners (Law et al. 2009).

For example, (MacDonald 2001) notes the importance of sensorial qualities in products and introduces a design process that aims to facilitate product design that can evoke empathy between users and products. The author stresses elements such as culture, storytelling, aesthetics and designing for the senses.

(Kouprie and Visser 2009) also evoke the notion of empathic design and introduce a framework for empathic design that can act to help designers relate to their users' experience. The framework includes methods to discover a user's context by immersing yourself in their world.

The importance of users' emotional reaction is also emphasized by (Barnes and Lillford 2009), who introduce a framework that supports *the development of emotionally appealing products*. (Artacho, Ballester, and Alcántara 2010) also emphasize how the small changes in product design can affect the user's emotions.

These brief examples highlight the importance given to emotional aspects of products, and introduce frameworks that support the creation of products that appeal not only on a functional level , but also target user emotions.

2.2 *Tangible User Interfaces*

A current trend to the importance of the user experience in designing interactive products is the changing nature of what we perceive as computing. Weiser (1991) played an important role in challenging the notion of computing as an activity that only involves a pointing device (such as a mouse), a keyboard and a screen (Bell and Dourish 2006). Ishii and Ulmer further stated that the advent of the personal computer has contributed to a loss of the richness offered by a variety of man made objects (Ishii and Ullmer 1997). The authors present a future vision of the world as an interface, where different types of objects can be used as input and output devices.

Accompanying this vision is the notion of interactivity embedded into ever more products (Satyanarayanan 2001; Saha and Mukherjee 2003). Satyanarayanan (2001) discussed the movements within research in the domain of pervasive computing and notes the introduction of "smartness" in certain spaces and the disappearance of technology into our environment. The resulting effect of this invisible technology is an ever increasing amount of intelligence in our surroundings, including various intelligent appliances, floor surfaces or environmental sensors in our domestic or work environment (Saha and Mukherjee 2003).

While an extensive review of cases that represent this vision (e.g. see (Shaer and Hornecker 2009)) is beyond the scope of this paper, we introduce some state-of-the-art examples below to illustrate this.

Recently, (Fortmann et al. 2013) introduced the MoveLamp, an ambient display whose aim is to encourage office workers to move more. The system tracks how long the user is stationary and subsequently provides cues when stretching is recommended. REENACT, also uses ambient information to encourage history learning, focussing on allowing students to re-enact, replay and debate (Blanco-Fernández et al. 2014). Using tactile mobile devices, the system provides students with augmented reality vision, allowing them to see historical events. (Peschke et al. 2012) focussed more on providing tactile feedback for DepthTouch, an installation that provides elastic feedback on touch surfaces, allowing rich interaction with future displays.

These examples illustrate how interactivity is becoming part of our surroundings. We also notice their emphasis on emotional aspects rather than improving efficiency or reduce errors. The progression towards TUIs that provide an enhanced user experience poses a challenge to SMEs hoping to innovate in this domain, especially if their core business does not involve interactive products.

2.3 *Higher Education as Source of Innovation*

While large companies such as Apple, Samsung, Philips or Google are performing R&D into consumer products to bring interactive and emotional appealing products beyond the desktop, most SMEs lack the expertise and resources to achieve this kind of R&D. More specifically, SMEs involved in sectors such as furniture, interior design or household appliances lack knowledge to adapt their product design in order to bring more interactive experiences to their customers.

A source for this knowledge can be found in collaboration with higher education. As argued by (Agrawal 2001), there is a rich history of university to industry knowledge transfer spanning various domains, but specifically prevalent among engineering disciplines. (Ahrweiler, Pyka, and Gilbert 2011) also emphasize the importance of university and industry collaboration, asserting that university-industry links *improve conditions for innovation diffusion*. This aligns well with the view that organizations are increasingly using external R&D as innovation source (Gassmann, Enkel, and Chesbrough 2010). (Flores et al. 2009) also notes the importance of universities as facilitators to achieve *collaborative environments* where industry and university work together and where the university plays a role to diffuse knowledge and technology to the industry.

2.4 *TUIs in Higher Education*

The design of TUIs is gaining more interest in higher education, providing an ideal setting for interdisciplinary teamwork and preparing the students for a future career in a digital world.

The design and development of tangible interfaces is suitable when teaching students to manage multiple disciplines in one project. For example, (Camarata, Gross, and Do 2003) present a course centred on the development of physical computing experiences in multidisciplinary teams. The authors emphasize a studio setting, where students can physically meet to collaborate on projects. Similarly, (Klemmer, Verplank, and Ju 2005) also notes the benefit of a studio setting, where there is less emphasis on lectures, but a stronger focus on supervising projects. Broad themes such as *(Nearly) Invisible Computing* or *Urban Computing* were introduced to students. These themes guided the types of projects developed by students. Projects ranged from chairs with built in sensors to alert users of bad posture (Klemmer, Verplank, and Ju 2005), to a musical couch that generates sound using embedded sensors (Camarata, Gross, and Do 2003).

(Shaer, Horn, and Jacob 2009) also presents a course centred on the design of TUIs to multidisciplinary teams. The authors note the student challenges involved in creating TUIs, which demand skills in multiple domains including engineering, social science and art. Students participated in a studio setting where they intensively collaborated on the design of TUIs linked with a yearly theme

While these examples do not include any industry collaboration, (Schmid, Rümelin, and Richter 2013) introduce a project in collaboration with BMW, where TUI concepts were designed, focusing on glass as new material.

These examples of higher education courses show the emphasis on TUIs within higher education and the collaborative nature of these efforts. However, they are limited in their involvement of industry, SMEs specifically.

In the following section we will introduce our TIII platform that functions as a framework to realize TUIs in close collaboration with SMEs.

3 TIII Platform

Our aim within the TIII platform is to assist SMEs in the design and development of interactive products while taking into account a positive user experience. To achieve this, our approach contains three elements: (1) a network of companies and collaborating higher education institutes, (2) a method used during the process and finally, (3) an accessible lab with the necessary infrastructure and materials. Below we will expand on each of these components.

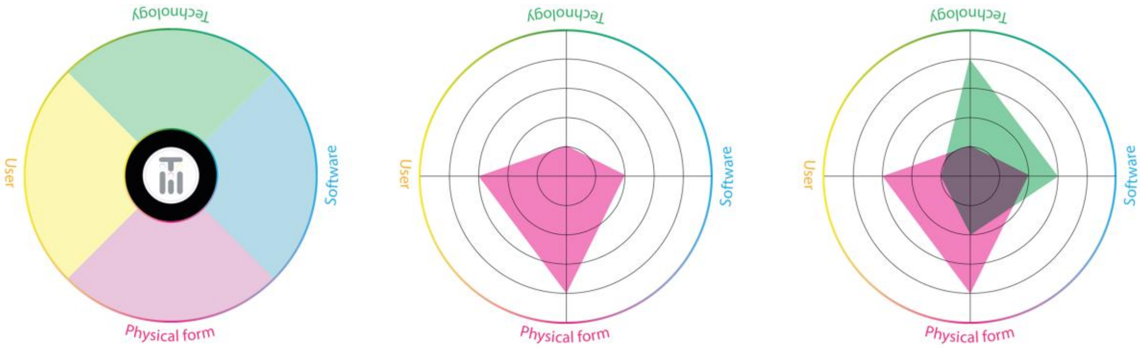
3.1 Network

For this project a network has been build, consisting of 4 large scale companies, 10 SMEs, 2 freelancers and 5 educational institutions. To facilitate idea sharing between partners, our first aim was to create an open network where concepts could be openly discussed with other companies and educational institutions.

A concern within the project was competitiveness between participating companies, which inhibited discussions about company strategy, innovation and goals. To overcome this, we focused on the creation of a network where everyone knows each other’s expertise and therefore knows if a certain company can become an interesting partner or might become a competitor.

This was done through the creation of personal profiles, which indicated the area of expertise of every partner, helping our partners to position everyone within the network. Partners supplied information about their core focus and expertise. The focus of an organization was selected from the following areas: strategy, concept generation, research, development, consulting, production, marketing, distribution and sales or end-users. Next the domain of expertise was drawn on a radar plot relative to their TUI knowledge about the physical form, the technology, the user or the software (Figure 1). Finally, they indicated their quantity of product units on a scale from one custom-made product to mass production.

Bringing together these diverse stakeholders leads to complementary cooperation, stimulating partnerships between multiple partners with different kinds of expertise, and thus combining the expertise needed to create TUIs. This also emphasizes the multidisciplinary nature of the network.



a) PUTS-circle *b) Radar plot one company* *c) Radar plot two companies*

Figure 1: Visual representation of the four TIII domains in relation to the expertise of a company

To create this open platform we organized several events. The first one was a creative session. Partners were analysed according to their domain of expertise and grouped into interdisciplinary teams letting them brainstorm about their needs. In this way companies from the same domain, possible competitors, are not in the same team.

We used visual panels per TIII domain so the teams would get inspired. Each team was asked to generate ideas per panel and to add them on post-its. After 15 minutes we rotated the teams, giving each team the opportunity to add ideas on every panel. Each team got to talk about TUIs while getting to know each other's expertise.

In the afternoon we presented a TIII template that guided every team into describing one defined idea. We found those ideas inspiring but general and not that specific to the core activity of a partner which taught us that it would be hard to focus on generating new project ideas for a company in an open environment because a partner would always feel threatened on some level when it comes to their own internal ideas. Companies however felt less threatened by academic partners than industrial partners.

We decided our role should be to inspire and guide our network and act as an objective and non-competing partner. As long as an idea or project is exploratory, it can be discussed openly within the network and further explored by students. From the moment a network member has a defined idea that he wants to pursue within his company, it becomes confidential for all partners involved. The platform then offers guidance by offering assistance in the development of a fitted roadmap and the composition of an appropriate interdisciplinary team for a specific case. This required a certain method that needed to be developed.

To keep our partners motivated, other events were organized, such as seminars, brainstorm sessions, expos and workshops with TUIs as a recurring theme. We found the feedback during these events important to gain insights on the obstacles our partners experienced and on topics we could address more within the project. After these events they took their inspiration within their company getting them to think about internal opportunities to create TUIs.

In order to create a close-working relationship with the other partners we found it important to keep them triggered and to communicate openly about the project and its progress. A central online platform was created, www.tiii.be, which focuses on offering information about the project, the design cases and current state of the art.

This website is also the first contact point for external parties. Part of this website is private, making some selected pages only visible after logging in. To keep our network updated we reminded TIII partners of our events, progress, calls and developments using a two-monthly newsletter

3.2 *Method*

Besides the creation of a network including tools for collaboration, we also developed a method to develop TUIs in partnership with others. We define four domains of expertise needed to create TUIs:

Physical form: Knowledge concerning the design, materialization and production techniques to create tangible products.

User: Knowledge about the user and his context to strive for an optimal interaction to enhance the user experience and making a TUI a desired and wanted object.

Technology: Knowledge about electronics, state of the art sensors and development platforms that are available to create TUIs that allow new forms of interaction with the user.

Software: Knowledge about programming and middleware, using software applications to provide the intelligence and connectivity of the TUI.

These four domains are a basis to further understand the individual needs of each partner, but also to guide the broad TUI design and development process.

3.2.1 TUI Development Roadmaps

A central tenet throughout the project was to gain better understanding in the development of TUIs using a user centred focus within the existing structures and daily routines of a participating partner. To get an insight of the optimal work method for the development of TUIs, the workshop guides the participants to define a project roadmap consisting of different challenges that need to be solved in order to obtain a successful TUI at the end of the project. The idea here is that it is more important to first look for the right questions and challenges rather than already come up with solutions. This was inspired by the Usewell (2014) method, where challenges are selected that are relevant and recognizable. Some examples of challenges are; “The customer is not always the user.” or “We want to make our product easier to use.” After selecting a challenge, Usewell provides solutions in the form of techniques that allow you to tackle your challenge by involving different stakeholders.

We organised 2 workshops with a total of 7 domain experts and 11 partner companies. Previous discussions with the partners lead to a workshop format that starts with an assignment (e.g. “a TUI to improve the indoor tracking of a person”). The group was divided into 5 interdisciplinary teams. Based on the assignment each team selected the set of challenges related tot the PUTS-domains that needed to be tackled in order to develop the envisioned TUI (Figure 2). Workshops were based on the generative brainstorm method, a tool that bundles strategies that visualise the needs, wants and expectations of those that participate.

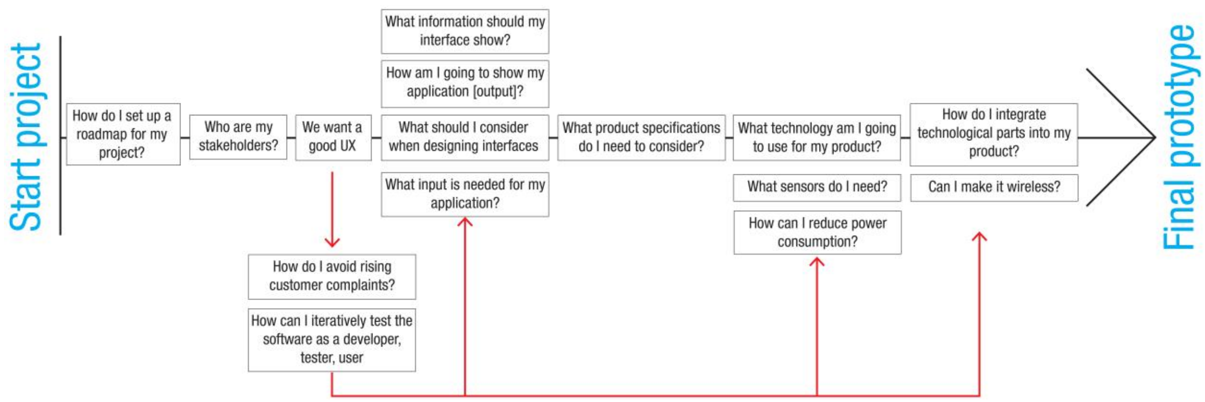


Figure 2: Example of one of the TUI Development roadmap results from the workshop

3.2.2 Understanding partner needs

While the roadmaps assist in understanding the broad needs of the partners and contributes to understanding how TUIs could be designed and developed, they do not focus on individual partners. To better understand each partner SME, every individual TUI project was framed as a design case. Partners submitted project ideas that could either become a student case, or a professional case.

Student cases are exploratory product concepts within a defined context. Usually these cases have a duration of several weeks, with a maximum of one semester. The result is always a working prototype made by students. After this first exploratory phase, a partner can better estimate the potential value of his/her initial idea. If they think it is valuable, next steps can be taken to set up a professional case. If a concept is better defined and the TIII member has plans to pursue and market the idea, the case becomes an individual closed project.

With professional cases, when a partner has a more defined idea of what they want to develop, we organize several meetings to discuss the expectations of that partner and then map the intern knowledge available and the absent expertise, using the roadmaps defined earlier. If applicable, funding for innovative projects is sought. Based on the expertise that is not available, partners with the necessary expertise are being linked to the project. For these cases we developed a general framework that we applied at the start of the process for defining and communicating the project to the partners involved.

3.2.3 Rapid Prototyping

Prototyping is a crucial part of building products (Yang 2005). Through prototypes, usage can be simulated without the high costs associated with building a complete product (Houde and Hill 1997). Throughout the process of each design case there is a strong emphasis on rapid prototyping of TUIs. This allows hands-on testing with users and also enables students to discover interaction flaws early during the design process. By constantly making iterations of the design and testing it with the user an optimal user experience is being pursued.

This iterative design process has the benefit of identifying limitations to interaction early in the design process, but also identifies issues with the technologies used in each case. Initial concepts might be prototyped using paper or cardboard, while interactions might be simulated through techniques such as experience prototyping (Buchenau and Suri 2000). Following these early steps, first working prototypes can be developed, using technologies such as Arduino and Phidgets. Students with non-technical backgrounds were also encouraged to start exploring the possibilities of these tools as soon as possible. Partners in the project were given access to the available tools and technologies.

We sought a strong link with the DIY (Make) culture, using open source hard- and software. While we motivated the students to document their results, facilitating sharing and re-using of results.

3.3 Lab

A physical component of our platform is the TIII lab where a collaborative environment is created to work on interactive prototypes. The lab setting also fosters a studio culture mentioned by Camarata (2003) and Klemmer (2005), where students can meet and collaborate on projects. It acts as a place where students and companies can explore various technologies, but also where prototypes can be built and tested. Our TIII lab offers different kinds of electronic boards, such as Arduino, Raspberry Pi and Beaglebone (see Pearce (2012) for an overview). A large range of state of the art sensors is also available, such as new gesture recognition sensors and others. It also offers different development platforms such as Android, iOS and Sifteo. Furthermore it also has the basics available to create electronic prototypes such as wire, soldering tools, and basic electrical and mechanical components. Although the components described above are not that expensive for companies, we found that it is still less of a risk for them to experiment with our material and to see the potential of a certain technology for their own company and products before buying it.

4 Students and Industry Participants

Most design cases were introduced in the course, Mechatronic Design, aimed at undergraduate Industrial Design students. In this course, the students learn how to use sensors, actuators and microprocessors to create interactive products. They work in team on the design and materialization of a working interactive prototype. The inputs for this course are the product ideas generated by the project's members (described below). A few months before the start of this course a call is launched to the project's partners asking them to submit an exploratory idea. We mostly worked with Industrial Design students due to the diversity and the broad knowledge that these students have of multiple disciplines, making them well suited to work on interdisciplinary projects.

Nonetheless, we also aimed to involve students from different backgrounds in the cases, including Digital Design & Development, Digital Arts and Entertainment, Industrial Engineering and Social Science backgrounds.

As mentioned above, our industry partners were mostly SMEs with a specific profile. While large-scale companies may have more resources to invest into R&D, and smaller start-ups may already have a strong culture of focussing on user experience, there are companies found in the middle of these two categories. They include SMEs that are focussed on making various durable goods for a specific market, but lack the knowledge and expertise to develop and design innovative interactive products.

5 Design Cases

During the design cases, students prototyped their ideas in an iterative manner, making it possible to test the user interaction of a concept throughout the different stages in the design process (Figure 3). We define four phases:

- **Phase 1: Idea generation**: Brainstorming tools are used to generate a lot of ideas related to the case. In this phase we noticed students contacting the company to help them define the boundaries of the case description. Personas and storyboards where used to generate ideas for a specific user group. [sketches]
- **Phase 2: Concept definition**: Low fidelity prototypes were materialized using scissors, cardboard and paper to assess the feasibility of the concept with end-users and other stakeholders involved in the process. User insights were obtained through scenarios, interviews and context mapping. [Low fidelity prototypes]
- **Phase 2: System prototype**: The concept was divided into mechanical and technical sub-problems. Aluminum foil, Arduino and laser-cut parts were used to prototype technical solutions making it possible to test the effect of a certain interaction on its user. [Functional prototypes]
- **Phase 4: Integrated prototype**: All sub-solutions are integrated into one final working prototype. A flow chart was used to map communication between different components and to visualize the interaction of the system into a schematic overview. 3D printing and laser-cut parts where often used to materialize and finish the final prototype. Sensors and circuit boards where custom made to fit the prototype, creating a highly finished end-result. [high fi prototype]

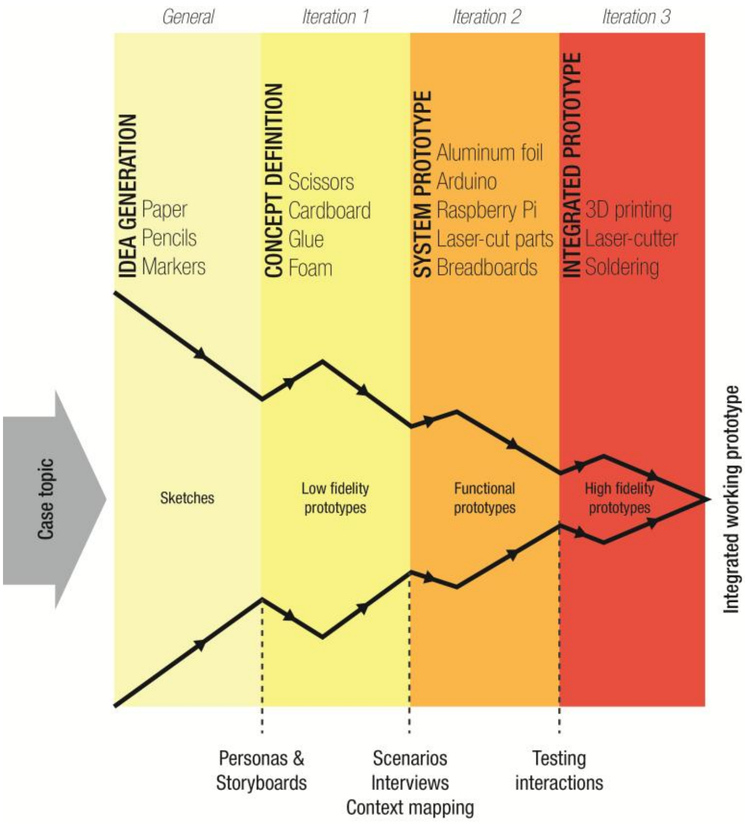


Figure 3: Schematic overview of the development process of a TUI based on the design funnel by (Pugh 1991).

From all 77 cases, 4 specific cases are highlighted and discussed in more detail. Each of these design cases resulted in a different outcomes leading to new research, new technologies or new products.

a) Whist *b) Caars lamps* *c) Innovative mirror*

Figure 4: Pictures of three example cases

5.1 Whist

In this case, the students were asked to come up with concepts for interactive playing cards for card manufacturer Cartamundi. The manufacturer had been experimenting with the integration of new technologies (e.g. RFID) into traditional playing cards, and was looking for concepts of part physical and part digital card games. Over the course of the project, the students redefined this initial design brief: in consultation with the company, they decided instead to create a technology demonstrator for Cartamundi to use at trade fairs. They ended up creating an interactive luminaire named Whist, which uses playing cards as a construction element for the luminaire's shade. The shade of Whist consists of six petal-like elements that can be opened or closed through a DC motor. Each petal is made up from a flexible laser-cut backbone that holds 68 playing cards. The petals of the lamp can be opened or closed through hand gestures: an ultrasonic sensor at the centre of the lamp detects the motion of the hand and controls the DC motor accordingly. Fully opened, Whist acts as a functional light source; closed, it creates a soft, ambient glow. Overall, this project shows that allowing students to freely interpret and expand their initial assignment can lead to unique and valuable end prototypes. After discussing several ways to commercialise Whist, Cartamundi told us they are mainly interested in selling cards and do not want to focus on creating lamps. One of the students decided to keep on enhancing the design of the lamp and is currently looking for a way to market it independently.

5.2 CAARS lamps

In this project, the students were tasked with the creation of a technology demonstrator that combines the technologies of two companies: Modular (a light fixture manufacturer) and Quad Industries (a membrane and capacitive switch manufacturer). The end result, CAARS, is a light source that is designed to assist during an indoor night walk. The system is made up from a network of wirelessly connected spheres. The spheres use capacitive sensing to detect when a user is approaching and light up accordingly. When one sphere is picked up, all other nearby spheres (measured using ZigBee radio signal strength) start to glow, allowing the user to navigate his surroundings in the dark. Caars uses the custom made sensor by Quad Industries in a new and interesting way.

5.3 Drum Duino

Figure 5: Three iterations of the Drum Duino

The Drum Duino was conceptualized in the first year of our mechatronics course. As mentioned earlier, the first year's cases were not connected to any external organisations or companies. Instead, students were completely free to create any sort of interactive device. One of the groups wanted to create a new type of musical device, which instead of a speaker uses solenoids to produce sound. The device consists of a central console, functioning as a music sequencer, and 3 solenoid modules, which can be connected to various objects using Velcro straps. Users can change musical patterns by inserting control batons into the central console. The resulting beat pattern is sent from the central console to the solenoid modules, which strike an object to produce sound. The students' efforts during the mechatronics course resulted in a working prototype, which inspired us to continue our research on the Drum Duino. We described a second iteration of the device in a paper (De Ville and Saldien 2013) for the International Conference on Tangible and Embedded Interaction (TEI) offering us input for a third iteration that further refined the functionality and interactivity of the device.

5.4 Innovative mirror

Our last design case is the "Innovative Mirror" project for Deknudt Mirrors and De Keyzer, both partners of the TIII project. Deknudt Mirrors has expertise in developing high-quality mirrors and De Keyzer has expertise in the development of bathroom furniture. But both SMEs have very little experience with electronics and concepts such as user experience design. For this project, they wanted to explore what the bathroom mirror of the future could look like. As a first step, a student group worked on this as part of the mechatronics course. They created a prototype bathroom mirror with an integrated LCD screen and three IR-sensors. The interface offers a newsfeed, radio, weather report and toothbrush timer. Users can navigate through the different functions by waving their hand, which is detected through the integrated IR-sensors. Thus, the interface can be controlled without touching the mirror, eliminating the problem of smudges and fingerprints. Partially thanks to the prototype created by the students, funding was secured for a feasibility study, the goal of which was to determine features and specifications that are relevant to the target user group. This study showed that users are not interested in news and weather updates on their mirror. Instead, they would rather have features that enhance the basic functionality of a mirror, such as showing a zoomed-in view of the face or showing the back of the user's head. Finally, funding was requested and granted for the further development of this project into a commercial (patented) product, which will be launched in 2015.

6 Conclusion

In this paper we introduced our TIII design platform, a case study for the development of user centred TUIs, in close collaboration with SMEs. Due to the increasing importance of UX and the prevalence of TUIs, there is a need for SMEs to better incorporate these principles in their products.

We reviewed our TIII platform that consists of a Network, Method and Lab, while introducing four cases that illustrate this process. Finally, we reflected on our experiences within this project.

Our main contribution is the process and lessons learned in this project.

Subject	**Education**	**Industry**
Working with the industry	Offers a good insight of real-world design problems	Low risk for exploring TUIs and new technologies
Working with students	It is not guaranteed that the results are going to be useful	It costs time and involvement of a company when guiding a case
Integration in student curriculum	It was hard to integrate interdisciplinary projects into unilateral courses	It was not always possible to approach a case in an interdisciplinary way
Gathering cases	Students got to choose their preferred case to enhance their motivation	Close contact with the industry is needed to guide them to submit a case
Case description	As opposed to defined cases, widely described cases lead to more creative results	New opportunities can be found in creative explorations
UX testing	By prototyping interactions the user experience could be tested resulting in innovative ideas	Companies got convinced about the importance of implementing user testing into the development process
Availability of tools	Students had quick access to platforms and tools to test with.	Companies learned about the possibilities of new platforms and technologies by the resulting prototypes
Feedback	Students got feedback on their blog from co-students, teachers and companies	By reading the blog, companies could follow the status of a case from a distance and offer feedback
Prototyping	By iterative prototyping the students got to test technical aspects of a concept	The result was always a working prototype that the company could use

Table 1: Overview of the lessons learned for both students and companies

Within our educational program for industrial design we found collaborating with the industry for prototyping TUIs to be enriching. The students got the chance to work on cases that comprise real-world design problems introduced by the industry. This offered them an insight into the challenges they will encounter in their future jobs when working on interdisciplinary design cases. For the industry, this cooperation lowered the threshold for the creation of innovative TUIs and the insight into the importance of involving the user into the development process. By offering them a low-risk opportunity to explore new ideas and technologies they got the chance to evaluate the feasibility of a product at an early stage.

Our first ambition was to integrate our vision on prototyping TUIs across the courses of several disciplines. We analysed the curriculum of the students Industrial Design, Digital Design & Development, Digital Arts and Entertainment, Industrial Engineering and Social Sciences to find an overlap with the design cases and to find possibilities to let students work interdisciplinary. Although the coordinators of these courses were enthusiastic, we found it hard to integrate the cases into the curriculum because of a non flexible educational system where course contents need to be described at least one year in advance. Another difficulty was to match interdisciplinary projects into unilateral courses so we tried to merge students from different disciplines into one course. Aligning the timetables across the disciplines for the different courses was hard and only succeeded once in the academic year 2012-2013. An interdisciplinary course of mechatronics design was offered simultaneously to a mix of Industrial Design students and Electronics students working in interdisciplinary teams.

At the beginning of a new academic year a call was launched to the companies to submit a case for the mechatronics course. The course was scheduled in the first semester (12 weeks) meeting once a week for a 5h session. All industry-cases where presented in the first weeks. Students could indicate their preferred case making them more motivated to come to a satisfying result. This meant that the students did not choose unpopular cases submitted by the companies.

Descriptions of cases varied between broad, open questions such as “making time tangible”, to more specific: “Design a tangible interactive cube for elderly to navigate within a digital photo book”. We found more openly described assignments generated the best end results. Students were given more creative leeway, so they generated more concepts and created prototypes that they felt more engaged with.

The course series started with an introduction of mechatronics and the basics of Arduino. Because of its open source platform, students where able to find assistance on online fora where they found existing code to adjust or where they could ask the opinion of experts to help them formulate their code. Depending on the specific case, other platforms such as Raspberry Pi, Makey Makey, Beaglebone were suggested. It was important to have these kinds of tools and platforms available in the lab making immediate technical and user testing with go or no-go decisions quickly possible. If sensors or platforms needed to be ordered, the team lost a lot of valuable time.

To overcome communication difficulties between multiple stakeholders (teachers, students, companies, etc.), a blog was used to document the progress of a case and to offer feedback at any time by anyone who had access. At certain moments the lecturers issued medals to the blogs according to the progression on the case. During the concept phase a top three medal could be achieved based on the following points: practical approach, motivation and concept. A case could also get a yellow warning, meaning “watch out” or a red one meaning “unsatisfactory, try a different approach”. Later in the process new medals could be achieved for functionality and best prototype. A team could also lose their medal to another team making it more competitive and stimulating to do their best.

We found that companies were skeptical about the importance of involving the user at an early stage in the product development process. Mostly they develop a product and perform user testing in a final phase, making it only possible to make small adjustments even though the whole concept could be wrong or unappealing for the user making them not wanting to buy the product. With these student cases, companies could see the innovation potential of the end-results making it easier to convince them about the added value and the importance of implementing user testing into the development process of their company.

The end result was always a highly finished working prototype that offered the companies the opportunity to use it for further user testing and adjusting the concept to a commercial product.

7 Acknowledgments

We would like to thank al of the TIII participating partners for their input and feedback and to help us steer the project into the right direction. We also want to thank all of our students who worked with us for their motivation and creativity and the lecturers for their assistance during the courses.

8 Funding

This work was supported by IWT, Flemish government agency for Innovation by Science and Technology [110157 and 120147]

9 References

Agrawal, Ajay K. 2001. "University-to-Industry Knowledge Transfer: Literature Review and Unanswered Questions." *International Journal of Management Reviews* 3 (4): 285–302. doi:10.1111/1468-2370.00069.

Ahrweiler, Petra, Andreas Pyka, and Nigel Gilbert. 2011. "A New Model for University-Industry Links in Knowledge-Based Economies." *Journal of Product Innovation Management* 28 (2): 218–35. doi:10.1111/j.1540-5885.2010.00793.x.

Artacho, Miguel Angel, Alfredo Ballester, and Enrique Alcántara. 2010. "Analysis of the Impact of Slight Changes in Product Formal Attributes on User's Emotions and Configuration of an Emotional Space for Successful Design." *Journal of Engineering Design* 21 (6): 693–705. doi:10.1080/09544820902875058.

Barnes, Cathy, and Stephen Paul Lillford. 2009. "Decision Support for the Design of Affective Products." *Journal of Engineering Design* 20 (5): 477–92. doi:10.1080/09544820902875041.

Bell, Genevieve, and Paul Dourish. 2006. "Yesterday's Tomorrows: Notes on Ubiquitous Computing's Dominant Vision." *Personal and Ubiquitous Computing* 11 (2): 133–43. doi:10.1007/s00779-006-0071-x.

Blanco-Fernández, Yolanda, Martín López-Nores, José J. Pazos-Arias, Alberto Gil-Solla, Manuel Ramos-Cabrer, and Jorge García-Duque. 2014. "REENACT: A Step Forward in Immersive Learning about Human History by Augmented Reality, Role Playing and Social Networking." *Expert Systems with Applications* 41 (10): 4811–28. doi:10.1016/j.eswa.2014.02.018.

Buchenau, Marion, and Jane Fulton Suri. 2000. "Experience Prototyping." *Proceedings of the Conference on Designing Interactive Systems Processes, Practices, Methods, and Techniques - DIS '00*. New York, New York, USA: ACM Press, 424–33. doi:10.1145/347642.347802.

Camarata, Ken, Mark D. Gross, and Ellen Yi-Luen Do. 2003. "A Physical Computing Studio: Exploring Computational Artifacts and Environments." *International Journal of Architectural Computing* 1 (2): 169–90. doi:10.1260/147807703771799166.

De Ville, Jolien, and Jelle Saldien. 2013. "Drum Duino: A Tangible Interface to Create Rhytmic Music with Everyday Objects." In *7th International Conference on Tangible, …*, 7. https://biblio.ugent.be/publication/4177595.

Flores, Myrna, Claudio Boër, Charles Huber, Adrian Plüss, Roger Schoch, and Michel Pouly. 2009. "Universities as Key Enablers to Develop New Collaborative Environments for Innovation: Successful Experiences from Switzerland and India." *International Journal of Production Research* 47 (17): 4935–53. doi:10.1080/00207540902847454.

Fortmann, Jutta, Tim Stratmann, Susanne Boll, Benjamin Poppinga, and Wilko Heuten. 2013. "Make Me Move at Work! An Ambient Light Display to Increase Physical Activity." In *Proceedings of the ICTs for Improving Patients Rehabilitation Research Techniques*. IEEE. doi:10.4108/icst.pervasivehealth.2013.252089.

Gassmann, Oliver, Ellen Enkel, and Henry Chesbrough. 2010. "The Future of Open Innovation." *R&D Management* 40 (3): 213–21. doi:10.1111/j.1467-9310.2010.00605.x.

Hassenzahl, Marc, and Noam Tractinsky. 2006. "User Experience - a Research Agenda." *Behaviour & Information Technology* 25 (2): 91–97. doi:10.1080/01449290500330331.

Houde, Stephanie, and Charles Hill. 1997. "What Do Prototypes Prototype?" In *Handbook of Human-Computer Interaction*, 367–82. Amsterdam: Elsevier Science.

Ishii, Hiroshi. 2008. "Tangible Bits." In *Proceedings of the 2nd International Conference on Tangible and Embedded Interaction - TEI '08*, xv. New York, New York, USA: ACM Press. doi:10.1145/1347390.1347392.

Ishii, Hiroshi, and Brygg Ullmer. 1997. "Tangible Bits." In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems - CHI '97*, 234–41. New York, New York, USA: ACM Press. doi:10.1145/258549.258715.

ISO. 2010. "Ergonomics of Human-System Interaction - Part 210: Human-Centred Design for Interactive Systems (ISO 9241-210:2010(E))." *ISO*. doi:10.1039/c0dt90114h.

Klemmer, Scott R., Bill Verplank, and Wendy Ju. 2005. "Teaching Embodied Interaction Design Practice." In *DUX '05 Proceedings of the 2005 Conference on Designing for User eXperience*. New York, NY, USA: ACM New York, NY, USA.

Kouprie, Merlijn, and Froukje Sleeswijk Visser. 2009. "A Framework for Empathy in Design: Stepping into and out of the User's Life." *Journal of Engineering Design* 20 (5): 437–48. doi:10.1080/09544820902875033.

Law, Effie Lai-Chong, Virpi Roto, Marc Hassenzahl, Arnold P.O.S. Vermeeren, and Joke Kort. 2009. "Understanding, Scoping and Defining User Experience." In *Proceedings of the 27th International Conference on Human Factors in Computing Systems - CHI 09*, 719. New York, New York, USA: ACM Press. doi:10.1145/1518701.1518813.

MacDonald, Alastair S. 2001. "Aesthetic Intelligence: Optimizing User-Centred Design." *Journal of Engineering Design* 12 (1): 37–45. doi:10.1080/09544820010031562.

Moczarny, I. M., M. R. (Ruth) de Villiers, and J. A. (Judy) van Biljon. 2012. "How Can Usability Contribute to User Experience?" In *Proceedings of the South African Institute for Computer Scientists and Information Technologists Conference on - SAICSIT '12*, 216. New York, New York, USA: ACM Press. doi:10.1145/2389836.2389862.

Pearce, Joshua M. 2012. "The Case for Open Source Appropriate Technology." *Environment, Development and Sustainability* 14 (3): 425–31. doi:10.1007/s10668-012-9337-9.

Peschke, Joshua, Fabian Göbel, Thomas Gründer, Mandy Keck, Dietrich Kammer, and Rainer Groh. 2012. "DepthTouch: An Elastic Surface for Tangible Computing." In *Proceedings of the International Working Conference on Advanced Visual Interfaces - AVI '12*, 770. New York, New York, USA: ACM Press. doi:10.1145/2254556.2254706.

Pugh, Stuart (Wokingham: Addison-Wesley). 1991. *Total Design: Integrated Methods for Successful Product Engineering.*

Saha, Debashis, and A. Mukherjee. 2003. "Pervasive Computing: A Paradigm for the 21st Century." *Computer* 36 (3): 25–31. doi:10.1109/MC.2003.1185214.

Satyanarayanan, M. 2001. "Pervasive Computing: Vision and Challenges." *IEEE Personal Communications* 8 (4): 10–17. doi:10.1109/98.943998.

Schmid, Magdalena, Sonja Rümelin, and Hendrik Richter. 2013. "Empowering Materiality: Inspiring the Design of Tangible Interactions." In *Proceedings of the 7th International Conference on Tangible, Embedded and Embodied Interaction - TEI '13*, 91. New York, New York, USA: ACM Press. doi:10.1145/2460625.2460639.

Shaer, Orit, Michael S. Horn, and Robert J.K. Jacob. 2009. "Tangible User Interface Laboratory: Teaching Tangible Interaction Design in Practice." *Artificial Intelligence for Engineering Design, Analysis and Manufacturing* 23 (03): 251. doi:10.1017/S0890060409000225.

Shaer, Orit, and Eva Hornecker. 2009. "Tangible User Interfaces: Past, Present, and Future Directions." *Foundations and Trends® in Human–Computer Interaction* 3 (1-2): 1–137. doi:10.1561/1100000026.

Ullmer, B., and H. Ishii. 2000. "Emerging Frameworks for Tangible User Interfaces." *IBM Systems Journal* 39 (3.4): 915–31. doi:10.1147/sj.393.0915.

Usewell. 2014. "Usewell." *2013*. www.usewell.be.

Weiser, M. 1991. "The Computer for the 21st Century." *Scientific American* 272 (3). New York: Munn & Co. 94–104.

Wiberg, Mikael, and Erica Robles. 2010. "Computational Compositions: Aesthetics, Materials, and Interaction Design." *International Journal of Design* 4 (2): 65–76.

Yang, Maria C. 2005. "A Study of Prototypes, Design Activity, and Design Outcome." *Design Studies* 26 (6): 649–69. doi:10.1016/j.destud.2005.04.005.