Focal Point:
Analyzing the Shift Of Focus When Prototyping

by

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Ethics Statement

The author, whose name appears on the title page of this work, has obtained, for the research described in this work, either:

a. human research ethics approval from the Simon Fraser University Office of Research Ethics

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Abstract

Prototypes are at the core of many interaction design projects. They not only allow designers to formally evaluate their design, but also to explore their project's design space, generate ideas, and discover new design opportunities. This requires the designer to engage in a reflective conversation with her prototypes - closely listening for feedback, combining ideas, and discovering new qualities.

This thesis analyzes the prototypes developed for an outdoor light installation, the Urban Data Posts, in order to gain a better understanding of the interplay between designer and prototype. Using a framework to track intentionality and unintentionality in prototypes, this thesis aims to understand how individual prototypes informed the design process and the final design of the Urban Data Posts project.

This will provide a better understanding of what prototypes do and exemplify what impact unintentionality in prototypes can have in design. The main contribution of this research is the Focus Framework, which captures intentional as well as unintentional design aspects in a prototype.

Keywords: Research through Design; Design; Prototyping; Theory; Annotated Portfolio; Public Display; Installation; Sensing

For my Mom and Dad.

There are not enough words in this world to express my gratitude, respect, and love for you.

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So many people. Like… seriously, I don't even know where to start. But I'll give it a try. So, here it goes:

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There are more, but to save my time (and yours in case someone is actually reading this) I'll stop right here. So, thank all of you very much!

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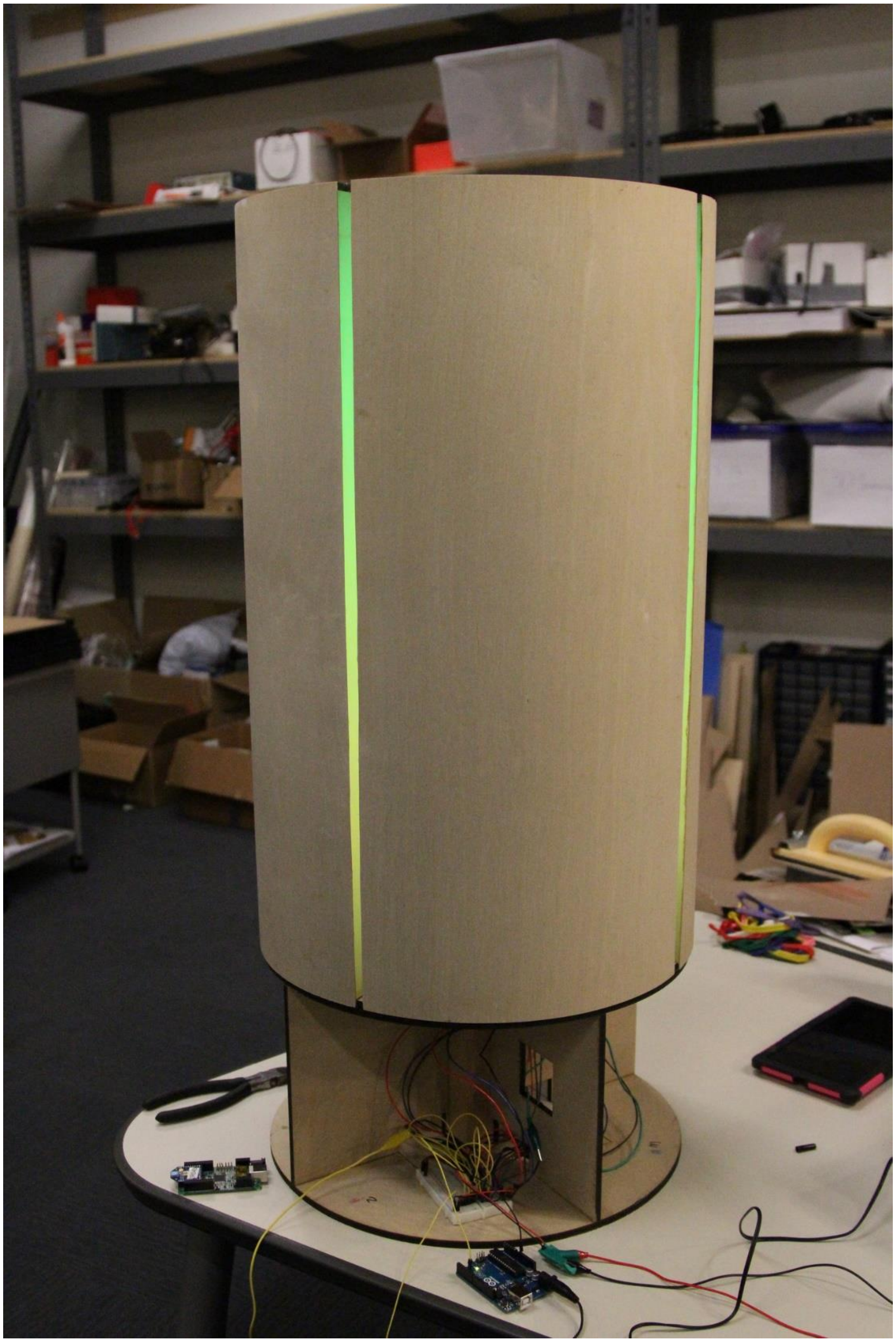
List of Acronyms

GCAP 2020	Greenest City Action Plan 2020
HCI	Human Computer Interaction
I/O	Input / Output
LED	Light Emitting Diode
RGB	Red, Green, Blue
RtD	Research through Design

Glossary

Adafruit NeoPixel library	An Arduino library provided by Adafruit to control addressable LED strips
Arduino	Open sources electronics platform consisting of various different microcontrollers and an integrated development environment
Breadboard	A board which allows the solder less connection between electronic components and wires. Often used for prototyping purposes.
DC Power Supply	Electronic device that supplies constant DC voltage
Epoxy	Term used to refer to both, resin and hardener which mixed together can bond almost any material
FastLED library	An Arduino library to control addressable LED strips
Jumper Wires	Wires used for electronic prototyping
Laser cutter	Device that uses a laser to cut materials
Microcontroller	A small computer with a processor, memory and programmable I/O peripherals
RGB LED strip	A strip consisting of LEDs which can display different colors combing the channels RGB (red, green, blue).
vvvv	A visual/textual programming language used for prototyping and developing large media installations with physical interfaces, real-time graphics, as well as audio and video



Chapter 1. Introduction

Prototypes are ubiquitous in design projects. They not only enable designers to formally evaluate their design, but also to generate new ideas and find new design opportunities. They open up the design space.

Prototypes are generally well understood and used, both in design and research. Various different kinds of prototyping techniques, methods, tools and spin offs of prototypes exists (Boer & Donovan, 2012; Borchers, 2000; Buchenau & Suri, 2000; Höök & Löwgren, 2012; McCurdy, Connors, Pyrzak, Kanefsky, & Vera, 2006; Odom et al., 2016) But despite this good understanding of what prototypes are, what they can do and a general consent of their versatility and usability, the nuanced interplay between designer and prototype received less attention from the design research community.

Schön (2000) has explained the reflective nature of design in general, while Lim et al. (Lim et al., 2008) have provided an understanding of the underlying structure of prototypes. This thesis acts at the intersection of these two contributions. Using Annotated Portfolios (B. Gaver & Bowers, 2012) as a tool, this research investigates how exactly a designer engages in a reflective conversation with her prototypes. How a design evolves over the course of a design project. How different design manifestations (Lim et al., 2008) enable the designer to find new design opportunities.

Especially within Research through Design, a research field which generates knowledge through the act of designing (W. Gaver, 2012), understanding the back and forth between designer and her prototype could provide useful knowledge. The same is true for the professional design context. A better understanding of what prototypes and designers do, how they interact with each other, how they inform each other, yields the potential to inform how a designer goes about his every day job. After all, design is a complex endeavour with "*potentially infinite and limitless sources of information, requirements, demands, wants and needs, limitations, and opportunities.*" (Stolterman, 2008, p. 57). Rittel and Webber (1973) refer to these complex situations, which often even have contradictory needs and concerns, as 'wicked problems'. And any additional tool that can potentially help the designer navigate this space, is useful.

1.1. Goals, Contributions, and Limitations of this Research

This section gives an overview of the goals, contributions, and limitations of this research. The goals are explained through the main research question which underlies this research, and the contributions are foreshadowing some the findings explained in detail in Chapter 6.

1.1.1. Goals of this research

This thesis is based on the Urban Data Posts project, a public light installation which was deployed at Telus World of Science in Vancouver, BC. During the project, the design team used various prototypes to advance the design. During the prototyping process, the design team discovered various small errors, malfunctions and flaws in their prototypes. These didn't hinder the prototype to serve its purpose and were mainly neglected. However, at a specific point during the project, the design team suddenly realized that one error reoccurred in several of the prototypes. It also suddenly became clear that this "error" held the potential to solve one of the main issues in the design. Exploring the qualities of this error, the design team was eventually able to turn an unwanted design aspects into a main feature. The final design is very much based on the same qualities that were once perceived as errors in various prototypes.

Based on this project, this thesis documents on the research done to explore how the single prototypes of the Urban Data Posts project did influence the final design. It aims to understand the nuanced interplay between prototype and designer, a reflective conversation (D. A. Schön, 2000) between the designer and her materials.

The main research question of this research is:

- How did the individual prototypes in the Urban Data Posts project influence the project's final design?

The sub-questions of this research break down the main research question into subtopics and allow a retroactive examination of the design process of the Urban Data Posts project. The sub-questions for this research are:

- What design aspects have (and could have) influenced the final design?

- What was the design team looking for when building the single prototypes?
- What are intentional and unintentional design aspects?
- How did we recognize that an unintentional design aspect has desirable design qualities?
- How did the unintentional design aspects occur in our prototypes?

1.2. Contributions of this research

Based on the analysis of the Urban Data Posts design and prototyping process, this thesis has three main contributions:

(1) A Focus Framework is presented as an extension to the Anatomy Framework

(2) Images a proposed as a tool to reframe prototypes

(3) Interactive Sketching is proposed as a tool for design exploration

1.2.1. Focus Framework as an extension to the Anatomy Framework.

The Anatomy Framework by Lim et al. (2008) allows designers to understand the fabric of prototypes and how prototypes can be used to address a very specific design aspect of their design. This allows designer to build prototypes for a very specific purpose and make sure they choose the right materials, resolution and scope for the prototype to perform. The anatomy framework has therefore a very strategic character, as it helps designer to understand, plan and build their prototypes.

The Focus Framework is distilled from the data analysis of this research. It captures a prototypes purpose (intention) and any unintentional side effects it produces. These unintentional design aspects (also referred to as design anomalies) have the potential to inform the project's design process and in case of the Urban Data Posts project, they fundamentally changed the final outcome. Thus, the Focus Framework can be seen as a 'generative tool'. It captures the design possibilities a prototypes offer through its "back-talk" (D. A. Schön, 2000).

Together, the Anatomy Framework and the Focus Framework provide tools for the designer to understand, strategically plan and build (Anatomy Framework) their prototypes as well as to evaluate and analyse (Focus Framework) them.

1.2.2. Reframing prototypes

The second contribution is a tool helping the designer to better listen to a prototypes “back talk” (D. A. Schön, 2000), in order to find design anomalies that have the potential to create new design opportunities.

Prototyping is a very immersive activity. The designer plans, builds and evaluates an artifact for a specific purpose and intention, often with related questions in mind. When the prototype is build, the designer then looks for answers and evaluates the outcome. But because the designer built the prototype for a specific purpose, her view is often limited. She does not necessarily conceive everything the prototype is telling her. Especially when the prototype actually does serve its purpose but has additional things to say. Things that are not related to its purpose or the designers questions. And it is hard for the designer to take a step back and conceive this information, because she is so immersed in the design situation.

I propose taking pictures as a way for designers to step back from their design and, literally, flatten the design situation. The actual design and prototyping environment gets transformed into a 2 dimensional object that is easily digestible which gives the designer the ability to oversee the situation.

1.2.3. Interactive Sketching

Third, based on the analysis and contribution of this research, I propose Interactive Sketching as a way to open up the design space when needed. Especially during the early stages of a design project, the designer is interested in generating as many design ideas as possible and explore opportunities. As I will show in this thesis, the Focus Framework allowed me to capture design anomalies in the prototypes of the Urban Data Posts project, which had a major impact on the final design.

I propose Interactive Sketching as a way to purposefully build prototypes that are prone to have design anomalies. This way, the designer creates unforeseen and unexpected design opportunities which help her exploring the design space.

Interactive Sketches prefer low cost and ready at hand materials over more precise prototyping tools (e.g. laser cutter) and are executed in short amounts of time. This way, the designer is not able to control all factors that influence a prototypes outcome and they are hence prone to show unexpected behavior and include design anomalies.

However, despite their “low-fidelity”, Interactive Sketches do have a computational aspect to them – hence the name *Interactive* Sketching. This is a crucial differentiation between Interactive Sketching and other quick prototyping methods.

1.3. Limitations of this research

This section briefly foreshadows the two main limitations of this research.

First, this research and its conclusions are based on a single design case. Furthermore, I am not interviewing or observing someone else’s design project, but one of my own. On the other hand, this also allows me to access knowledge about the project which might be otherwise hard to elicit from interviews and observations, or which could get been lost in translation.

The second limitation of this research is that the design project was conducted in an academic research setting and not in a professional design context. As a result, the design project was not exposed to limitations common in design practice such as budget, resources, freedom of choice, and especially time. While the contributions of this research could theoretically be beneficial for design practice, it cannot be guaranteed.

1.4. Approach

This thesis uses two main research methods to analyze the Urban Data Posts project: Research through Design (RtD) and Annotated Portfolios. Research through

Design is the underlying methodology, while Annotated Portfolios are used to analyze the project's design process.

The following section will provide an overview of this thesis and how the single chapters contribute to this research.

1.4.1. Overview

This section summarizes the single chapters in chronological order and explains how they are related to each other in order to support the overall argument. In total, this thesis has seven chapters, including the introductory chapter.

Chapter 2: Literature Review

The second chapter provides a summary of related research to this thesis. This is done in order to show adjacent research fields as well as to locate this research in relation to other research fields and publications. The chapter has three main parts which correspond to the three overlapping research areas this thesis is situated in: Design & Design Process, Research on Prototypes, and Research through Design.

Chapter 3: Methodology

The purpose of the methodology chapter is threefold. The first section is used to reiterate the purpose of this thesis through the research questions. The second section introduces the methodologies used in this research, while the third section explains how the research was conducted.

Chapter 4: Design Case: Urban Data Posts

The fourth chapter describes the Urban Data Posts project which represents the very ground this thesis is built on. The chapter starts by describing the Urban Data Posts project and how it was executed. This is similar to the description how this thesis was conducted (found in Chapter 3) but with a focus on the design and prototyping process. Next, the chapter highlights key prototypes which represent important moments in the design process. This is done in preparation for the next chapter in which the design process will be analyzed.

Chapter 5: Shifting Focus: Analysis of the Urban Data Post Prototyping Process

This thesis starts with a detailed description of the Anatomy Framework introduced by Lim et al. (2008) and then introduces the Focus Framework which will then be used to analyze the prototyping process of the Urban Data Posts project. The actual analysis will follow three distinct design aspects through the prototyping process of the Urban Data Posts. As I will show, this will highlight how the Urban Data Posts project evolved and how the single prototypes influenced the final design.

Chapter 6: Discussion

Chapter 6 presents a discussion based on the data analysis from the previous chapter. The discussion includes a detailed description of the three main contributions of this research:

- Focus Framework as an extension of the Anatomy Framework
- Reframing prototypes
- Interactive Sketching

The second section of this chapter talks about the limitations in this study, as well as future research opportunities.

Chapter 7: Concluding Remarks

The final chapter of this thesis summarizes this research. It revisits the main research question, summarizes the findings of this research and reiterates possible implications for design, as well as future opportunities for design research.

Chapter 2. Literature Review

The following chapter gives an overview of research related to this thesis. The main goal of this chapter is to narrow down what research area this thesis is situated in and to identify related key contributions.

The chapter is divided into 3 sections. The first section, Research on Design and Design Process, gives a very brief overview of design and how the process of designing is understood as a reflective conversation. The second section, Research on Prototypes, summarizes key ideas of what prototypes are, how they are applied in design, and the ways they can contribute to knowledge development. The third section explains Research through Design (RtD) and addresses how it aims to contribute to the body of research through the act of designing.

All three sections together help to situate this thesis, which is an intersection of the three sections: Design & Design Process, Prototypes, and Rtd (see Figure 1).

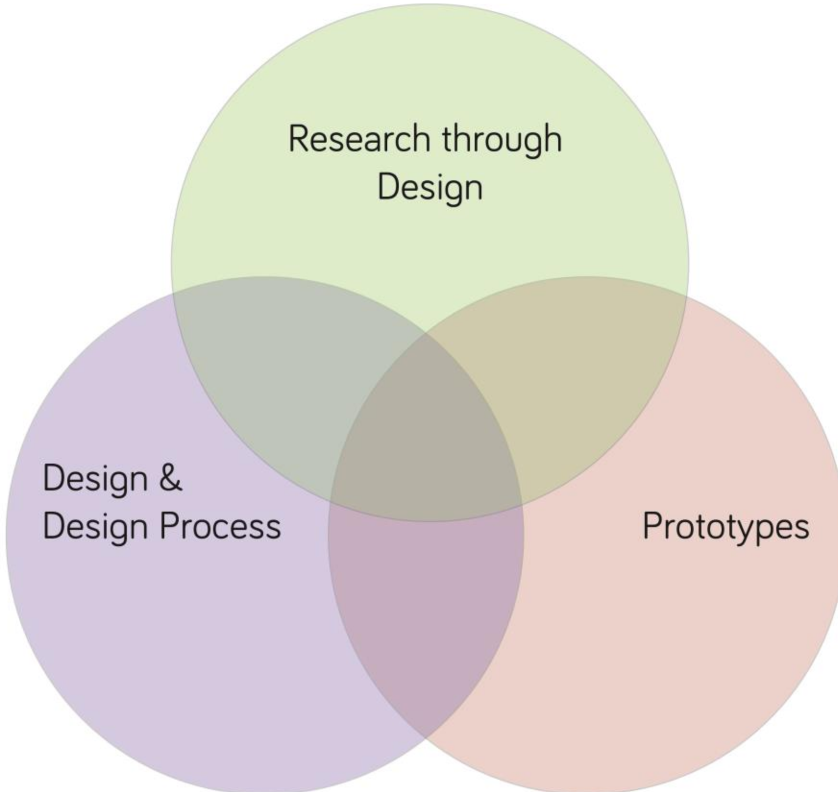


Figure 1 **Design & Design Process, Prototypes, and Research through Design overlap to create the field for this research.**

2.1. Research on Design and Design Process

This sections summarizes work related to design and design process. This is, of course, a very broad field and cannot be captured to its full extend. But it will serve as a starting point, and capture an important element underlying this thesis in Schön's (2000) work on reflective practice.

2.1.1. Design

In his book "The Sciences of the Artificial", Simon (1981) distinguishes between the natural sciences and design. The natural sciences "*are concerned with how things are*" (p.114) while design "*is concerned with how things ought to be, with devising artifacts to attain goals.*" (p.114). Alexander (1964) describes design as goodness of fit. According to him, it tries to "*achieve fitness between two entities: the form in question and its context.*

The form is the solution to the problem; the context defines the problem. In other words, when we speak of design, the real object of discussion is not the form alone, but the ensemble comprising the form and its context." (p.15). Stolterman (2008) describes how everyday design situations of a designer offers "*potentially infinite and limitless sources of information, requirements, demands, wants and needs, limitations, and opportunities.*" (p.57). Rittel and Webber (1973) refer to these complex situations, which often even have contradictory needs and concerns, as 'wicked problems'.

2.1.2. How Design is Different

A broad stream of researchers is focusing on understanding the design process itself. As identified in the previous section, designers deal with 'wicked problems' (Rittel & Webber, 1973) and to successfully solve these, designers have to navigate a complex web of information, restrictions and possibilities. Cross (2006) suggests there are designerly ways of knowing and he makes an argument to introduce design as a third area of education, next to the sciences and humanities. In total he identifies 5 aspects of designerly form of knowledge.

(1) Designers tackle what he calls 'ill-defined' problems. 'Ill-defined' problems correspond to Rittel and Webber's (1973) concept of 'wicked problems'

(2) Designers solve problems via synthesis and not analysis

(3) Designers have a constructive way of thinking

(4) Rather than relying on numerical, verbal or literary modes, designers tend to work with 'codes' (drawings, sketches, diagrams) to think and communicate

(5) Designers use these 'codes' to communicate with and through objects

2.1.3. Design as a reflective practice

Schön's (2000) definition of design as a reflective practice is an instrumental contribution to the understanding of how a designer works. By analyzing the transcript between an architect teacher and his student talking about a school project, Schön unpacks how designers are navigating complex scenarios. Schön analyses that there is a 'language of designing', a combination of drawing and talking which designers use to communicate with each other - but not only are the designers communicating. Schön argues that a designer also engages in a conversation with her own designs. Schön (2000) famously argues that a designer "*shapes the situation, in accordance with his initial appreciation of it, the situation "talks back", and he [the designer] responds to the situations back-talk.*" (p.79). This is what Schön refers to as reflection-in-action. As mentioned earlier, design situations are complex scenarios and a designer is hardly capable of fully understanding these scenarios. When she starts to design to solve the design problem at hand, the situation and the artifact she creates "talk back" to her and shows new restrictions, possibilities, and problems alike. The designer is then required to respond, she reflects-in-action on the new situation as well as on her decisions that led to it. And ultimately, she creates a new design in response which in turn open up a new web of restrictions, possibilities, and problems. Reflection in action is the ability of a designer to think "*about what she is doing while doing it, in such a way as to influence further doing.*" (D. Schön & Bennett, 1996). Schön and Bennett (1996) also compare this to jazz improvisation – players listen to oneself and one-another while still playing and reacting to each other's actions.

Schön and Bennett (1996) also identify two other forms of reflection: Reflection on Action and Reflection on Practice. Reflection on Action is when a designer is "*pausing to think back over what she has done in a project, exploring the understanding that she has brought to the handling of the task.*" (D. Schön & Bennett, 1996, p. 173). And Reflection on Practice for instance is the recognition of the designer to have developed a repetitive design behavior and pattern. According to Schön and Bennett (1996) it is this reflective nature of the designer that enables her to deal with complex situations in the first place. As "*any move has side effects*" (D. Schön & Bennett, 1996, p. 175), the designer is required to respond to (unforeseen) consequences every step of the way.

2.1.4. Creativity in Design

Although Schön's idea and description of the design process as reflective practice is commonly seen as an important step in understanding how design process works, the actual creative aspect of design is less understood. According to Dorst and Cross (2001) a so called 'creative-leap' happens in most design processes. A creative-leap is the occurrence of a significant event in a design process. Often, designers are only able to identify the occurrence of such an event in hindsight. In their work, Dorst and Cross (2001) shed more light on the creative aspect of the design by analyzing the think-aloud protocols of nine experienced industrial designers. "*The designers were requested to think aloud as they were solving the design problem, and the design session was preceded by a short training exercise, to help them become accustomed to thinking aloud.*" (Dorst & Cross, 2001, p. 428). Based on the outcomes of this study, Dorst and Cross suggest that creative design is "*not a matter of first fixing the problem and then searching for a satisfactory solution concept. Creative design seems more to be a matter of developing and refining together both the formulation of a problem and ideas for a solution, with constant iteration of analysis, synthesis and evaluation processes between the two notional design 'spaces'—problem space and solution space.*" (2001, p. 434). Dorst and Cross also point out, that Maher, Poon & Boulanger (1996) proposed a design model based on such a co-evolution of design space and problem space.

2.1.5. Mastering the Skill of Design and Design Thinking

Lawson on the other hand tries to understand how designers think (2005) and how they develop their skills (2004). In his work "Schemata, gambits and precedent: some factors in design expertise" Lawson (2004) identifies 5 areas which a designer must pass through in order to be considered an expert in his field. He points out that these areas seem to have a logical order but there is probably no need to complete one area before another can begin. The five areas (or stages) are:

(1) Acquire the language designers use (design schemata) to refer to design ideas, concepts, etc.

(2) Develop a growing set of exemplar design cases (precedent)

(3) Identification of guiding principles to structure and filter various design cases

(4) Recognizing situation with little or no analysis

(5) Developing design gambits used to deal with recognized design situations

As Lawson (2004) also points out, developing these skills may take a considerable amount of time. Because mastering design takes such a long time and design itself is such a complex behavior, many tools and methods have been developed over the years that aid the designer in various situations. One of the more popular approaches to design has emerged in the last years and is called ‘Design Thinking’. Tim Brown (2009), CEO of IDEO, shows how design thinking cannot only be applied within the creative industry but to all businesses and at every level. Design thinking for him is an “*approach to innovation that is powerful, effective, and broadly accessible, that can be integrated into all aspects of business and society, and that individuals and teams can use to generate breakthrough ideas that are implemented and that therefore have an impact.*“ (Brown, 2009)

2.1.6. Conclusion

The above mentioned literature shows what a long way design has come. From Simon’s (1981) distinguishing between the natural sciences and design, to Cross’ (2006) suggestions that ‘designerly ways of knowing’ should result in a third area of education (next to the sciences and humanities) to Schön’s (2000) understanding of design as a reflective practice, to recent design strategies being recognized as applicable to more than just the creative industries (Brown, 2009). Design has proven its value and many researchers are trying to further understand and unpack the design process and its complex nature while developing new strategies and methods to practice design.

A key component in every design process is of course the design artifact itself. A tool that is widely accepted by designers to approach the final design artifact throughout the design process are prototypes.

2.2. Research on Prototypes

This section describes research aiming to understand the nature of prototypes, how they produce knowledge, as well as various other perspectives and takes on prototypes.

2.2.1. What are prototypes

Among other definitions, the Oxford English Dictionary describes a prototype as "*a first full-size working version of a new vehicle, machine, etc., of which further improvements may be made; a preliminary version made in small numbers for evaluation, or from which improved or modified versions may be developed.*" ("Prototype," 1552)

This definition captures very well how prototypes are traditionally understood in Industrial Design, i.e. as the very first model of the design, ready for production. As Stappers points out, however, the use of prototypes has shifted and they are "*increasingly used to denote objects made for purposes of exploration and testing.*" (2013, p. 85). This purpose for exploration and testing is quite different from its initial definition and use. Stappers (2013) states that "*prototypes are as much about failing and changing course as they are about demonstrating and proving. In that sense, they can be seen as research instruments, both for exploring new directions and for validating expectations.*" (Stappers, 2013, p. 86).

Buchenau and Suri (2000) agree with the notion of prototypes as means for exploration and write that "*'Prototypes' are representations of a design made before final artifacts exist.*" (p.424). This allows the prototypes to inform not only the design process but also further design decisions. The prototypes themselves can be sketches as well as other models showing how the final design looks, behaves, or works (Buchenau & Suri, 2000).

This shift from a prototype as a final design before production towards an explorative and generative tool also means a shift in tools and materials. Indeed, Sanders and Stappers (2014) point out that prototypes can range "*from rough (giving the overall idea only) to finished (resembling the actual end result)*" (p.9) and can be "*made from a very wide array of materials including clay, foam, wood, plastic, simple digital and electronic elements.*". (p. 9).

2.2.2. Anatomy of prototypes

Lim et al. (2008) were interested in understanding the fabric of prototypes. Their work 'Prototypes as Filters' and 'Prototypes as Manifestation of Design Ideas' is very relevant to this research, as the notion of 'Prototypes as Filters' shows resemblance to the filters *In Focus* and *Out of Focus* which are introduced in this thesis (more about their resemblance can be found in Chapter 5).

Lim et al. (2008) describe how prototypes are rarely used by designers "*for formal evaluation (such as usability testing)*" (p.2) but enable them to *"organically and evolutionarily learn, discover, generate, and refine ideas*" (p.2). In order to aid the designer in this process, Lim et al. propose a framework and a foundation for the study of prototypes which they call the Anatomy of Prototypes. The framework consists of two fundamental aspects:

> *(1) "prototypes are for traversing a design space, leading to the creation of meaningful knowledge about the final design as envisioned in the process of design, and*
>
> *(2) prototypes are purposefully formed manifestations of design ideas."*
>
> (Lim et al., 2008, p. 3)

The idea behind 'Prototypes as Filters' is that designers can choose to only address the filtering dimensions in their prototype in which they are currently interested in. The filtering dimensions Lim et al. identify are Appearance, Data, Functionality, Interactivity, and Spatial Structure. By only addressing a prototype's appearance, for instance, the designer can work on the size, form and weight of her prototype and ignore the rest. This allows the designer to traverse the design space and make informed decisions about her design without having to resolve other aspects.

The idea behind 'Prototypes as Manifestations of Design Ideas' is that a designer externalizes her ideas by materializing them. The materialization happens across 3 dimensions: Material, Resolution (which corresponds to the notion of Fidelity) and Scope. Lim et al. write that these "*manifestations can take almost any form, shape, and* *appearance, based on the choice of material. (…) Even simple configurations of images and text can serve an important design service.*" (2008, p. 9).

2.2.3. Additional perspectives on what prototypes do in the design process

For Buxton (2011) there is a difference between sketching and prototyping in the design process. He writes that both are a visible representation of the design concept, but they serve a different purpose. He writes that "*sketches dominate the early ideation stages, whereas prototypes are more concentrated at the later stages where things are converging within the design funnel.*" (Buxton, 2011, p. 139). He also emphasizes that he sees the two as the two sides of a continuum and illustrates their characteristics. A sketch for instance is more provoking whereas a prototype is resolving. A sketch questions and a prototype answers, a sketch proposes and a prototype tests (Buxton, 2011). This is an interesting differentiation and I will come back to this in Chapter 6.

Houde and Hill (1997) proposed a shift away from naming prototypes after the tools they are built with and towards naming them after their purpose – that is what they (the prototypes) actually prototype. They propose three categories to indicate a prototypes purpose: Role, Look and Feel, and Implementation prototypes. Role prototypes describe what the prototype will be doing for the user of the design. Implementation prototypes are concerned with the technical aspect of the design, i.e. how it would work from a technical perspective. Look and Feel prototypes are concerned with the form, shape and materiality of the prototype, but also what it would be like to interact with. A fourth category, the Integration prototype, is created by combining the above three prototyping types. By utilizing these categories to describe real prototypes, Houde and Hill (1997) also identified suggestions helping designers to work with and to communicate their prototypes:

- Anything that represents a design idea is a prototype "*e.g., the pizza-box prototype of an architect's computer [Example 10] and the story-board notebook [Example 1]*" (Houde & Hill, 1997, p. 379)

- The complexity of designing an interactive artefact might require the build of multiple prototypes

- Different audiences require different kinds of prototypes

- Clearly communicate to your audience what design questions are explored in a certain prototype

With various existing strategies and types of prototypes to utilize in the design process, McCurdy et al. (2006) propose the use of mixed fidelity prototypes. While the terms low-fidelity prototypes and high-fidelity prototypes refer to low-cost methods on the one hand and high-end prototypes on the other, mixed-fidelity prototype "*refers to a prototype which is high fidelity in some respects and low fidelity in others.*" (McCurdy et al., 2006, p. 1233). McCurdy et al. identify 5 dimensions which can be either low- or high-fidelity in prototypes: visual refinement, depth of functionality, breadth of functionality, level of interactivity, depth of data model. According to McCurdy et al., various combinations of low- and high-fidelity in these dimensions yields a prototype with a different purpose. Knowing when to apply which can help to advance different tasks in the design process.

2.2.4. Various takes on prototypes & knowledge development

In his journal article "On the Significance of Making in Interaction Design Research" Jonas Löwgren (2016) sees "*an increasing interest in unboxing making*" (p.28) from the design research community, instead of only focusing on the final prototype for empirical studies. He suggests that there are 4 ways in which making can be useful for interaction design research. First, making can be useful when creating interactions outside of the norm. That is, interactions that the designer has not seen before and therefore cannot draw from her pool of experience. Second, and related to the first point, making can be a way to create responsive experimentations. The designer materializes ideas and then carefully listens to the prototypes backtalk. Third, when working together with collaborators (companies, organizations, non-governmental organization, individuals), making helps to fulfill the different agendas of the participating stakeholders in the project. And fourth, Löwgren argues that the process of making itself, as well as the artifact carry knowledge. Not in the sense of the artifact being a prop in a design experiment but as "*experiential knowledge embodied in artifacts*" (Löwgren, 2016, p. 32). Löwgren also points out that this is different from traditional research, where knowledge is expected to be embodied in academic writing. From the 4 points Löwgren lists, especially the first three are also very applicable in the design process.

On a similar note, Wensveen and Matthews (2015) identify 4 different roles for prototypes in design research: prototype as an experimental component, prototype as means of inquiry, prototype as research archetype, and prototyping as a vehicle for inquiry. Each archetype fulfills a different purpose, requires a different set of data, a different method of analysis and provides a different kind of research contribution.

In his book chapter "Prototypes as a Central Vein for Knowledge Development" Stappers (2013) analyzed what roles prototypes played in various research projects. He writes that "*the prototypes served different roles: facilitating discussion, bringing abstract discussions to a concrete level, being visible and reminding other researchers of the project and how they could contribute to or gain from it, posing challenges on how to develop technology to fit the theory or focusing or adjusting the theory towards technologically feasible areas. All together, the prototypes serves as a means to promote exploration and reflection as much as (or maybe even more than) means of validation and proof.*" (Stappers, 2013, p. 91). Based on these observations, Stappers also sees different design functions for prototypes. Namely: Prototypes Confront Theories, Confronting the World, Evoking Discussion and Reflection, and Testing a Theory.

Another proposal to extend the use for prototypes comes from Galey and Ruecker (2010). They argue that a prototype can work in the form of an argument and suggest that if a set of conditions are met, a prototype itself can therefore be the basis of an academic peer review, instead of using verbal language to describe a prototype. The conditions proposed are:

- "*Is the argument reified by the prototype contestable, defensible, and substantive?*
- *Does the prototype have a recognizable position in the context of similar work, either in terms of concept or affordances?*
- *Is the prototype part of a series of prototypes with an identifiable trajectory?*
- *Does the prototype address possible objections?*
- *Is the prototype itself an original contribution to knowledge?"*

(Galey & Ruecker, 2010, p. 414).

2.2.5. Beyond prototypes

Other researchers are using the idea of prototypes as a stepping stone to develop and introduce new ways of knowledge creation through the act of making.

Boer and Donovan (2012) for instance introduce the notion of Provotypes – provocative prototypes. The intention of provotypes is to embody the tensions surrounding a field of interest between two stakeholders. This way "*provotypes can serve as platforms for collaborative analysis and exploration of a design space."* (Boer & Donovan, 2012, p. 397).

Odom et al. (2016) introduce the concept of a research product as an extension to the research prototype. Odom et al. (2016) argue that research prototypes have limitations "*to create perspectives that are necessary to inquire into the complex and situated matters of human (and non-human) relations to technology, everyday practices, and creative actions over time.*" (p.2557). A research product supports these investigations through 4 qualities (inquiry-driven, fit, finish, and independent) which need to be present at the same time.

2.2.6. Conclusion

Although there are many more examples of different prototype definitions, analyses and spin-offs, this chapter shows how the prototype has developed from an artifact depicting the start of production, to a tool used throughout the design process for idea exploration and generation, to considerations about prototypes as an argument in itself. This recognition of the importance and versatility of prototypes has in turn triggered the development of new tools and concepts based on making.

2.3. Research through Design

This section summarizes Research through Design (from now on referred to as RtD), a relatively new field within HCI that is becoming widely accepted.

2.3.1. What is Research through Design?

RtD aims to produce knowledge through the practice of design and can be seen as a bridge between design practice and research. The term was first popularized by Cristopher Frayling in his piece “Research in Art and Design” (Frayling, 1993). Frayling describes how researchers, artists, and designers are commonly seen in the public eye and how this view is often heavily influenced by media. While researchers are seen as very cognitive people following strict rules and structures, artists and designers are seen as expressive, acting out of emotion. However, he also argues that this public view is not accurate, that researchers can just be as expressive as artists, and designers can be cognitive. For artists and designers, he identifies 3 categories with which they can contribute to their respective research fields: *Research into*, *through*, and *on Art and Design*. Research through Art and Design found the most resonance and was transformed into what RtD is today.

2.3.2. Current discussion about knowledge development in HCI

RtD is receiving growing interest within HCI. Specifics of RtD are still being discussed and as a result some researchers are concerned about the validity of this kind of research. Concerns have been raised asking for RtD to develop research standards such as generalizability and formalization in order to elevate RtD from a loose research field to one with clear expectations and standardized methodology to produce rigorous theory (Zimmerman, Stolterman, & Forlizzi, 2010).

Another viewpoint of this discussion is that a formalization of RtD would actually restrict the development in this subfield of HCI. This view is articulated by William Gaver’s essay “What Should We Expect From Research Through Design?” (W. Gaver, 2012). Using two prominent theories from the Philosophy of Science (Popper’s *Theory of Falsifiability* and Lakatos’ theory of *Scientific Research Programmes*), Gaver argues for the output of RtD as theory that “*tends to be provisional, contingent, and aspirational.*” (W. Gaver, 2012, p. 938). This is largely due to design being a generative practice in general. Design is not interested in the current state of the world. Design is constructing future and (hopefully) better worlds, often tackling what Rittel and Webber (1973) describe as ‘*wicked problems*’. As a result, there is a need for flexibility. Designing the ‘*right thing*’ (Zimmerman et al., 2007) also requires the designer to navigate a complex web of decisions and factors. Gaver also argues, among two other theories, that RtD might not have a paradigm on how to do research like other scientific fields because of its own nature. The arts (Architecture, Product Design, Fashion Design, Interaction Design, etc.) do not converge on a common ground like other fields. It is in their nature to rethink the current state of its field, constantly overhauling, improving and rethinking. A common ground might be more restrictive than productive from this perspective.

In front of this background, Annotated Portfolio has been proposed as a tool to draw research knowledge from artifacts while still retaining the connection to the particularity of the design (Bowers, 2012).

2.3.3. Annotated Portfolio

Annotated Portfolios is a concept introduced in order to respond to a growing conversation and concern revolving around the question how design can be a form of research. Within HCI, more and more voices have been asking for more rigor in RtD. In his paper "*The Logic of Annotated Portfolios: Communicating the Value of 'Research Through Design*'" Bowers (2012) summarizes these concerns and proposes the notion of Annotated Portfolios as a response.

Annotated Portfolios are a collection of designed artifacts (a portfolio) represented in a suitable medium (images, videos, etc.) and commented with short texts (annotations) (Bowers, 2012). Gaver and Bowers (2012) point out, that a designer puts a considerable amount of thought into her design (e.g. functionality, aesthetics, practicalities, motivation, etc.). However, a designed artifact hardly speaks for itself and it can therefore be understood from countless different perspectives. Gaver and Bowers argue that carefully articulated annotations help to communicate a design from a very specific perspective and thus create a more generalizable theory, legible to a wider audience. At the same time, the medium representing the design artifacts allows the Annotated Portfolio to retain a connection to the particularity of the artifacts. This allows Annotated Portfolios to meet the requirements of communicating design and research at the same time.

While Bowers (Bowers, 2012) see the annotations and the medium representing the designed artifacts in an Annotated Portfolio as inseparable from each other, Löwgren (2013) thinks of Annotated Portfolios as a form of Intermediate-Level Knowledge. Intermediate-Level Knowledge is described as the space in between a particular artifact and general theory. These two points are the two ends in a linear progression of abstraction. The particular artifact is not abstracted at all, while the general theory is the most abstract. Löwgren (2013) argues that Annotated Portfolios reside in the space between '*Particular Artifact*' and '*General Theory*' and the abstraction comes from the Annotated Portfolio simply being a more abstract entity from its original design which is applicable to a wider audience. An Annotated Portfolio elicits key ideas, structures and considerations from the actual artifacts it represents, which can then be used in a generative and aspirational way. Thus, Annotated Portfolios show close resemblance to other forms of Intermediate-Level Knowledge – for example strong concepts (Höök & Löwgren, 2012) and design patterns (Borchers, 2000).

2.3.4. Conclusion

Research through Design is still a relatively young field within HCI, but receiving growing interest. RtD aims to develop knowledge through the act of designing and while specifics about this kind of research are still discussed, some researchers raised concerns about the validity of RtD. One proposal that emerged in this ongoing discussion is the use of Annotated Portfolios as a way to document the work as research, while also retaining a connection to the particularity of design.

2.4. Summary

To summarize this chapter: This research is situated in between research on Design & Design Process, Prototypes and Research through Design. One concept from either field is of particular importance for this thesis which is why they are included in Figure 2.

(1) Schön's concept of 'Design as a Reflective Practice' (D. A. Schön, 2000)

(2) Lim et al. concept of ‘Prototypes as Filters’ (Lim et al., 2008) and

(3) Annotated Portfolios (Bowers, 2012)

This is not to say these are the most important contributions in their respective field, but that they are of importance for this thesis.

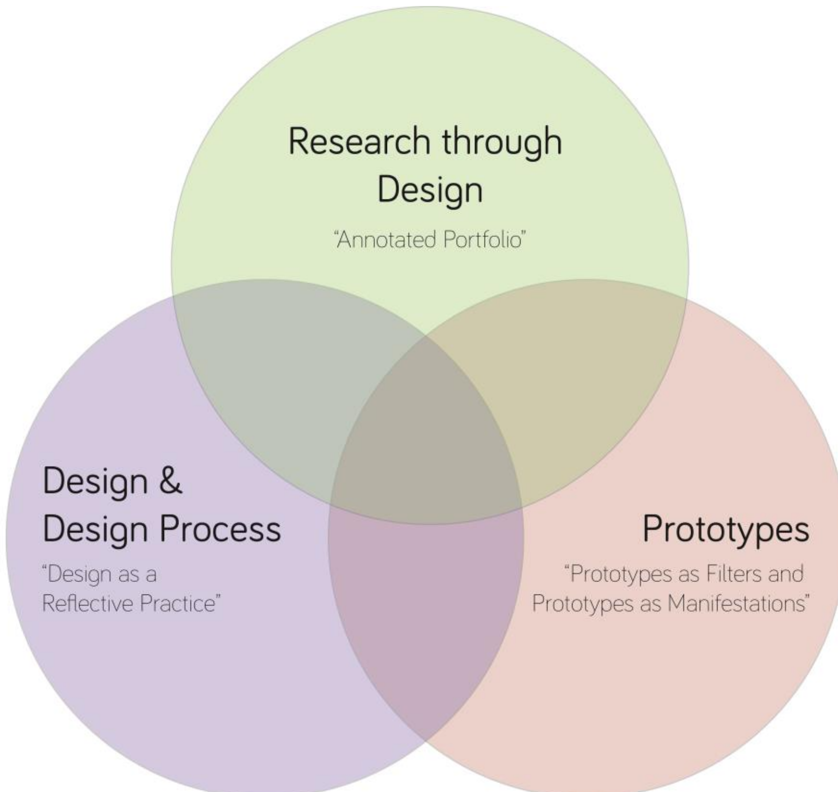


Figure 2 This thesis is situated in between the research areas of ‘Design & Design Process’, ‘Prototypes’, and ‘Research through Design’.

I mainly draw on Research through Design and Annotated Portfolio as my main core methodological tools for this research. Part of the next chapter explains why they are chosen for this research.

Chapter 3. Methodology

The following chapter is divided into three sections. First, I will state the research questions that motivated this research. The second section gives an overview of the research methods utilized in this research. Finally, the third section gives a detailed explanation of the actual procedure in which the study was conducted, echoing the used research methods.

3.1. Research Questions

This section revisits the research questions first introduced in Chapter 1. As a result, this section only acts as a reminder of what this research is set out to achieve. The main research question is:

- How did the individual prototypes in the Urban Data Posts project influence the project's final design?

The main research question of this thesis is inspired by the design process and design execution of the Urban Data Posts project. During the project's design process, the design team took advantage of unintentional and unexpected design aspects appearing in various prototypes. When first encountered, some of them were even categorized as design flaws and malfunctions in the prototype. In the end, however, the final design is very much based on those unexpected occurrences. This inspired this research to investigate how single prototypes, and their individual design aspects in particular, influenced the final design of the Urban Data Posts project. And on a more holistic level, how a designer engages in a reflective conversation with her designs.

The sub-questions of this research break down the main research question into subtopics and allow a retroactive examination of the design process of the Urban Data Posts project. The sub-questions for this research are:

- What design aspects have (and could have) influenced the final design?
- What were we looking for when building the single prototypes?
- What are intentional and unintentional design aspects?

- How did we recognize that an unintentional design aspect has desirable design qualities?
- How did the unintentional design aspects occur in our prototypes?

These sub-questions all contribute to the understanding of the main research question, but explore different aspects of it.

3.2. Research Methods

This section outlines the two methodologies that play into this research. The core methodologies utilized in this thesis is Research through Design (RtD) and Annotated Portfolio.

3.2.1. Research through Design

Since RtD was already introduced in the previous chapter, this section briefly summarizes RtD's intention and then justifies why this research can be identified with RtD.

Research through Design

RtD aims to produce knowledge through the practice of design and can be seen as a bridge between design practice and research. Gaver argues for the output of RtD as theory that "*tends to be provisional, contingent, and aspirational*" (2012, p. 938) because design is a generative practice and a common paradigm could therefore be more restrictive than productive.

To better communicate RtD, Gaver and Bowers (2012) propose Annotated Portfolios, which will be introduced right after the justification of RtD.

Why Research through Design?

Research through Design shares many underlying epistemological attitudes with the research of this thesis – both are provisional, annotative and aspirational.

The goal of the Urban Data Posts project was to find new and novel ways to engage the public with urban and communal data. The purpose of this project was not to find one correct way of displaying data or comparing various ways of eliciting public engagement with each other. The project shows a vision of how such a system could look like, how the data is represented (which is also inspired by ludic design), and how it behaves when people interact with it. The project's character is therefore very generative and suggestive. As a result, the very ground this thesis is built on, the Urban Data Posts project, is situated within RtD.

On the other hand, and more importantly, the main purpose of this thesis itself is to examine how the design process, and specifically how individual aspects of single prototypes, informed the final design of the Urban Data Posts project. This research is a close examination of a reflective conversation between designer (or design team) and her (or its) prototypes. As a result, the knowledge produced by this thesis is provisional as it is annotative and aspirational – characterizations mentioned by Gaver to have contributed to RtD. This work aims to (1) give other designers new tools to understand and utilize prototypes in their design process and (2) to shed more light on the ramifications of prototypes.

3.2.2. Annotated Portfolios

Annotated Portfolio was also introduced in the methodology chapter. The first section therefore quickly summarizes Annotated Portfolio before the second part justifies its use in this research.

What are Annotated Portfolios?

Annotated Portfolios are a collection of designed artifacts (a portfolio) represented in a suitable medium (images, videos, etc.) and commented with short texts (annotations) (Bowers, 2012). This way the Annotated Portfolio communicates both, research and design. Gaver and Bowers argue that carefully articulated annotations help to communicate a design from a very specific perspective and thus create a more generalizable theory, legible to a wider audience. At the same time, the medium representing the design artifacts allows the Annotated Portfolio to retain a connection to the particularity of the artifacts.

Löwgren (2013) thinks of Annotated Portfolios as a form of Intermediate-Level Knowledge, as they reside in the space in between a particular artifact and general theory. An Annotated Portfolio elicits key ideas, structures and considerations from the actual artifacts it represents, which can then be used in a generative and aspirational way.

Why Annotated Portfolios?

It is important to understand that this research uses Annotated Portfolios as a starting point for the analysis of the Urban Data Posts project. This research is, so to say, inspired by the notion of Annotated Portfolios.

As stated earlier, the goal of this thesis is to examine the design and prototyping process of the Urban Data Posts project. Löwgren (2013) agrees with Bowers that "*the designer of an artifact is in a somewhat privileged position to provide valuable knowledge in the form of abstractions (…). The designer has unique access to the original design intentions, the history of how the design space was explored, how the process related to previous work, how different treatments were assessed, what data came out of empirical evaluations, and so on.*" (p. 32).

Because I was part of the design team developing the Urban Data Posts project, I have access to this intimate knowledge. At the same time, as a researcher, I am interested in understanding the impact of the single prototypes on the final design. Therefore, there was a need to generate a more holistic understanding of the prototypes and how they are connected, an understanding that has its origins in the details of each prototype (e.g. a prototypes intention, the tools and materials used, competencies as a designer, etc.). The use of Annotated Portfolios allows to gain this holistic perspective of the prototypes by, literally, annotating them with inside knowledge about the design process gained through the design of the prototypes in the Urban Data Posts project.

3.2.3. Summary

To summarize why the above mentioned methodologies are chosen: This research itself aims to understand the decision making that underlies the Urban Data Posts projects design process, especially the interplay between designer and prototype. Although there are other ways of understanding a project's design and prototyping process (e.g. Case Study, etc.), using RtD seemed advantageous. What better way to conduct research on prototyping than to actually *engage in* prototyping? And using the Urban Data Posts project, in which I was involved as a designer, allows this research to receive a first person research through design perspective.

At the same time the overlap between being a designer and being a researcher requires me to take two positions. As a researcher I need data from the project – data I can provide from my position as a designer who worked on the project. And since I need to understand the prototypes from a more holistic perspective (how they are connected and how they influenced each other), I need to use the data I have access to, to gain this perspective. Annotated Portfolios allows taking this point of view, by eliciting the knowledge about each prototypes purpose, build, outcome, and resulting design decisions.

3.3. Study

The final part of this chapter explains how the Urban Data Posts project was conducted and analyzed. It is divided into 2 distinct phases: 'Design Process' and 'Data Collection and Analysis'.

3.3.1. Phase 1: Design Process

The first phase of this thesis research work is the Urban Data Posts Project itself and its specifics. The project's design process is explained in more detail in Chapter 4. This section will therefore provide a more holistic overview of the project and how it was conducted.

The Urban Data Posts was a public light installation eliciting public engagement displaying urban and communal data. It was deployed for three weeks in November 2015 at Telus World of Science in Vancouver, BC. The project was a collaboration between the Everyday Design Studio (EDS), Telus World of Science in Vancouver, and SAP Vancouver. The core team of the project were three members of the Everyday Design Studio who were responsible for the development and deployment of the project. Members of Telus World of Science Vancouver and SAP Vancouver provided support in areas familiar to their expertise. For instance, members of SAP Vancouver helped with initial research about finding and processing data for the project while members of Telus World of Science helped with the logistics for the deployment of the installation on their premise. Regular meetings were held in order to update everyone involved about the latest progress of the project and to gather feedback. The project was supported by an NSERC Grant.

The project began with the creation of an overarching theme, which was found after a daylong workshop with members from SAP. The project's theme was called "Making the Invisible, Visible" and was situated in the near future. In it, the City of Vancouver is seen as a hub for renewable energies and technology has advanced to harvest these various energy resources such as wind, solar, tidal, geo-thermal, and kinetic energy from biking and walking. Harvesting these energies would transform the city from an energy consumer to an energy producer. The goal of the project was not to show detailed information about the energy resources but to make Vancouverites aware that they are surrounded by energy. Hence "Making the Invisible, Visible.".

After we had chosen a concept as a starting point for our project we immediately started prototyping. Overall we developed 16 different prototypes. The prototypes ranged from simple setups (*RGB LED Test)* to form explorations (*Cardboard Scale Model*) to technical improvements (*Battery Test*) and blueprints for manufacturing (*Hexagonal Data Post*). The final two prototypes (*Urban Data Posts Assembly* and *Animations* + *Reactions*) represented the final Urban Data Posts which were deployed at Science World for three consecutive weeks in November 2015.

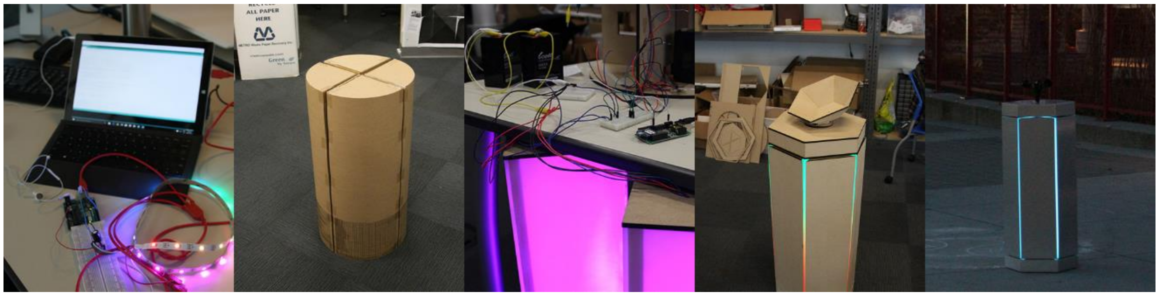


Figure 3 Range of different prototypes created in the Urban Data Posts project.

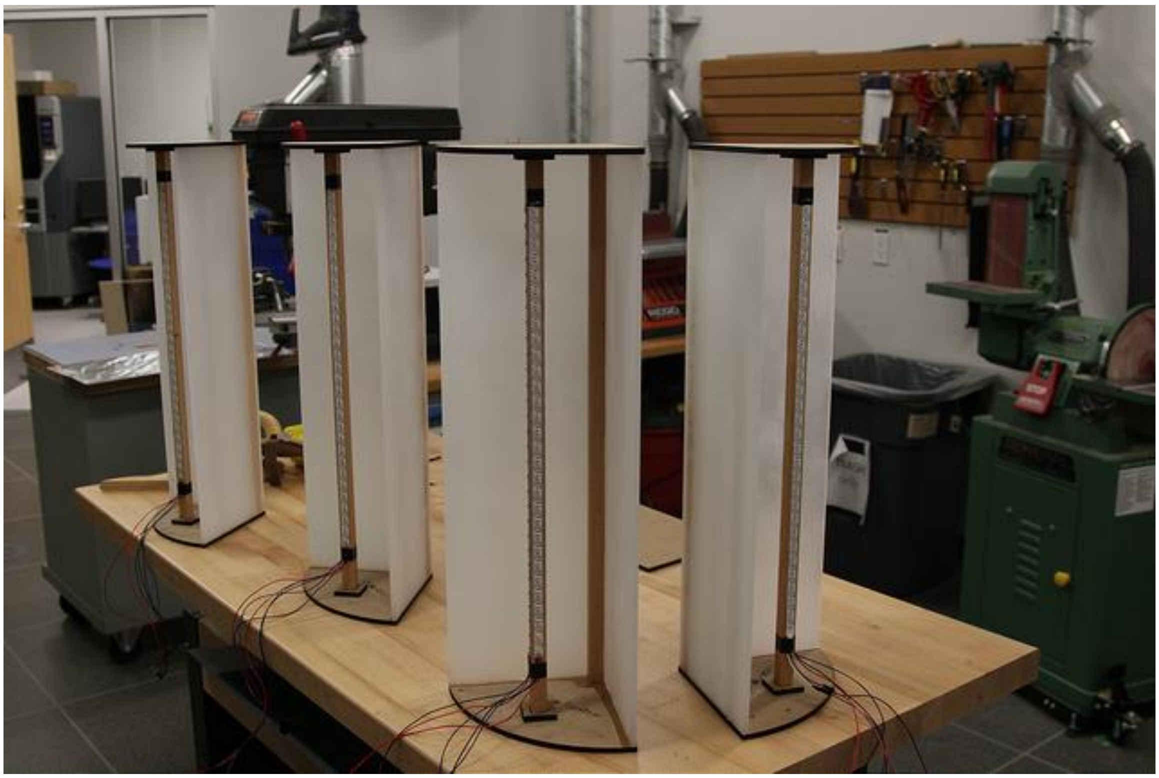


Figure 4 Assembling the wedges for the *Round Data Post* prototype in the digital fabrication and prototyping lab

Almost all of the prototypes were developed at SFU's Everyday Design Studio and the adjacent Solid Space – a digital fabrication and prototyping lab (see Figure 4). Whenever possible, we used tools and materials ready at hand to save time and costs. Because of that, some of the prototypes are built out of foam board or cardboard and put together using crafting materials such as clear adhesive tape, pins, and glue. The parts themselves were often cut using scissors or carpet knives. More elaborate prototypes were mostly built using ¼” MDF as material, which was cut using a laser cutter or a band saw. The parts were then assembled with glue (e.g. Epoxy) or a power drill and screws. Only the parts for the final prototype were professionally manufactured and spray painted.

A more detailed description of the prototyping process of the Urban Data Posts project is following in chapter 4.

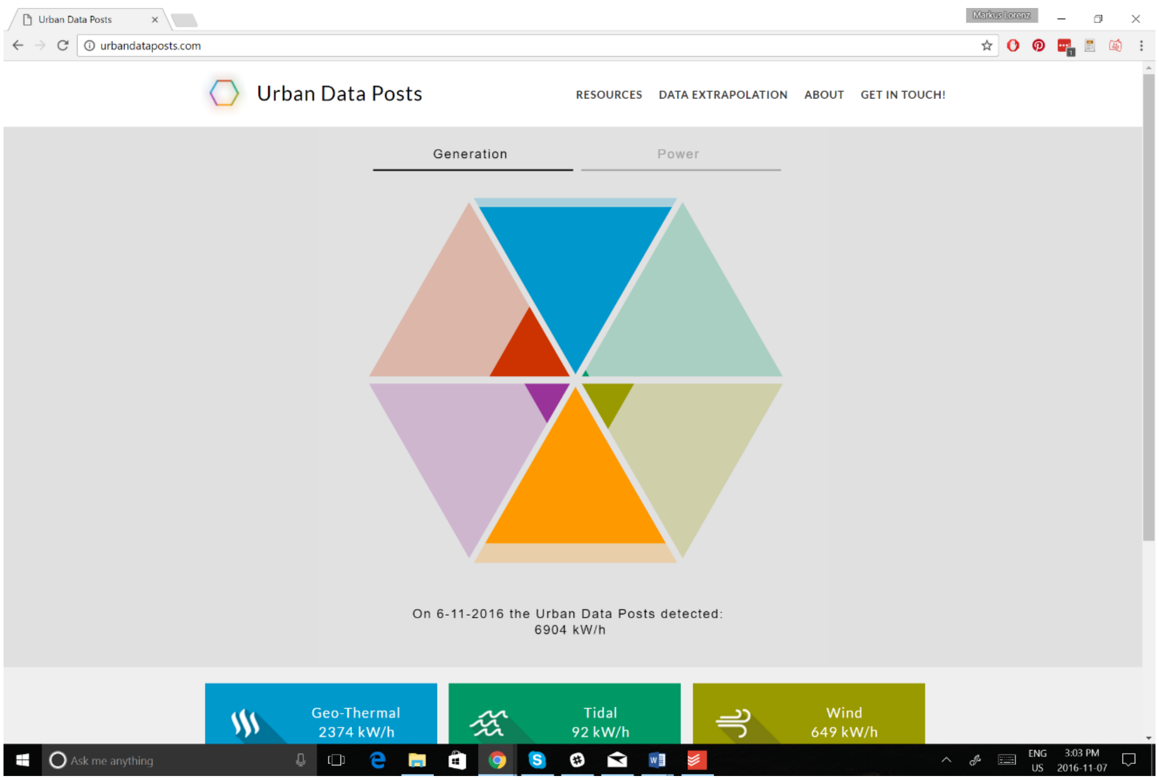


Figure 5 Screenshot of the Urban Data Posts website

In addition to the artifacts, a website (Figure 5) for the project was designed – http://www.urbandataposts.com. The website was also developed by the members of the Everyday Design Studio and it is meant to provide additional information about the project such as energy output, energy resources and project purpose. The website itself was developed using WordPress and is hosted on a private server. After the final prototypes were built and the website was ready, the Urban Data Posts were deployed at Telus World of Science in Vancouver, BC for three consecutive weeks.

During the first week, the design team made some additional changes to the code and the animations displayed on the Urban Data Posts. This was done in order to adjust the posts to their actual, outside environment. During the remaining two weeks the members of the Everyday Design Studio attended the installation to observe public reaction and interactions as well as to answer questions and document the work with pictures and videos. Posters on site let passers-by know about the website if they wanted to access additional information about the project.

3.3.2. Phase 2: Data Collection and Data Analysis

After the project had been deployed, there was a discussion among the members of the Everyday Design Studio on how the final design is built on what was once perceived as an error/malfunctions/design flaw in early prototypes. The error was a crack in one of our prototypes through which the light of RGB LED strips could shine through. At a certain point in the design process, the design team made the conscious decision to utilize the design qualities of this “error” and turn it into a design aspect. This decision ultimately led to the way the final prototype works (see Figure 10). The discussion around the utilization of cracks led to the question of how the single prototypes and more specifically single design aspects influenced the final design outcome. In order to answer this question, analysing the design process of the Urban Data Posts project seemed a logical next step. The focus of this analysis was especially on the single prototypes that were developed and their various design aspects.

As a first step, all different prototypes were identified. In total, the design team developed 16 prototypes including the one deployed at Telus World of Science (for an overview see, Figure 11). The prototypes were then ordered chronologically and given names. Most prototypes already had been given a name during the design process but some needed a name. The names were not necessary for the analysis itself but enabled a better identification and communication. Since I used Annotated Portfolios as a starting point for the analysis, I had to find a medium to represent the prototypes in. I chose to work with images for two reasons. (1) Throughout the Urban Data Posts project we documented the progress with images (~500) and videos (~41). Using images in the Annotated Portfolio would therefore allow me to draw on already existing representations of the single prototypes. And (2) using images to represent a digital artifact that visualizes data just seemed adequate.

Before images for the Annotated Portfolio were selected, an album for each prototype was created on our studio's Flickr account (Figure 6). After uploading all of the pictures and videos to their respective album (Figure 7), 2-5 pictures were selected to represent each prototype. Only one prototype is represented with a single image. This is because this specific prototype is very simplistic and could easily be captured within a single image. The pictures selected were chosen to show the prototype as a whole as well as to highlight prominent features, errors or other points of interest.

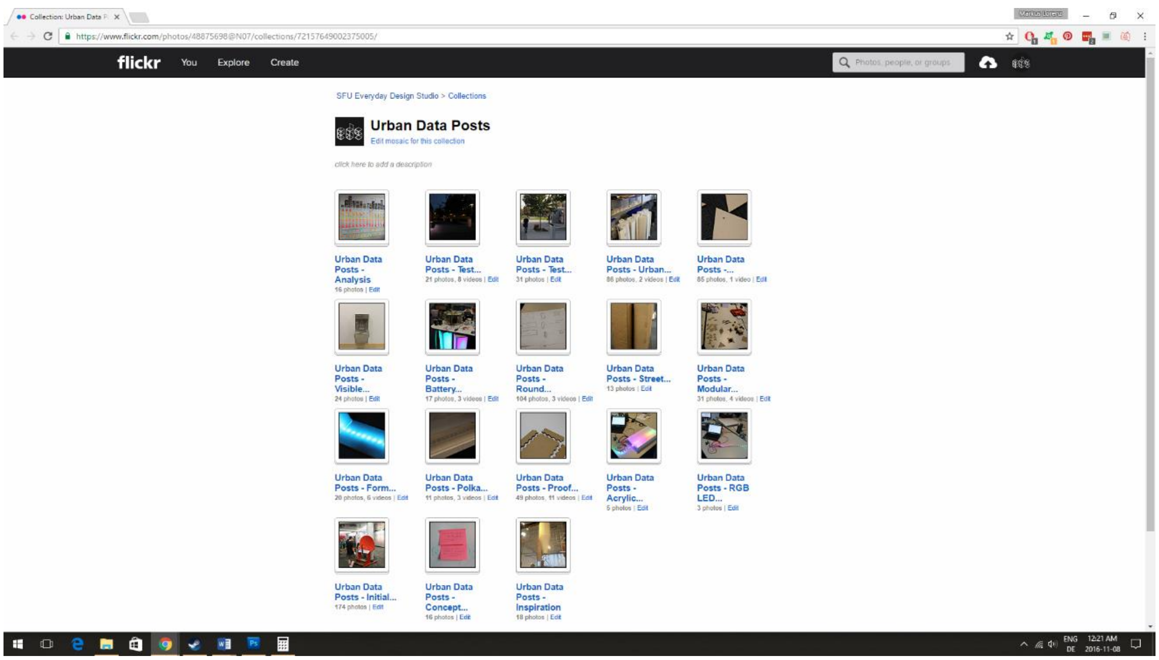


Figure 6 **Urban Data Posts Flickr collection with various albums about the project's design process.**

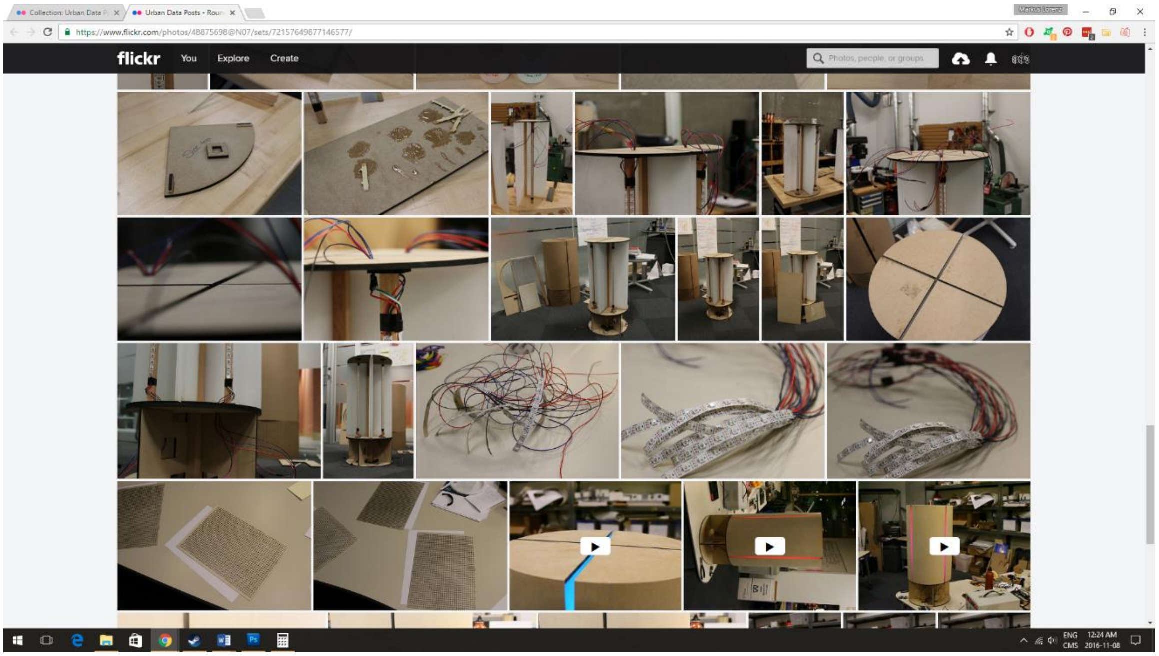


Figure 7 Album of the *Round Data Post* prototype

After the pictures for each prototype had been selected, the perspective of the Annotated Portfolio was established. As described earlier, Annotated Portfolios allow to view design artifacts from a specific perspective. As Bowers (Bowers, 2012) writes "*a portfolio can be annotated in several different ways reflecting different purposes and interests.*" (p. 72). Since this research is interested in understanding how the single prototypes and specifically its design aspects influenced the final design, the following annotations points were created:

Table 3.1. Annotation points and their description

ANNOTATION POINT	DESCRIPTION
Intention	The reason why a prototype was being built
Conceptual Decision	Decisions made outside of the design and prototyping process (e.g. "Decision to work with RGB LED strips")

Problems Encountered	Problems we encountered during the build of the prototype (e.g. “Parts for prototype too big for laser cutter. Needed to split design in half.”)
Design Insights	Insights we gained while building or reviewing the prototype (e.g. “Moiré effect occurred after removing the acrylic sheets behind each mask.”)
Outcome	Description of the prototype (e.g. ”Wooden frame with polka dot box on two sides and RGB LED strips inside.”
Design Decisions	Design decisions we made after the prototype was evaluated (e.g. “Using Adafruit NeoPixel library over FastLED library.”)
Time	The approximate time we spent building a prototype (e.g. “3 days”)
Material & Components	The materials and components we used to build a prototype (e.g. “Arduino, Breadboard, Jumper Wires, RGB LED Strips, Nails, Screws, Wood, 1/8” wooden veneer, ¼” acrylic”)
Tools	The tools we used to build a prototype (e.g. “Frosted Spray Paint, Laser Cutter, Table Saw, Sand Paper, Hammer, Clear Adhesive Tape, Screw Driver, Power Drill, DC Power Supply”)
Competencies	The competencies we needed for the build (e.g. “Arduino, Basic circuitry and electronics, basic woodworking”)

After the single annotation points had been established, the annotations for each prototype were created. During the process, it felt easiest to move from annotation point to annotation point, instead of filling out all annotation points for each prototype. The process itself was executed on a dry board in the Everyday Design Studio space. The single prototypes and their respective pictures were aligned horizontally and all the annotation points vertically. Post-it notes were used to create the single entries (Figure 8). The whole process took approximately one week.

Figure 8 **Work in progress on the Annotated Portfolio of the *Urban Data Post* prototypes**

It is important to note here again that the Annotated Portfolio was only a starting point for the analysis. Its use allowed a close reflection on the Urban Data Posts project, retracing the single steps in the prototyping process and thus gaining a new perspective on the single prototypes. At the same time, the annotation points listed above were only the beginning. During the analysis new points were added to reflect on newly gained information and points of interest.

The most interesting points were the cross reference of a prototype’s purpose, the problems we encountered during its build, and the outcome. It suddenly became clear that things we had identified as “errors” in the design process, were really just design anomalies (see chapter 5 for detailed description on design anomalies). These “errors” did not interfere with the purpose of the prototypes they appeared in. They simply were side effects of the tools used to build the prototype, the time spent during the build, competencies, as well as material characteristics. This changed our perspective on them and we started to refer to these “errors” as unintentional design aspects.

As a result, the analysis matrix was slightly changed to emphasize both – a prototype’s intentional and unintentional design aspects. After a few more iterations, these categories eventually turned into the lenses *In Focus* and *Out of Focus* (see chapter 5). Since these lenses also showed similarities to the notion of prototypes as filters (Lim et al., 2008), the analysis was extended to include the filtering and manifestation dimensions of each prototype. The final analysis matrix with a focus on the prototype’s intentional and unintentional design aspects, as well as the filtering and manifestation dimensions was transferred to a Google Spreadsheet (Figure 9). This matrix builds the base of the analysis of this research, which is described in Chapter 5.

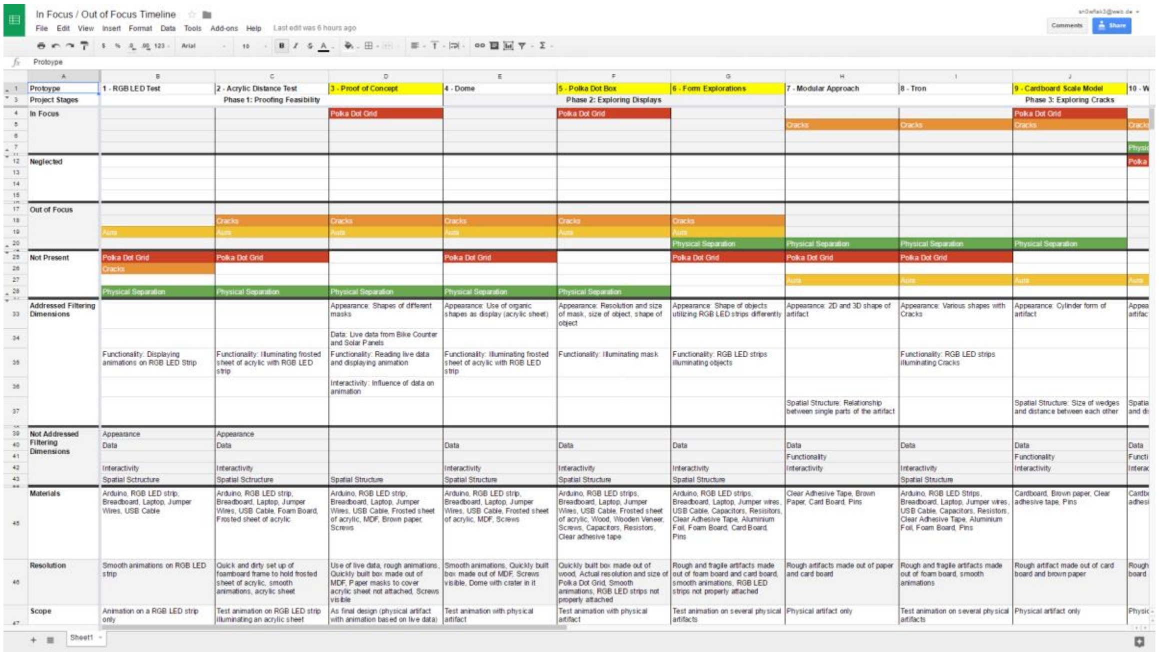


Figure 9 **The final analysis matrix in a Google spreadsheet showing a prototypes intentional and unintentional design aspects over time.**

3.4. Summary

This chapter described the methodology of this research. Starting from the main research question and its sub questions, the chapter introduced and justified the methodologies used and then described how the study was approached and conducted. This is done in preparation for the next two chapters.

Chapter 4 describes the Urban Data Posts project in more detail, with a focus on key prototypes developed during the design process. Chapter 5 then analyses the prototypes of the Urban Data Posts project with the lenses *In Focus* and *Out of Focus*, which were distilled from the Annotated Portfolio.

Chapter 4. Design Case: Urban Data Posts

The following chapter is divided into three sections: Project Description, Project Timeline, and the Description of Selected Prototypes. Following this introduction, section one gives a holistic description of the *Urban Data Posts* project and section two gives an overview of the project's design process. Section three then highlights selected prototypes by describing them in more detail.

The information provided in this chapter builds the foundation for the analysis following in chapter 5. There, the design process will be analyzed through two lenses (*In Focus* and *Out of Focus*) to understand how the prototypes were framed.

4.1. Project Description

The *Urban Data Posts* project was a collaboration between the Everyday Design Studio at SFU, Telus World of Science Vancouver, and SAP Vancouver. The outcome of the project was a public light installation, deployed at Telus World of Science World in Vancouver, BC. The installation was situated outside of Science World, along the side walk, over the period of three weeks in November 2015. Being situated outside, a key criteria for our light installation was visibility, as we wanted the visualization work at day and at night.

The installation consisted of three *Data Posts*, hexagonal cylinders emitting light. The animations displayed by the light represented the energy level of three different renewable energy resources: Solar, Wind, and Walking. The purpose of the Data Posts was to create awareness about a city being a resource for energy, by highlighting the energy resources surrounding us.

4.1.1. The Data Posts

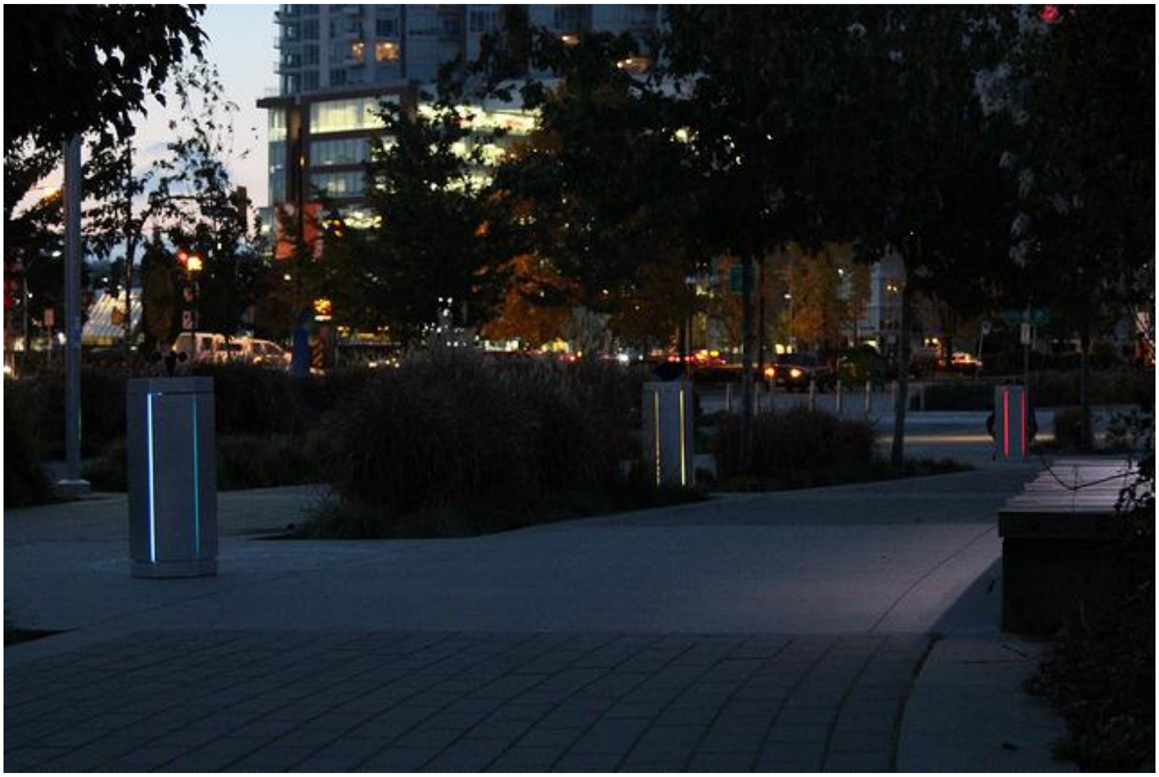


Figure 10 The Urban Data Posts along the sidewalk in front of Telus World of Science in Vancouver, BC.

Figure 2 shows the *Urban Data Posts* during the deployment at Telus World of Science in Vancouver, BC. As seen in the picture, the installation consists of three hexagonal cylinders, the *Data Posts*. Each *Data Post* is made out of the same three parts: the *Base*, the *Wedges*, and the *Visible Sensor*. The *Base* is a simple hexagonal cylinder on which the remaining parts stand on. The heart of each artifact are the *Wedges* – six triangular cylinders which together form a hexagon. The wedges do not lean against each other but have ¼" space in between. This space is referred to as *Cracks* – a central idea in the design. The *Visible Sensor* is the top part of each *Data Post.* Much like the *Base*, it is a hexagonal cylinder but with small model of a sensor attached to it (either a solar dish, an anemometer, or cameras). These sensors measure the current energy level of the energy resource (Solar, Wind, and Walking) and their form gives a hint on what energy resource is being displayed by each posts – hence the name *Visible Sensor*.

The setup works as following. The *Visible Sensor* of each *Data Post* hosts various electronic components. On one hand there are sensors to measure the current energy level of either Wind, Solar, or Walking. On the other hand there is an Arduino UNO which processes the measurements and triggers animations according to the measurements. The animations are displayed on six RGB LED strips, one inside each *Wedge*. Each *Wedge* is made out of one ¼" MDF sheet and two ¼" frosted acrylic sheets. The single *Wedges* are arranged so that all acrylic sheets face each other inwards while all MDF sides face outwards. This way the animations of the RGB LED strips can shine through the frosted acrylic and illuminate the space in between the *Wedges*, the *Cracks*.

4.1.2. Renewable Energy Resources and their Energy Levels

The idea to work with renewable energy sources as data stems from our decision to situate our project within Vancouver's Greenest City Action Plan (GCAP) 2020. The GCAP of the City of Vancouver encompasses various action plans and strategies with the goal of making Vancouver the greenest city in the world by the year 2020. Since energy production and energy consumption is a big part of sustainability, we wanted to show that that a city cannot only be a consumer of energy, but also a producer. While this might not be possible with current technologies, we situated our project in the future, where various technologies could exist to harness the various energy resources available in a city.

Although there are ways to measure energy levels and energy production accurately, data accuracy was not an important aspect in our project. We wanted to create awareness that there is energy available in the city and that it is in fact surrounding us. The exact energy output was therefore secondary. Because of that our *Data Posts* did not show how much energy is being produced, but instead showed the energy level of a renewable energy resource. This was done with simple animations. To give an example: our *Wind Data Post* showed the energy level through a rotating animation. The more wind, the faster the animation.

4.1.3. Purpose

The purpose of the Urban Data Post project was to create awareness of the energy available in a city. We also wanted to find novel ways of displaying the data and create public engagement with the installation. To do so we brought in a very unusual factor when it comes to data representation: time.

Because of the way our data was presented, one could not understand its meaning on first glance or over a short period of time. This is very different from other, more common forms of data representation, in which the information needs to be comprehensible to an individual within a short period of time. Successive interactions on different days and at different times were necessary in order to develop an appreciation and understanding of the installation. This way we hoped to evoke curiosity and create a more lasting engagement with the installation. Our installation had therefore also a very specific audience in mind: Vancouverites living close to Science World or commuting past Science World on their way to work. These people would have the necessary frequent exposure to the installation to gain a deeper understanding of its inner workings and meaning.

4.2. Project Timeline

The following section gives an overview of the project team, as well as the single stages executed during the design process.

4.2.1. Project Team

The core team for this project consisted of three members of the Everyday Design Studio and were responsible for the design, development, and deployment of the project. Personal and professional projects include various design and research projects, media installations, as well as reviewing and building DIY projects and instructions. Each member therefore had a unique set of skills which he brought to the project such as modelling, programming, electronics, soldering, or woodworking. In addition, the Everyday Design Studio is located next to Solid Space – a digital fabrication and prototyping lab (see Figure 4) – and the design team therefore had access to a wide range of tools and equipment such as soldering irons, laser cutter, table saw, band saw, press drill, vacuum former, 3D printer, CNC machine, etc.

4.2.2. Design Process

The *Urban Data Posts* project was conceptualized, designed, and developed over the course of one year. The majority of the time was spent building and evaluating the 16 prototypes built over the course of the project. The following section summarizes the prototyping process, which can generally be split into 5 stages.

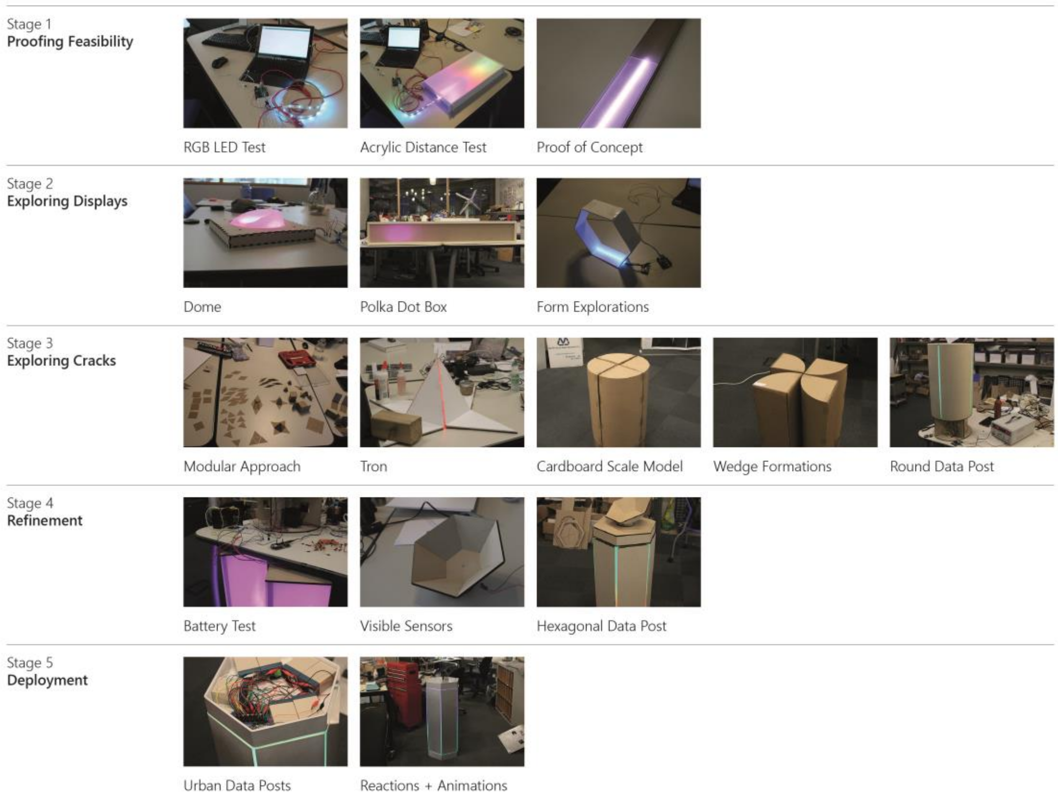


Figure 11 Overview of the 16 prototypes in their respective design stage.

Stage 1 – Proofing Feasibility

After we had developed a conceptual framework for the project we immediately started prototyping. During the first stage, which encompassed 3 prototypes (*RGB LED Test*, *Acrylic Distance Test*, and *Proof of Concept*), we were mainly concerned with the technicalities of the project. Since we wanted to use RGB LED strips in our project, we tested them towards visibility, versatility and ease of use (*RGB LED Test*). We then moved forward and tested how well they interact with frosted sheets of acrylic (*Acrylic Distance Test*) and then proofed the feasibility of the project by displaying live data from a renewable energy resource as an animation on an RGB LED strip (*Proof of Concept*). Although an RGB LED strip was able to illuminate a frosted sheet of acrylic, we decided not to illuminate bigger surfaces since the illumination was very uneven. Illuminating a bigger surface more evenly would require too many LED strips.

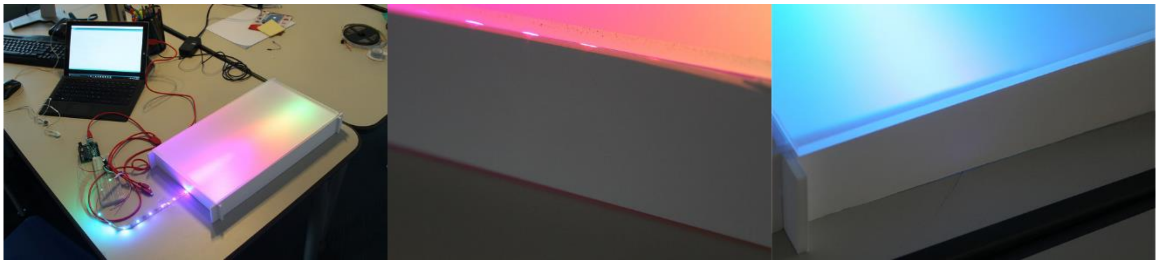


Figure 12 The *Acrylic Distance Test* prototype

Stage 2 - Exploring Displays

Because of what we learned during the first stage, our second stage, which also comprised of three prototypes (*Dome*, *Polka Dot Box,* and *Form Explorations*), was mainly concerned with exploring other forms of utilizing RGB LED strips. After quickly realizing the limitations of utilizing a vacuum former to mold frosted sheets of acrylic (*Dome*), we explored the use of masks.

Masks were an approach we developed during the *Proof of Concept* prototype. The idea was to cut patterns into opaque material and put it on top of a frosted sheet of acrylic. This way the light of the RGB LED strips would only be visible through the pattern, effectively hiding that the frosted sheet of acrylic is illuminated unevenly. Unfortunately, this approach failed due to a lack of visibility, which was a key concern for our project. This led us to explore other options of utilizing RGB LED strips in the *Form Explorations* prototype. During this prototype we made the discovery that most of our prototypes so far have something in common, which we had consciously ignored: little cracks between components through which light of the RGB LED strips leaked through. This discovery gave us the idea to explore cracks as a form of display.

Stage 3 – Exploring Cracks

The third, and largest, stage involved 5 different prototypes: *Modular Approach*, *Tron*, *Cardboard Scale Model*, *Wedge Formations*, and *Round Data Post*. During this stage we were exploring and refining the idea of utilizing cracks as a form of display. We started off with exploring possible shapes which utilized cracks effectively. In the *Modular Approach* prototype, we arranged laser cut shapes to different formations and extruded selected formations afterwards by building them with cardboard.

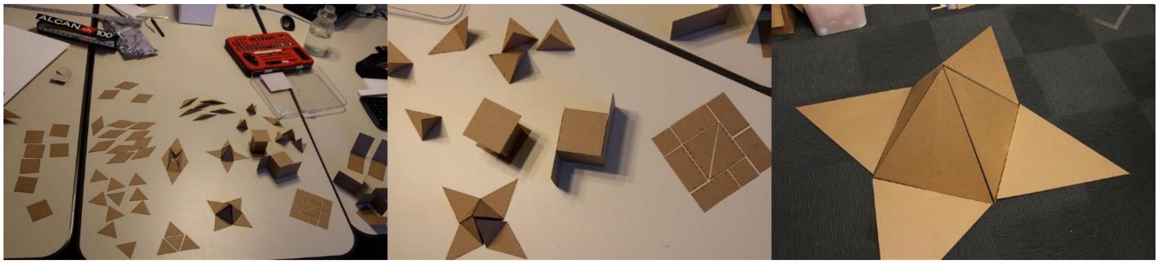


Figure 13 Exploring shapes with cracks based on geometric shapes in the *Modular Approach* prototype.

In the *Tron* prototype we then illuminated some of the shapes using RGB LED strips to see if the design is worthwhile pursuing. We were very satisfied with the visibility but still were not sold on the actual physical form. Because we wanted our design to blend into the urban environment we got inspired by street posts and decided to explore their shape in the *Cardboard Scale Model* and the *Wedge Formations* prototype. During these prototypes we developed 4 round wedges and arranged them to a street post-like shape. Since the post was made of 4 wedges the setup featured several cracks but also had a modular nature. The wedges could be rearranged to form different patterns, something we quickly explored in the *Wedge Formations* prototype. Happy with the recent developments, we then decided to build a high fidelity prototype, the *Round Data Post* prototype. We build the 4 round wedges out of sturdy material and included RGB LED strips to illuminate the space in between the wedges, the cracks. The outcome was very promising and we decided to go with this approach and move on to the next design stage.

Stage 4 - Refinement

The fourth design stage includes 3 prototypes (*Battery Test*, *Visible Sensors*, and *Hexagonal Data Post*) and was concerned with the iteration and refinement of the *Round Data Post* prototype. This was done to move closer to a final design which we could ultimately deploy at Telus World of Science.

The *Battery Test* prototype was set up to find suitable batteries to power our artifact. This was necessary since we would not have access to a power outlet along the sidewalk at Telus World of Science. Using the 4 wedges from the *Round Data Post*, we tested various batteries in terms of their ability and durability powering a single post. We also took this opportunity to refine the electronic circuit. The next prototype, the *Visible*

Sensors, was an idea that surfaced from the *Wedge Formations* prototype. While we were playing with different formations of the wedges we realized that the single artifacts for every energy resource could look different from one another. Up until that point we envisioned them to look the same, but with the *Visible Sensors* we developed a visually distinct top for every post that is also capable of measuring the renewable energy that the post is representing. In total we developed three Visible Sensors, one for each post.

Figure 14 The three *Visible Sensors*: Wind, Walking, and Solar.

The *Hexagonal Data Post* was the accumulation of our last design iterations. It included the new circuit, ran with batteries, had a visible sensor on top, and also had a more efficient design. In order to visually match the post with the Telus World of Science building (which has a very prominent geodesic dome) we designed the wedges of the data post as triangular cylinders, forming a hexagonal post.

Stage 5 - Deployment

The final stage of the prototyping process was concerned with the deployment of the installation and involved two prototypes: The *Urban Data Post Assembly* and *Reactions + Animations*. After we had finished the *Hexagonal Data Post* we approached a manufacturer and a spray painter to professionally build the single components of the posts for us. After receiving the components, we assembled the single posts and attached all the electronics (*Urban Data Post Assembly*).

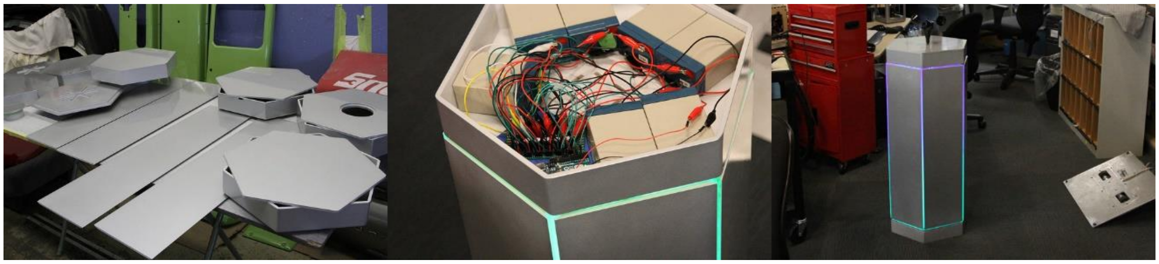


Figure 15 Impressions of the *Final Assembly* prototype.

We then moved the posts to Telus World of Science and spent a couple of days on site to check if everything was working. We made a few changes to the way the posts measured and reacted to the various energy resources (*Reactions* + *Animations*). This was necessary since the sensors obviously reacted differently in the actual environment than they had in our studio space.

After the final testing has been done, we deployed the posts over the period of two weeks at Telus World of Science and spent our days observing people interacting with the posts, answering questions, and documenting the project.

4.3. Description of Selected Prototypes

The following section highlights specific prototypes in the design process that played a major role in the outcome of the final design in one way or another. This thorough description is done in preparation for the analysis in the following chapter. The description of each prototype includes its purpose, conceptual decisions that informed them, problems we encountered, design insights we gained, the outcome of the prototype, design decisions we made based on the outcome, how much time we needed, material and components used, tools required, and competencies needed.

4.3.1. Proof of Concept

The *Proof of Concept* prototype was developed during the first stage of the design process and mainly served one purpose: to display live data from a renewable energy resource. A secondary goal was to find a way to address the issue of an uneven illuminated surface, something we wanted to tackle as soon as we had established a working connection with a renewable energy resource.

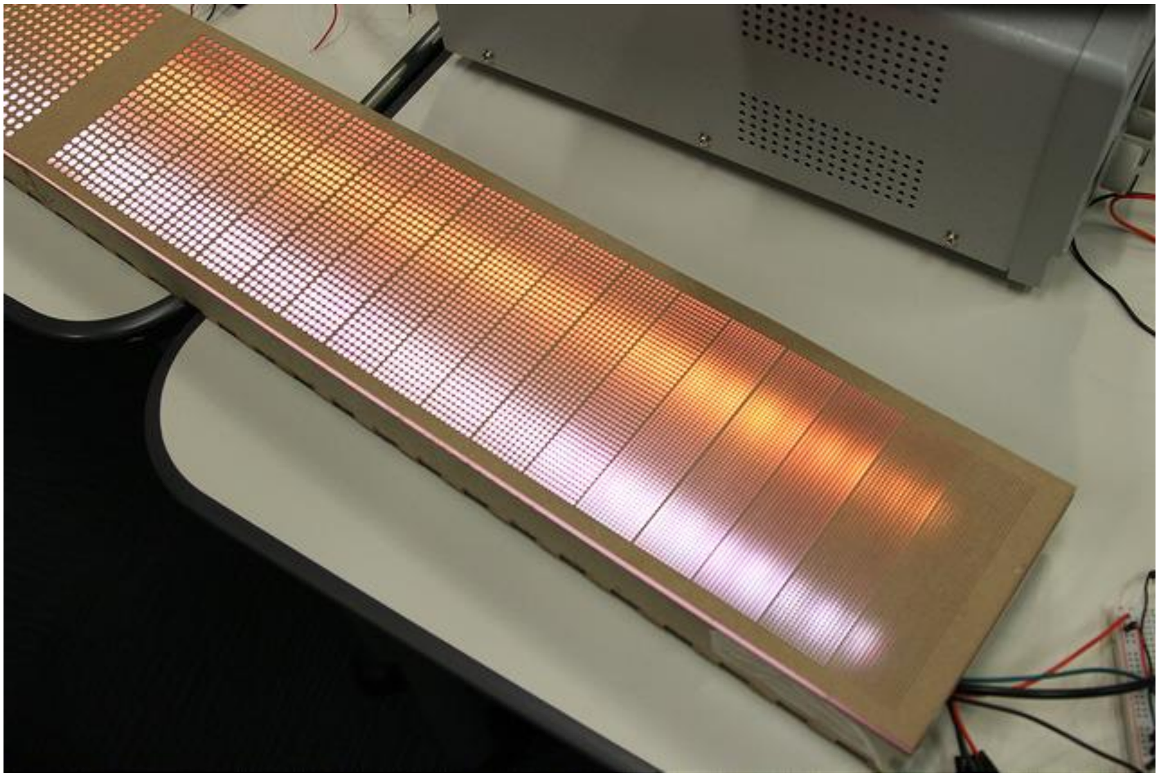


Figure 16 **Close up of the *Proof of Concept* prototype with a mask testing different polka dot sizes and grid resolutions.**

In order to use live data, we contacted technical staff from Telus World of Science to access data from their solar panels and bike counter. We were able to pull the data from their database using the visual programming language vvvv ("vvvv - a multipurpose toolkit," n.d.), and sent it to our Arduino Board using Serial Communication. The Arduino Board then changed the animation on the LED strips based on the data. This part turned out to be easier than expected, although we had to put a couple of days' work into it. For the physical side of the prototype we built an elongated box using ¼" MDF and frosted acrylic. The MDF was cut using a laser cutter and the two RGB LED strips were attached inside before we put a frosted acrylic sheet on top. A problem we encountered was the size of the box. The design we intended was bigger than the bed of the laser cutter. As a result, we had to split the design in two and assemble the parts afterwards. The left a small crack behind in the final design, running through the middle of the artifact.

In order to address the uneven illumination, we created masks – patterns cut into opaque material for the light to shine through – and put them on top of the frosted sheet of acrylic. This obscured that the acrylic was illuminated unevenly and certain patterns turned out to be very appealing to look at. Especially the polka dot grid received a lot of attention from us. Some of the patterns we cut were very delicate and in order to achieve that we also used the laser cutter to cut them. And just like the box, we had to split the mask into two and put it together afterwards resulting in a crack similar to the one on the box beneath.

The outcome of the prototype was an elongated box made out of MDF and acrylic and various paper masks to put on top. The prototype was a big step for our project since we were able to prove that the project is technically feasible, and we also found a way to address the uneven illuminated surface. The cracks we encountered in our artifact didn’t bother us since we knew we could address them if we built the box differently or approached a professional manufacturer.

4.3.2. Polka Dot Box

The *Polka Dot Box* was developed in the second stage of the design process and was built to validate our idea to use a polka dot mask as a display.

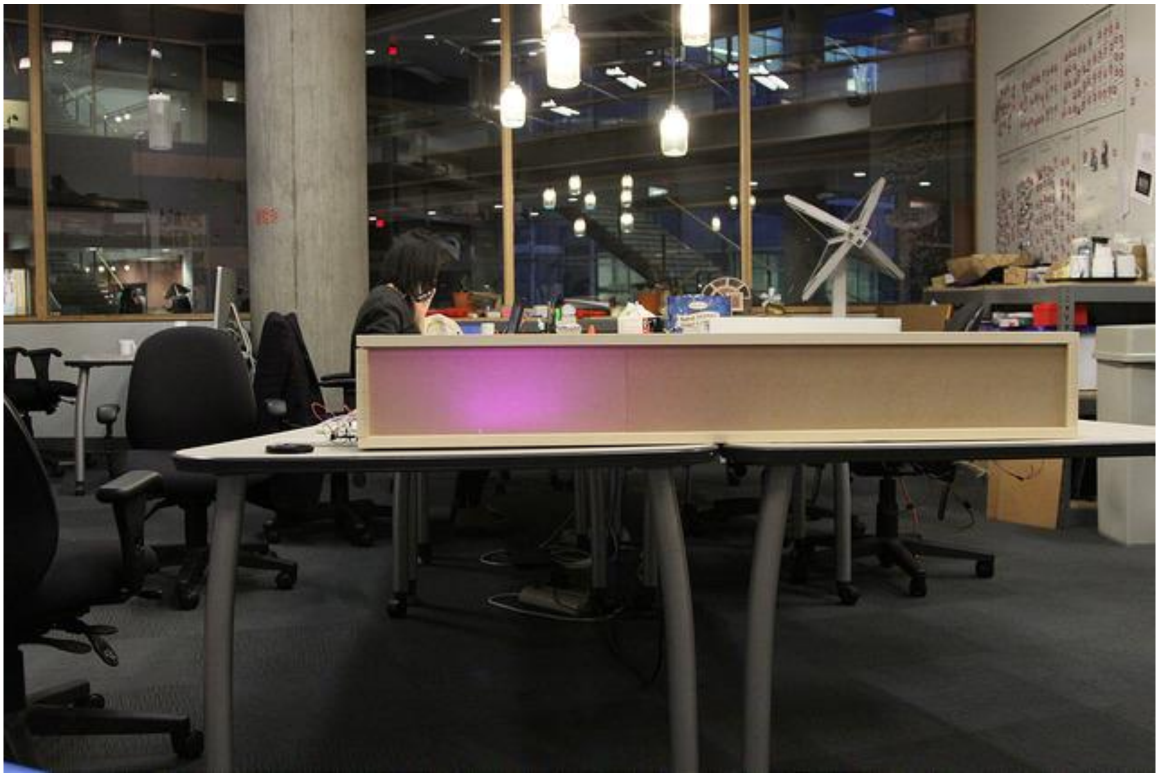


Figure 17 **The polka dot mask filtering the light of the RGB LED strips in the *Polka Dot Box* prototype.**

Using a table saw, we cut 1” thick wood to build an elongated box. The box had two slots in the inside, each a ¼” away from the edge. They were cut using a CNC router and each hosted a frosted sheet of acrylic and a mask. The mask was our main focus in this build. It was made out of thin wood and we cut the polka dot grid into it using a laser cutter. Just like in the Proof of Concept prototype, our design was bigger than the bed of the laser cutter which is why we had to split one mask into two pieces. That process left behind a little crack between them after the assembly.

This time, we were already prepared for this to happen and didn’t pay it any attention. However, our design had another small crack. We forgot to drill a small hole into the side of our box to run wires through, and instead of drilling one quickly, we lifted the top of the box and ran the wires in between the top piece of the box and the side wall. Like in the Proof of Concept prototype, we didn’t pay these cracks much attention since they could again be addressed by building the artifact more carefully or by having it professionally manufactured. Our attention was on the polka dot grid itself, especially because we weren't satisfied with the visibility of the light, a key concern for our design. Although the light was visible when standing perpendicular to the display (see Figure 17), only a slight change of angle was necessary for the light to "disappear". We tried several fixes – one of which created an interesting Moiré effect – but eventually gave up the idea.

The outcome of the prototype was an elongated box with a polka dot grid on two sides. Since visibility was a key concern for our project and the light was only visible in a very specific position, we had to dismiss this approach. We decided to move on and explore other ways to utilize RGB LED strips.

4.3.3. Form Explorations

Because we couldn't find a pleasing result with the *Polka Dot Box* prototype, we decided to fan out and explore various uses for RGB LED strips at once. Using crafting materials to allow quick iterations, we built the *Form Explorations*. Like the *Polka Dot Box*, it was developed during the second stage of the design process.

Using X-Acto knives, scissors, pins and clear adhesive tape, we worked with foam board and cardboard to design new shapes and immediately illuminated them with the RGB LED strips. We hoped to quickly find a new design direction which we could investigate. The biggest problem in this prototype was coming up with new shapes at all. We had a hard time doing so, but to our surprise, we made an interesting observation after we had built a couple.

It suddenly occurred to us that our current shapes also have various cracks with light leaking through. This time the cracks were the result of the material we used and because we built each prototype fairly quickly. Like in the previous prototypes, we ignored them, since our attention was elsewhere and the cracks were not a part of our intended design. However, the cracks suddenly were at the center of our attention because we realized we might be able to utilize them purposefully in our design. We even realized that we had been designing cracks as part of a bigger pattern when we explored the use of masks in the *Proof of Concept* prototype. But then we were looking at the mask as a whole and not at a singular crack.

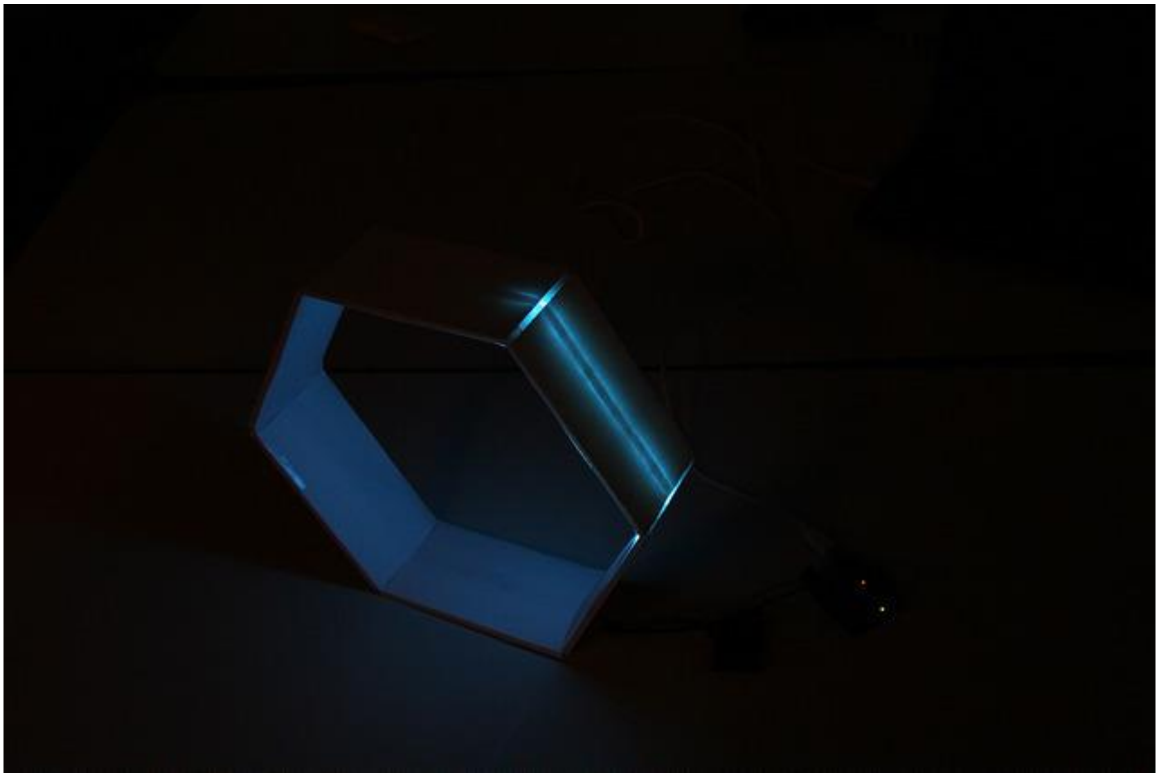


Figure 18 The foam board hexagon with an illuminated crack.

The outcome of the prototype were several shapes made out of foam board and cardboard exploring new ways of utilizing RGB LED strips. Although we didn't come up with a new shape to work with, we found a new design direction to explore: cracks.

4.3.4. Cardboard Scale Model

The *Cardboard Scale Model* was developed in the third stage of the design process. After discovering the cracks, we built some prototypes to verify the visibility of cracks illuminated by RGB LED strips but were unable to come up with a pleasing shape. With this prototype we wanted to solely explore shapes and decided to not include electronics.

One of our goals for the design of the artifact was for it to blend into an urban environment. This gave us the idea to work with a shape similar to a street post. Using cardboard and brown paper we built 4 round wedges and arranged them to build a round cylinder. Although we were satisfied with our approach, the design still seemed a bit dull.

We tried to improve the design in several ways and eventually reintroduced the polka dot grid. We took some of the brown paper, cut the polka dot patter into it and attached it to the bottom of each wedge. While we were arranging the wedges to form a post for the second time, we discovered the modularity of our approach. The single wedges could easily be rotated and moved to build other shapes. This made us realize that we could possibly have a slightly different shape for every energy resource we wanted to represent. Although we had explored many different designs and shapes in our design process at this point, we had never thought of building a different shape for each energy resource.

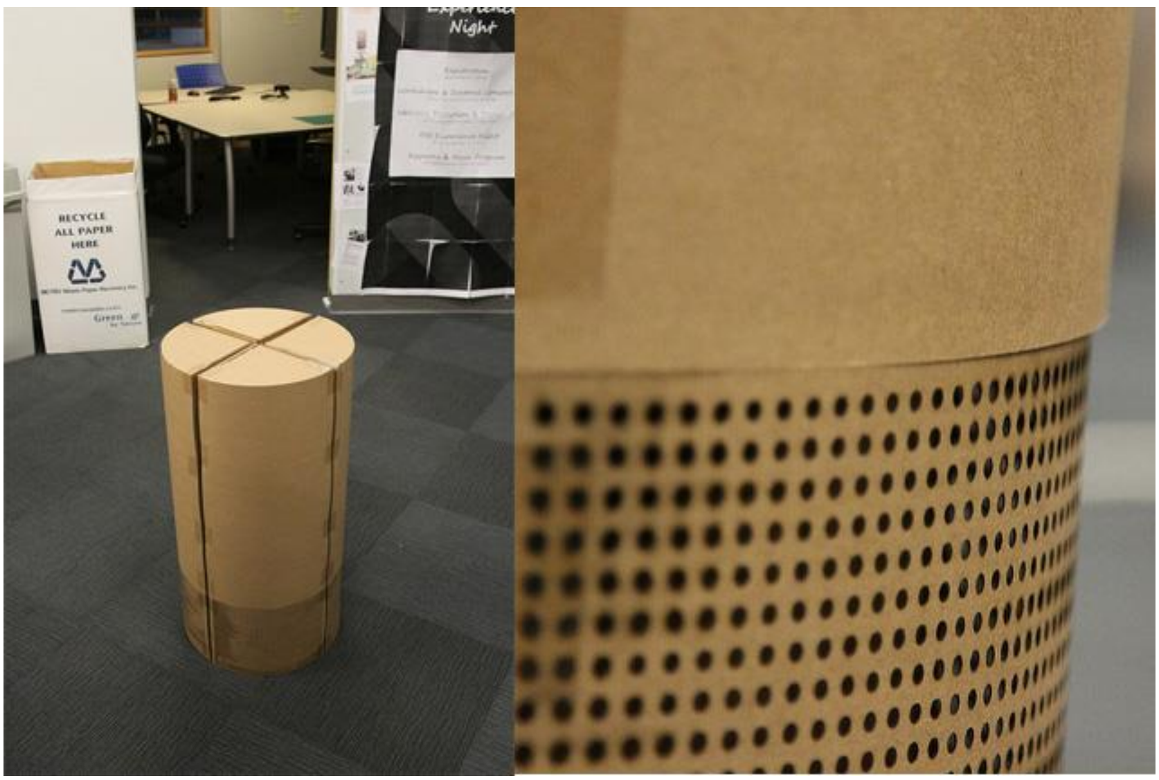


Figure 19 **Street bollard like shape made out of 4 round wedges + close up of the polka dot grid**

Overall we were very happy with the outcome of the Cardboard Scale Model prototype. Like previous prototypes, it lacked precision due to the materials used and the time spent with the prototype, but we had found a very promising shape. On top of that, we also made the realization that we could possibly build a slightly different shape for every energy resource.

4.3.5. Round Data Post

The *Round Data Post* was developed during the third stage of the design process. The idea with this prototype was to rebuild the shape of the *Cardboard Scale Model* prototype with proper material and illuminate the cracks in between the wedges with RGB LED strips. This setup would then serve as a verification of this design direction and allow us to work on the electronics.

In addition to the 4 wedges used in the *Cardboard Scale Model*, we planned to build a round pedestal for the wedges to stand on. This would provide support for the wedges and allow us to host the microcontroller to control the RGB LED strips and the main circuit. The wedges themselves hosted the RGB LED strips and were made out of frosted acrylic and wooden veneer. The veneer was used to achieve the curved surface of the wedges while the frosted acrylic allowed the light of the RGB LED strips to shine through. Arranging the wedges so all plane sides face each other, the RGB LED strips illuminated the space in between the wedges. One of the major difficulties with this build was the curved surface of both the wedges and the round pedestal. On one hand, sizing the wooden veneer was not easy due to the curved surface. On the other hand, the edges of each wedge and the pedestal provided almost no surface to attach the veneer to. We eventually decided to use epoxy and used balloons as rubber bands to hold the veneer in place while the glue was drying.

For the pedestal, we couldn't use epoxy to attach the veneer since we needed access to debug the electronics. We ended up attaching the veneer to the pedestal using double sided tape to enable us access if needed. Like the *Cardboard Scale Model*, the veneer in the bottom part of the post also had the polka dot grid cut into it, in an attempt to make use of the visual style we were very fond of and to make the design more intriguing. After the build however, we realized two things. Firstly, the polka dot grid didn't work although we made the polka dots fairly big. It didn't because there was no good way to place the RGB LED strip to face the Polka Dot Grid and as a result the light was again barely visible (if at all). So we decided to remove it once and for all from our designs. Second, we realized that we should further support the wedges by putting a structure similar to the pedestal on top of the wedges. This would give the whole structure more support and also would allow us to use the space to visually separate the single posts from each other.

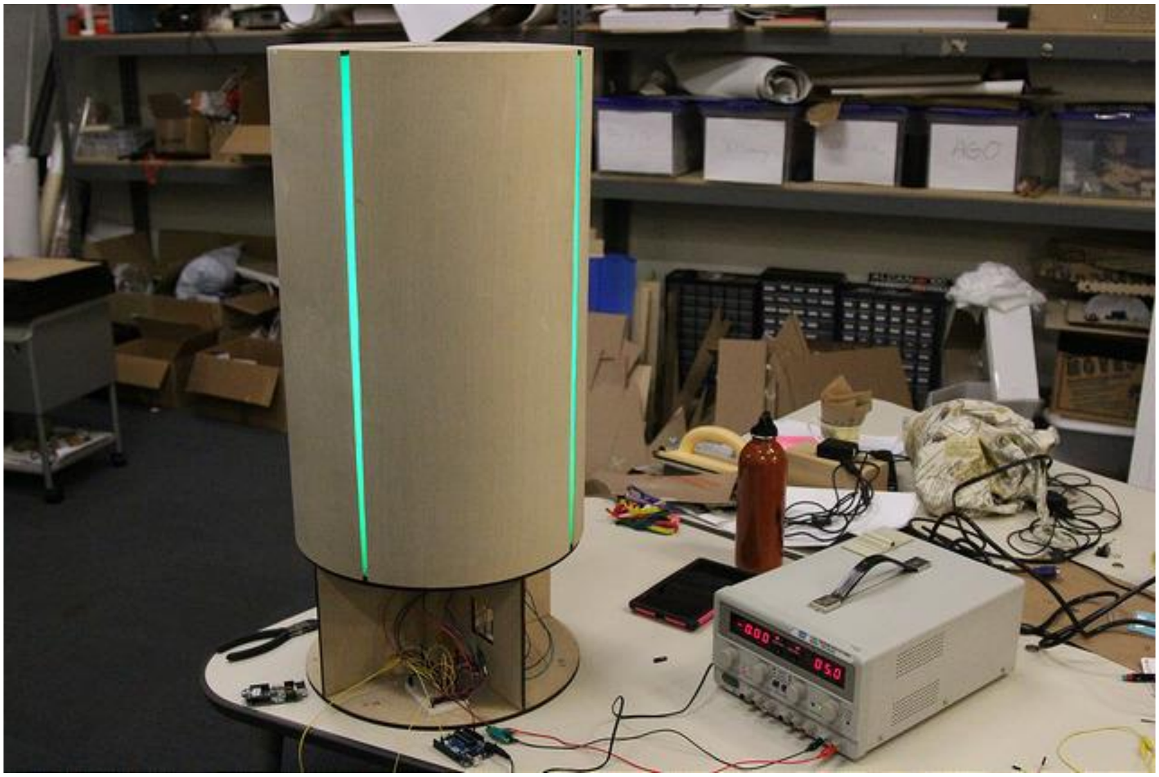


Figure 20 Testing the RGB LED strips while assembling the *Round Data Post*.

The outcome of the prototype was a round, street bollard-like post made out of 4 wedges sitting on a round pedestal. The overall light quality and visibility was very satisfying and we decided to begin iterating this design.

4.3.6. Hexagonal Data Post

The *Hexagonal Data Post* was developed during the fifth and final stage of the design process. The prototype was the last iteration of our design before we contracted a manufacturer to build the single components. The intention behind this prototype was therefore to finalize the design. In previous prototypes, we had already finalized the electronics and developed the *Visible Sensors* – visually distinct tops for every post that are also capable of measuring the respective renewable energy represented by the data post.

Figure 21 The *Hexagonal Data Post* + a close up of two miter joints.

Based on our experience with the *Round Data Post*, we had a few things we wanted to improve in our design. One of them, more support for the wedges, was already addressed by building the visible sensors. The two remaining issues were the round surface of the wedges and the accessibility of the electronics.

We chose to address the first issue by making the post hexagonal and the wedges triangular. This way, we didn't have to deal with round surfaces, and the posts also resembled Telus World of Science's geodesic dome. The second issue (accessibility of the electronics) we solved by putting all the electronics into the *Visible Sensor*. Although we tried to evade a difficult build by building triangular wedges, they themselves turned out to be a big challenge. In order to build the triangles we needed to bevel the edges of the acrylic and MDF sheets. However, our equipment didn't allow us to cut the needed angle for the mitred butt joint. We ended up creating a custom jug to make the necessary cut which ultimately took more time then creating the curved surface of the Round Data Post. And as mentioned earlier, we decided to not include the polka dot grid in our new design.

The outcome of the prototype was a fully functional *Hexagonal Data Post.* With this build we then contacted a professional manufacturer to build three of the posts, and then had them professionally spray painted.

4.4. Summary

This chapter looked at the background, design stages, and deployment of the *Urban Data Posts* project. The single design artifacts of the project were introduced and the various design stages leading to the final artifacts explained. Selected prototypes in various stages were explained in detail – with information about their purpose, how they were built, problems encountered during the build, design insights gained, and design decisions made based on the build. These selected prototypes will be anchor points for the analysis of the prototyping process following in the next chapter.

Chapter 5. Analysis

The following section analyses the single prototypes developed during the Urban Data Posts project in order to understand how they influenced the final design. To do so, I will chronologically examine the prototypes through two lenses: *In Focus* and *Out of Focus*. The two lenses can be seen as complementary to an Anatomy framework provided by Y.-K. Lim et al. which they introduced in their article "The Anatomy of Prototypes: Prototypes as Filters, Prototypes as Manifestations" (Lim et al., 2008).

The analysis is divided into two sections. In the first section I will summarize the Anatomy Framework introduced by Y.-K. Lim et al. and then introduce my own framework (focus framework), consisting of the two lenses *In Focus* and *Out of Focus*. This will help to clarify the differences in between the two and also make it easier to understand the purpose and meaning of the focus framework and its two lenses. In the second section, I will then use the focus framework to analyse the single prototypes of the Urban Data Posts project in chronological order. I will do so by looking at very specific design aspects of the Urban Data Posts and track them throughout the design process. As I will show, this enables one to better understand what the single prototypes do and how their respective design aspects have influenced (and could have influenced) the final design.

5.1. The two lenses: *In Focus* and *Out of Focus*

Before I explain the two lenses *In Focus* and *Out of Focus*, I want to give a brief summary of the Anatomy framework introduced by Lim et al. (2008). This will help to differentiate between their framework and the Focus Framework which I will describe later.

5.1.1. Prototypes as Filters and Prototypes as Manifestations

In their article "*The Anatomy of Prototypes: Prototypes as Filters, Prototypes as Manifestations*" (Lim et al., 2008), Lim et al. point out that prototypes are rarely used to evaluate a design (usability testing etc.). Prototypes are more commonly used by designers to explore a design space, generate ideas, discover possibilities, ask questions and reflect on the current design.

Because of that, it is beneficial for the designer to only focus on single dimensions when building a prototype instead of the design as a whole. Lim et al. identify 5 different filtering dimensions of a prototype: appearance, data, functionality, interactivity, and spatial structure. By focusing on one of these dimensions when building a prototype, the designer is able to extract knowledge from this dimension and make decisions about her design even though other dimensions have not been resolved yet. For instance, a designer might want to build a prototype to explore new functionalities of a digital photo camera based on technological advances, without being tied to decisions that have not been made yet. By building a prototype focusing on the functionality dimension, she is able to look into the functionalities, discover new possibilities and define a design space, without having to determine the appearance of the camera.

Ultimately, as Lim et al. also point out in their article, the filtering dimensions cannot be treated completely separately. Quite the contrary, the "*(…) dimensions are tightly related to and influenced by each other; (…)*" (Lim et al., 2008, p. 13). A new camera functionality, for instance, might need certain electronic components which need to be included in the camera, ultimately influencing the cameras size and thus its appearance.

Lim et al. further argue that a designer needs to consider three manifestation dimensions when building a prototype. The manifestations dimensions are: material, resolution, and scope. Material describes the materials used to build the prototype, both physical and digital. Resolution is comparable with the concept of fidelity and describes how much detail a prototype has. And scope determines the completeness of a prototype. Each of these dimensions influences the prototype's performance – that is, how well the prototype allows the designer to generate ideas, explore the design space, etc. and not as a final artifact. Because the prototype is not intended to be the final artifact, the designer is free to make changes in any of these dimensions in comparison to the final design as long as the prototypes purpose is not influenced.

This framework by Lim et al. is a great tool to understand the complexities and decision making involved when building a prototype as well as to analyse what a prototype is made out of. However, it is less suited to understand the interplay between designer and prototype – especially the way single prototypes can influence a designer's thinking process and decision making in terms of further developing the design. This is where the focus framework consisting of the two lenses, *In Focus* and *Out of Focus,* comes into play.

5.1.2. The Focus Framework: *In Focus* and *Out of Focus*

In Focus and *Out of Focus* describe the intentionality and unintentionality in prototypes. They highlight why a prototype was built and point towards creative potential that open up new design possibilities. *In Focus* and *Out of Focus* thus provide a deeper understanding of what prototypes do and the interplay between prototype and designer.

In Focus

In Focus describes *intentional design aspects* of a prototype. That is, design aspects the designer is *consciously and intentionally* building the prototype for – its purpose. It is the result of *deliberate action* during the building process. Design aspects *In Focus* can range from small parts of the design (e.g. exploring the material of a certain part of the design) to the prototype as a whole (e.g. creating a "blueprint" for manufacturing).

In Focus therefore shows resemblance to the filtering dimensions in the Anatomy Framework by Lim et al. (2008). Both describe the intentionality of a designer to build a prototype in order to explore a specific aspect of her designs. As explained earlier, this allows the designer to isolate the aspects of the design she is interested in, by leaving out other aspects. However, instead of using the filtering dimensions and the associated variables introduced by Lim et al., *In Focus* uses a more design-specific language to describe the prototype's purpose: It uses actual aspects of the current design. These aspects and features are obviously dependent on the current design project and therefore differ from case to case. Using the design aspects and features to describe a prototype's focus, instead of the filtering dimensions, is more practice-oriented at the expense of generalizing theory. For instance, a designer working on a prototype exploring a physical peripheral to interact with a digital device would probably say the prototype's purpose is the physical peripheral itself – and it might even have a name (such as "d-pad"). This example shows how *In Focus* is relevant to the designer while building, communicating, and reflecting on the prototype.

The way a prototype is built depends on the designer's choice in regards to material (both physical and digital), resolution and scope – the manifestation dimensions introduced by Lim et al (2008). As they point out, these dimensions do have an impact on the prototypes performance (how well the prototype serves its purpose). Besides these manifestation dimensions forming the prototype, the designer is also confronted with the context of prototyping. She needs to take into account the tools that are available, her own competencies, as well as the time and budget. All these considerations – from the filtering and manifestation dimensions to the tools, competencies, time and budget – go into the build of a single prototype. And although a designer makes choices in all these points, and they are all part of the prototype from an anatomical and contextual perspective, the designer is usually solely interested in the prototype's purpose. In the above example this focus would be the "d-pad" and therefore be considered as being *In Focus*.

Out of Focus

Out of Focus describes *unintentional design aspects with creative potential* in prototypes. That is, the designer is *unconsciously and unintentionally* building design aspects into the prototype which open up *new design opportunities*. Design aspects *Out of Focus* are the result of *accidental circumstances* during the building process. Like design aspects *In Focus*, design aspects *Out of Focus* can range from small parts of the design (e.g. faulty wiring causing an LED to behave differently) to the prototype as a whole (e.g. the shape of a prototype offering unexpected affordances).

First, let me break down what I mean by *unintentional design aspects with creative potential*. When building a prototype, the designer usually visualizes what she wants to build. The visualization can take many forms such as a mental image, a rendering, sketches, etc. However, building a prototype is a complex endeavour and as described earlier, many factors play into the build of a prototype. From the materials and tools the designer chooses, to the time she spends building the prototype, or her own shortcomings planning and executing a build, many factors can influence a prototype's outcome. As a result, the prototype the designer produces is often not equal to the one she visualized.

And any aspects in a prototype deviating from the visualization of the prototype (the intended design) is here referred to as an unintentional design aspect. Unintentional design aspects are unexpected. They are irregularities, deviations from the ‘intended’. Unintentional design aspects can obviously range from minor flaws to major issues. As long as they don’t interfere with a prototypes purpose, the designer is most likely to ignore them, and with good reason.

As explained earlier, prototypes are built for a specific reason. And as long as these unintentional design aspects don’t interfere with a prototypes purpose and the designer is able to extract the knowledge she is after, she does not need to pay them any attention. To illustrate: a designer exploring a d-pad as an input peripheral for a digital artifact might build her prototype with an Arduino Board and plan to build an enclosure to hide the electronics. To save time she builds the enclosure out of foam board, but some uneven edges cause gaps through which the Arduino Board and the circuit and other electronics are still visible. Being not a severe enough issue to interfere with the prototypes purpose, the designer is likely to ignore it. And when communicating the prototype to her peers, she will probably focus their attention away from these unintentional design aspects – the gaps in the enclosure – and towards its intention – the d-pad.

These unintentional design aspects can also be referred to as design anomalies. The Oxford English Dictionary (OED) defines anomaly as “*Irregularity, deviation from the common order, exceptional condition or circumstance.*” (“Anomaly,” 1591). The emphasis here is on the words *irregularity*, *deviation* and *common order*. Common order refers to the designer’s visualization of the prototype. It is what the designer has in mind, what he envisions the prototype to look like and do. Anything that does not match this visualization is irregular, as it deviates from what is being planned. I therefore use unintentional design aspects and design anomalies interchangeably.

Although a designer has good reason to ignore design anomalies in her prototypes, I argue that they might deserve a closer look. Especially when a design anomaly has *creative potential*, offering new design opportunities. Creative potential can be understood as the capacity of a design anomaly to inform the design process and generate new design ideas. They are a resource of creativity and can turn into a design aspect. But this switch, from being a design anomaly with creative potential to a design aspect, needs to be initiated by the designer. She needs to make the conscious decision to work with the design anomaly and explore it as a design aspect by moving it *In Focus*. For this to happen the designer needs to discover the creative potential within a design anomaly in the first place. The only way this can happen is when the designer is carefully listening to the prototype and looking for feedback outside of the intended purpose. Her focus needs to shift from the intended purpose towards the prototype as a whole, scanning it for clues or hints towards hidden creative potential.

There are of course various degrees to which a design anomaly shows its creative potential. Some might be very obvious and are detected right away, while others might require more attention or creativity. In other cases, a design anomaly might be reoccurring in several prototypes which increases its chances of being detected.

A key point of design anomalies with creative potential is that the designer is unaware of them when building the prototype. It is not a conscious decision of the designer to include them in the prototype or to leave them out. They are the result of the building process and its context (material, resolution, scope, tools, competencies, time, budget, etc.). As soon as they are detected, the designer can consciously turn them into a design aspect and move them *In Focus*.

Neglected and Not Present

There are two more states used in the analysis: *Neglected* and *Not Present*. Although they do not provide valuable information towards the analysis itself, they help to round out the concept of the two lenses.

Once a design anomaly has turned into a design aspect and is consciously put *In Focus* of a prototype, it can hardly go back to be *Out of Focus*. This is simply because the designer now knows of its presence. It is no longer something the designer is unaware of. In bigger design projects, or over long periods of time a designer might forget a design aspect, but it is very likely she remembers as soon as she sees a design aspect again that she once encountered. However, what a designer can choose to do is ignore a design aspect once it has been *In Focus*. In that case the design aspect is present in the prototype and the designer is aware of its presence. However, the designer attention, her focus is on a different aspect. Lastly, a design aspect can be *Not Present*. This is rather self-explanatory and simply means that the design aspect is not part of the prototype.

Summary of the Focus Framework

In conclusion, *In Focus* and *Out of Focus* form the core of the focus framework. Together they are able to describe a prototypes intentional design aspects which embodies the prototypes purpose – *In Focus* – as well as a prototypes unintentional design aspects (design anomalies) with creative potential – *Out of Focus*. Applied to all prototypes of a design process in chronological order, these lenses give insight to how a designer's focus shifts throughout the design process. Single design aspects move between the single lenses. Design aspects might start being *In Focus*, move to being *Neglected,* and end being *Not Present* in the final design. Other design aspects might start off being *Not Present*, move *Out of Focus,* then get picked up by the designer and are moved *In Focus*.

The focus framework reveals the ongoing conversation and interplay between designer and prototype. It brings recognition to the 'unseen' and the ways designers utilize their prototypes to elicit new knowledge, expand the design space, find new opportunities and generate ideas. As a result, the focus framework also points towards the resourcefulness of a designer when working with prototypes.

5.2. Shifting Focus

In the following section I want to showcase the application of the focus framework by analyzing the prototypes built during the Urban Data Posts project. This will (a) clarify the use and purpose of the framework and (b) unfold how various prototypes in the design process of the Urban Data Posts project influenced the final design.

5.2.1. 3 Threads: Polka Dot Grid, Cracks/Aura, and Physical Separation

In total I analyze 3 threads throughout the Urban Data Posts design process. Each thread highlights a selected design aspect (or aspects) and how they shifted between *In Focus*, *Neglected*, *Out of Focus*, and *Not Present*.

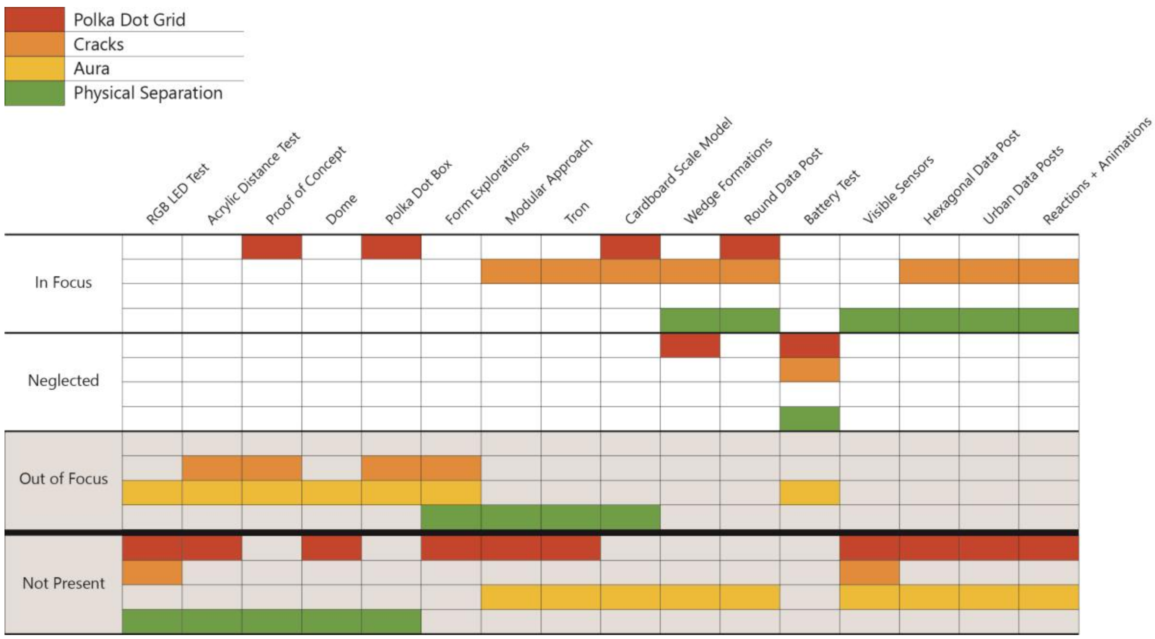


Figure 22 Overview of the single design aspects and their respective path in the design process.

Figure 22 shows the four different design aspects (colored boxes) and their respective status (vertical axis) throughout the design process (horizontal axis). If a design aspect is listed within the first three rows (*In Focus*, *Neglected*, *Out of Focus*) it is part of the respective prototype. The designer however, is only aware of the first two rows, which is indicated with a brighter background. The third row, *Out of Focus*, lists the design anomalies with creative potential that are undetected at this point. A jump from the third to first row indicates that a design aspect has been detected and is now being explored. Design aspects listed in the fourth row are not part of the prototype and are merely listed there for completion.

In the next section I will analyze these design aspects individually and explain how they shifted between the different statuses (*In Focus*, *Neglected*, *Out of Focus*, *Not Present*).

Thread #1: Polka Dot Grid

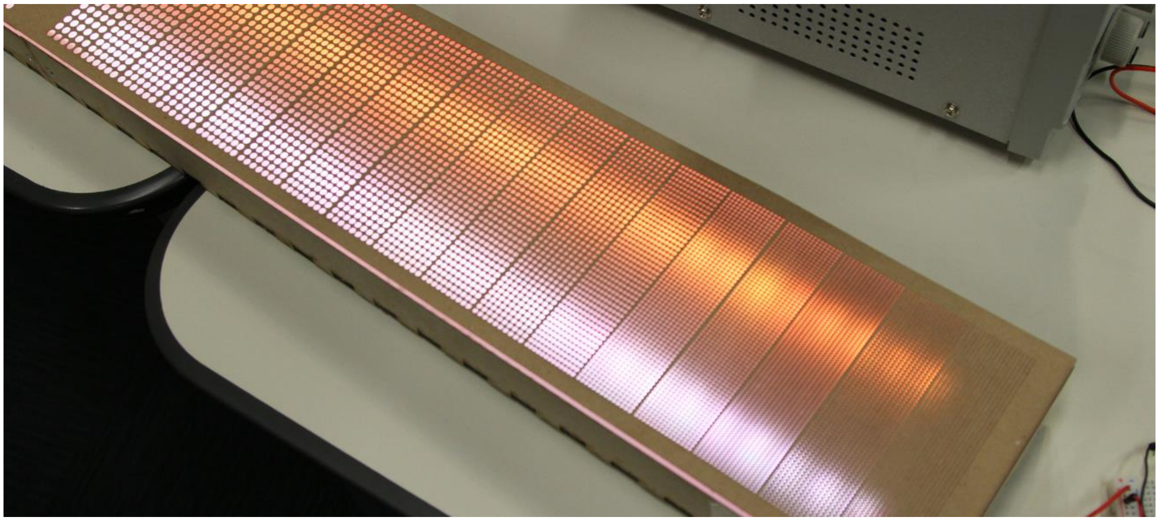


Figure 23 The Polka Dot Grid first appeared in the Proof of Concept prototype where we experimented with different masks.

Thread #1 follows a design aspect we called *Polka Dot Grid*. The *Polka Dot Grid* (see Figure 23) is a form of display we explored during the early stages of the project. A polka dot grid was cut into an opaque material and then used to cover an illuminated surface. Thus, the light would only be visible through the cut out pattern.

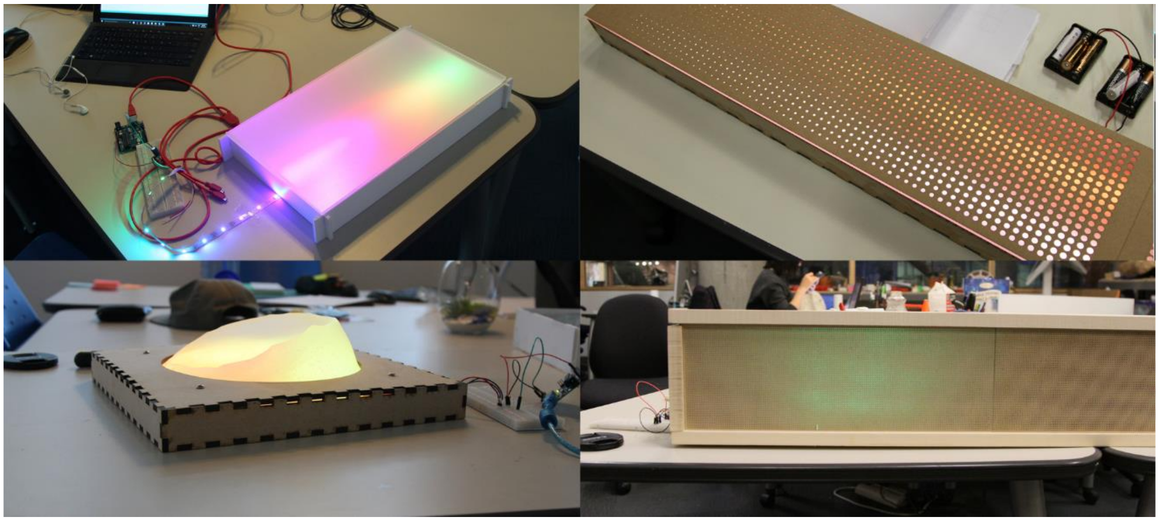


Figure 24 ***Acrylic Distance Test*****,** ***Proof of Concept*****,** ***Polka Dot Box*****,** ***Dome*** **prototypes (clockwise starting on the top left).**

The idea for the *Polka Dot Grid* originated after we had built the *Acrylic Distance Test* prototype (Figure 24 top left). We discovered that we couldn't easily illuminate bigger surfaces of acrylic sheets with a single RGB LED strip and would in fact need an excessive amount of LED strips. The *Polka Dot Grid* first appeared in the *Proof of Concept* prototype (Figure 24 top right) and it was immediately *In Focus* since it was a conscious decision to experiment with it. We quickly discovered the aesthetic quality of the illuminated *Polka Dot Grid* and decided to further investigate. However, the *Polka Dot Grid* was *Not Present* when we were exploring the possibilities of the vacuum former with the *Dome* prototype (Figure 24 bottom left), but immediately came back *In Focus* with the *Polka Dot Box* prototype (Figure 24 bottom right). Ultimately, the results of the *Polka Dot Box* were unsatisfactory due to its lack of visibility – which was a key concern for our design. We decided to explore other design directions and dismissed the idea. The *Polka Dot Grid* stayed *Not Present* for several prototypes (Figure 25) while we were developing the idea for the *Cracks*.

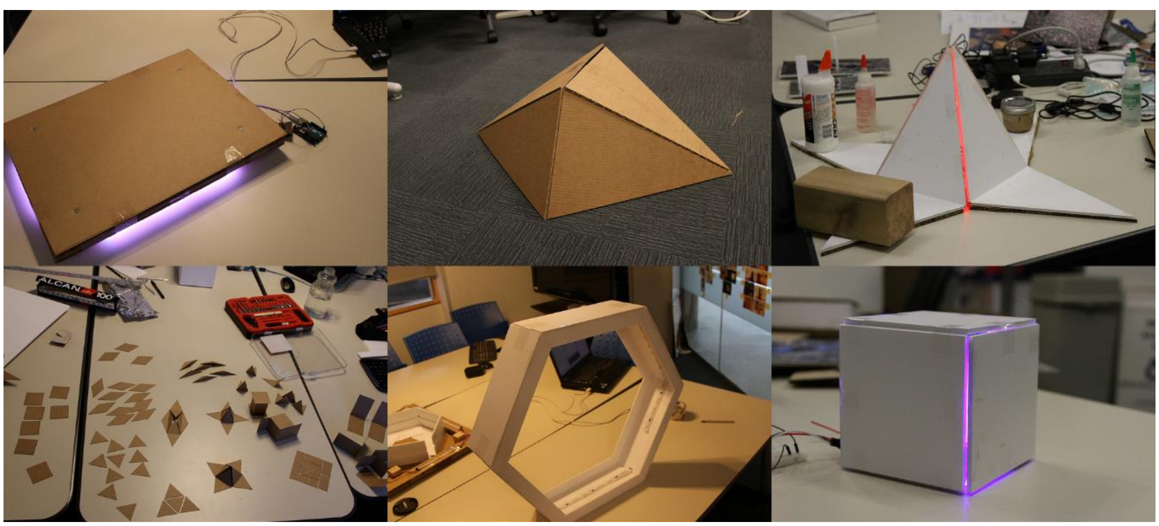


Figure 25 **While the idea of *Cracks* began to take shape, we did not make use of the *Polka Dot Grid*.**

When we were developing the *Cardboard Scale Model* prototype, we tried to recycle the *Polka Dot Grid* and bring it back into our design. This was done in an attempt to make the single wedges of the posts visually more intriguing. And in fact, the *Polka Dot*

Grid looked very promising in the *Cardboard Scale Model* prototype (Figure 26 far left). While we were exploring the modularity of the cardboard wedges in the *Wedge Formations* prototype (Figure 26 second from the left) the *Polka Dot Grid* was present but our attention was elsewhere. The *Polka Dot Grid* came back *In Focus* in the *Round Data Post* prototype (Figure 26 second from right). However, much like in the *Polka Dot Box* prototype, the *Polka Dot Grid* failed to convince us again as the light was barely visible through the grid. We once and for all decided to dismiss the idea and after the *Polka Dot Grid* was *Neglected* in the *Battery Test* prototype (Figure 26 far right), it was *Not Present* for the rest of the design process.

Figure 26 ***Cardboard Scale Model*, *Wedge Formations*, *Round Data Post*, *Battery Test* prototypes (from left to right).**

In summary: following the erratic path of the *Polka Dot Grid* (Figure 27), one can see the different attempts we made to include this aspect into our design. Although we failed to successfully implement the *Polka Dot Grid* in the early stages of our design process, we tried to bring it back and incorporate it during later stages. As a result, the *Polka Dot Grid* can be seen jumping back and forth between being *In Focus* and being *Not Present*. The time the *Polka Dot Grid* spent being *Neglected* is due to the fact that we repurposed parts of previous prototypes in which the *Polka Dot Grid* was part of.

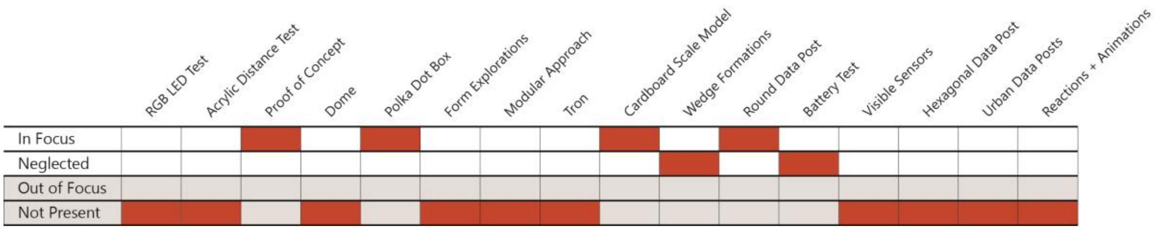


Figure 27 Overview of the "Polka Dot Grid" in the design process.

The Polka Dot Grid is also a good example of how a design aspect can be immediately *In Focus* due the conscious decision to explore a certain design idea. As a result, it hardly can be *Out of Focus* again since the designers are aware of its presence. The designer would need to completely forget an idea for it to become *Out of Focus* again. While this seems very unlikely during a single project, it might happen over a longer period of time and several projects. Still, the likelihood of it being rediscovered quickly is fairly high.

Thread #2: Aura and Cracks

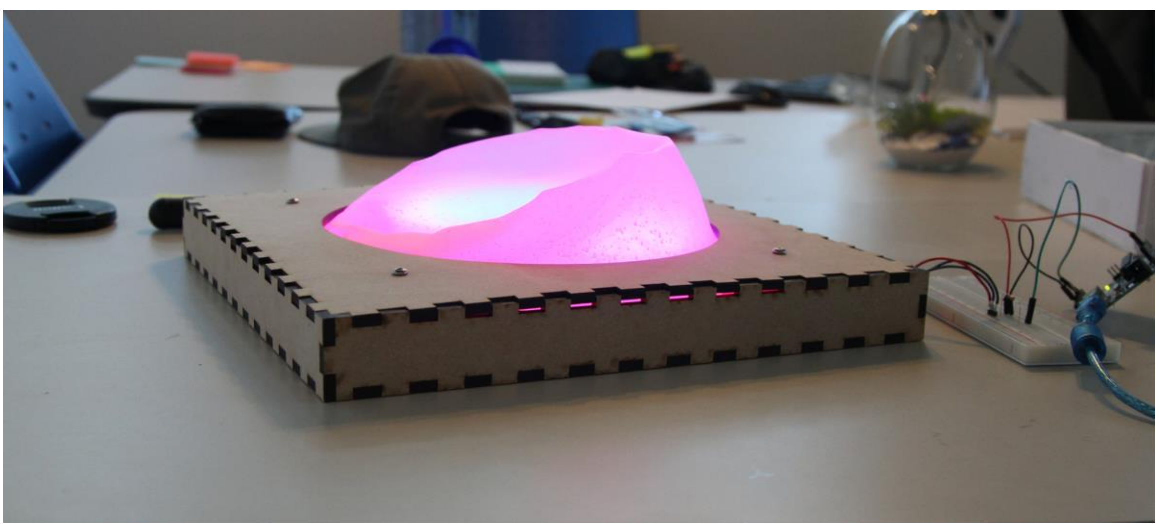


Figure 28 A crack appears in the *Dome* prototype because we were unable to completely close the lid.

Thread #2 follows two design aspects that showcase an almost mirrored path through the design process. The two design aspects are called *Cracks* and *Aura*. *Cracks* is a form of display which was discovered almost halfway through the design process and was then consciously explored. It describes the narrow space in between two objects or components of the prototype through which light is leaking through (see Figure 28).

Aura really is a design anomaly with creative potential in the purest sense since it was never explored. It was discovered during the analysis of the single prototypes and not during the design process itself. *Aura* describes the subtle glow surrounding an object (similar to a halo). This glow is not to be mistaken with the way a monitor or TV screens emits light and "glows". It is more intangible and cannot be pointed towards a source (see Figure 29).

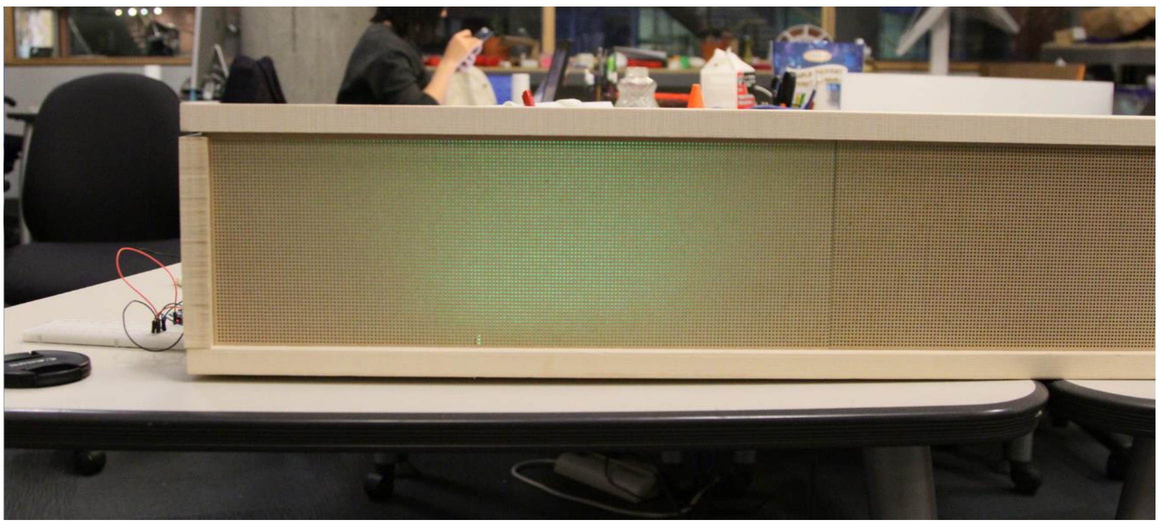


Figure 29 The Polka Dot Box is emitting and almost invisible and intangible glow – an effect we call *Aura*.

Cracks were part of our prototypes as soon as we had started to illuminate acrylic sheets in the *Acrylic Distance Test* prototype (Figure 30 top left). Between it and the *Form Explorations* prototype, every single prototype had some form of cracks in them, through which we could see light from the RGB LED strip(s) leaking through (Figure 30). The cracks were the result of the materials and tools we used, how much time we spent building the prototype and our own competencies. In case of the *Proof of Concept* prototype for instance, we had to split our intended design into two because the laser cutter we were working with had a small laser bed and could not fit our whole design. As a result we had to "stitch" the two parts together afterwards, resulting in a crack (Figure 30 top mid). In another prototype we made a mistake when creating a box joint for a lid to close the box hosting the RGB LED strips. Some of the joints were too big and we couldn't close the lid and had light leaking through the cracks (Figure 30 bottom left). However, we never these flaws much attention since we knew we could easily remove them by using better material and tools, or spending more time planning the design. Moreover, the flaws still allowed us to explore the design aspects we had built the prototype for. Simply put, the *Cracks* were *Out of Focus.*

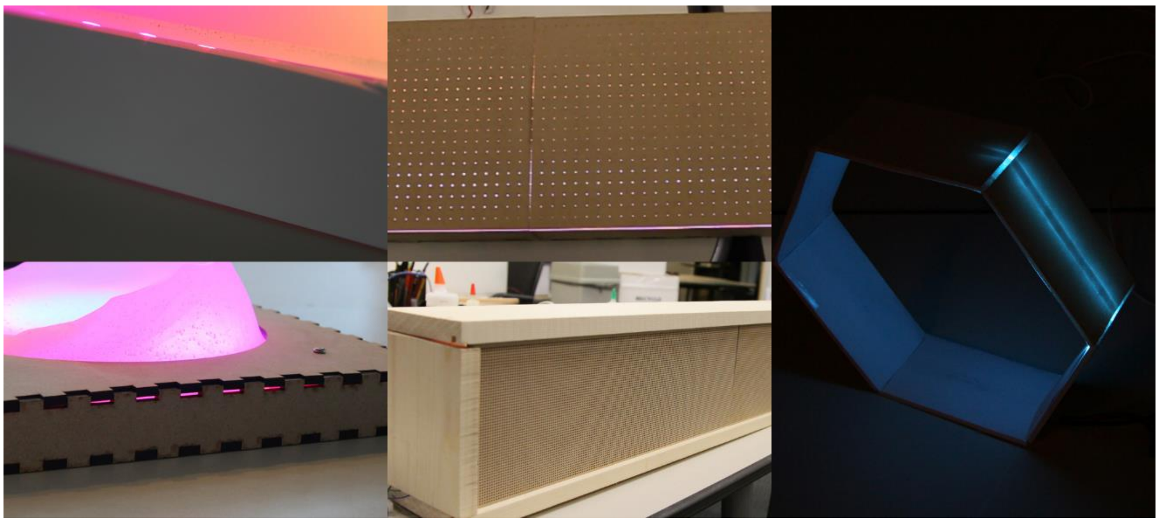


Figure 30 Cracks appeared in all prototypes between the *Acrylic Distance Test* and the *Form Explorations*.

However, the *Form Explorations* prototype (Figure 30 far right) marked a change in how we perceived these design anomalies. We suddenly realized that almost all our prototypes have or had cracks in them and that we could potentially use them for our purpose. We no longer saw them as design flaws but as an opportunity. They were highly visible although we didn't design them purposefully and we decided to explore their potential in upcoming prototypes. Our focus had suddenly shifted and we decided to explore a new design aspect: the *Cracks*.

At this point, I want to quickly go back to the beginning of the design process and follow the other thread: *Aura*. Just like the *Cracks*, *Aura* was also present in all of the above mentioned prototypes, but we didn't even notice it (unlike the *Cracks* which we noticed, if only as a flaw in our design). From all the prototypes, *Aura* was especially evident in the *Polka Dot Box* (see Figure 29). The mask somehow filtered the light of the

RGB LED strips so that it was not apparent where the light came from and it gave the object a very distinct glow. Other prototypes showed the same behavior (in various degrees) when looking at them. Unfortunately the pictures documenting *Aura* do the effect we saw no justice.

Unlike the *Cracks*, *Aura* never moved *In Focus*. And after we decided to work with the *Cracks*, it was *Not Present* in most of the prototypes. It only had one more (unnoticed) appearance in the *Battery Test* prototype (Figure 31) but was thus *Out of Focus*.

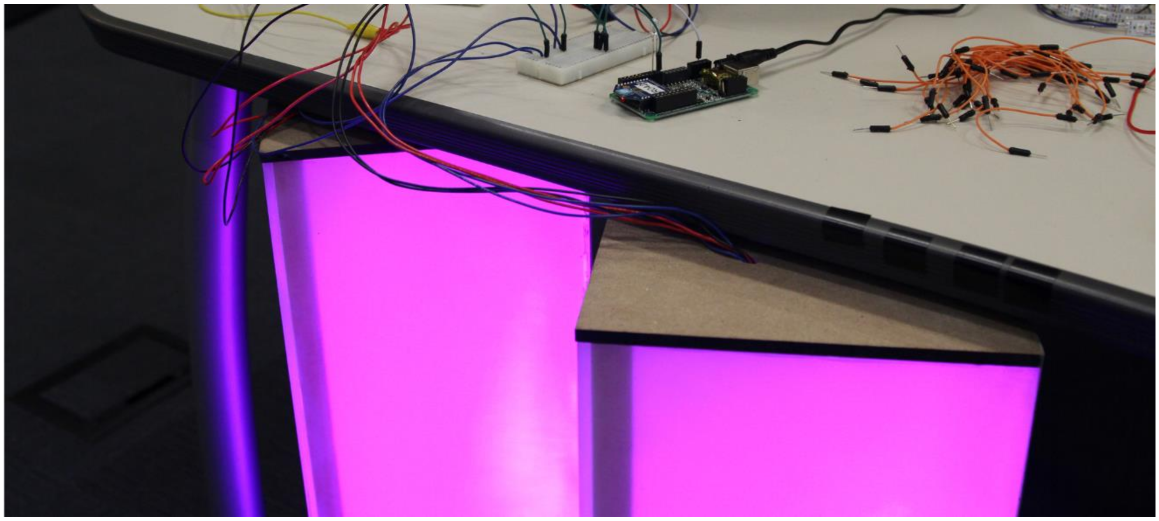


Figure 31 The last time *Aura* was present (but *Out of Focus*) was in the *Battery Test* prototype.

While *Aura* started to be *Not Present*, *Cracks* moved *In Focus* and stayed there for almost the rest of the design process. They were only *Neglected* once (during the *Battery Test* prototype in which we used an existing setup to test batteries) and were *Not Present* once (during the *Visible Sensors* prototype which focused on finding a form for a part of our installation not featuring any *Cracks*). Other than that, the *Cracks* became an integral part of the design. After they had proven their visibility in the *Tron* prototype (Figure 32 second from left), we found a suitable shape for them in the *Cardboard Scale Model* prototype (Figure 32 second from right), and we successfully coupled their functionality and form in the *Round Data Post* prototype (Figure 32 far right).

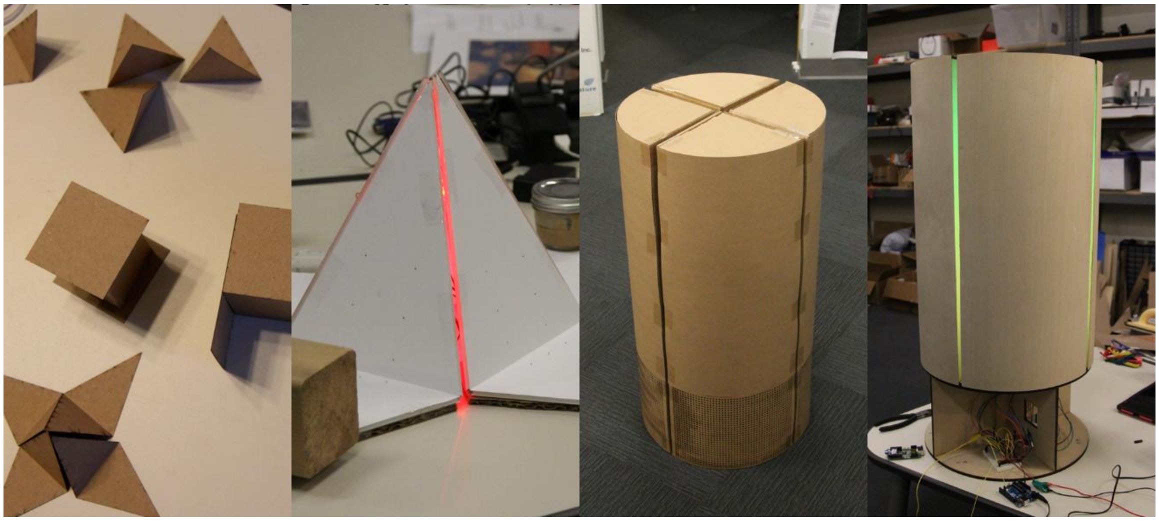


Figure 32 ***Cracks*** **became an integral part of our design and were** ***In Focus*** **in almost all of our prototypes after their discovery.**

In summary: both *Cracks* and *Aura* are very similar. Both were present during the early stages of our design process (Figure 33 and Figure 34). They were *Out of Focus* since they were either seen as a design flaw (*Cracks*) or we did not realize their presence at all (*Aura*). The main difference between them is that we recognized the creative potential of the *Cracks* halfway through our design process and made the conscious decision to explore them. *Aura* on the other hand was not discovered at all, and curiously enough, it almost completely disappeared from our prototypes after the *Cracks* had moved *In Focus*. The *Cracks* in the meantime became an integral part of our design.

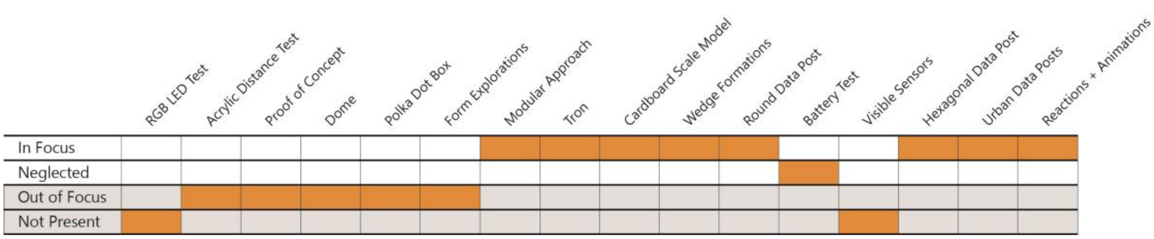


Figure 33 **Overview of "Cracks" in the design process.**

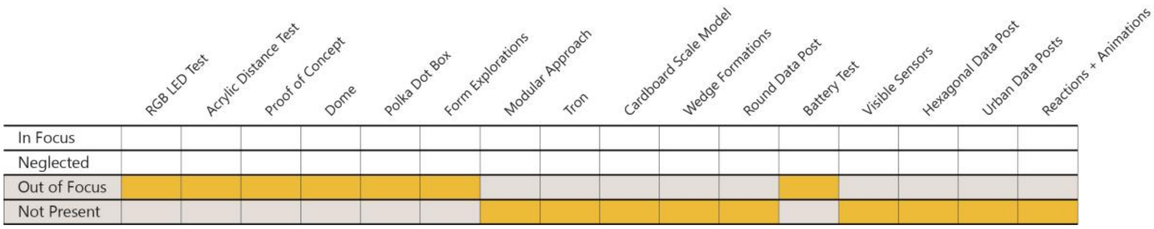


Figure 34 Overview of "Aura" in the design process.

This thread is a good example on how design anomalies with creative potential can have the potential to fundamentally change the final design. Especially because the cracks (as a design anomaly) had a negative annotation to them since they were initially seen as a design flaw. This also shows that is not always easy to recognize the potential of a design anomaly or even recognize the anomaly at all. *Aura* was discovered after the project was already deployed, while we were analyzing the single prototypes. It thus represents a missed opportunity which we could have used to explore other designs.

Thread #3: Physical Separation

Figure 35 The three Visible Sensors – physically separating the single data posts from each other.

Thread #3 follows the design aspect called *Physical Separation*. *Physical Separation* describes the idea to make the single *Data Posts* physically distinct from each other. The idea was first developed during the later stages of the design process and was ultimately implemented in the form of the *Visible Sensors*.

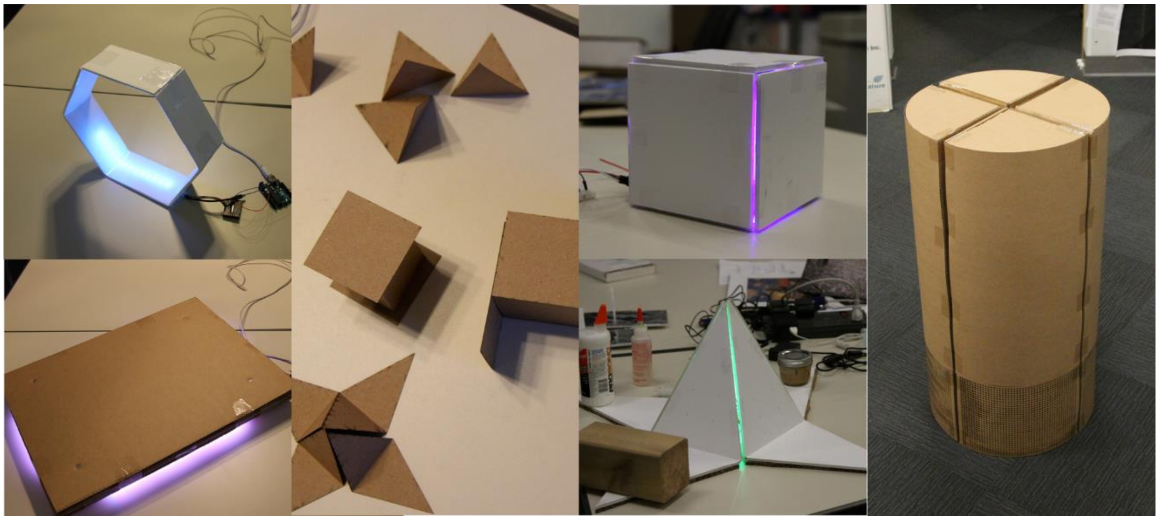


Figure 36 The idea of *Physical Separation* has its roots in exploring multiple shapes within a single prototype.

During the early stages of our design process, the idea of *Physical Separation* was simply *Not Present*. The concept first moved to *Out of Focus* with the *Form Explorations* prototype (Figure 36 left top and bottom) and stayed there until the *Cardboard Scale Model* prototype (Figure 36 right). The reason why the idea was suddenly present (but still *Out of Focus*) is because we were working with multiple shapes in one prototype (described earlier as a set of prototypes). We did this because we wanted to explore as many forms as possible with the *Form Explorations*, *Modular Approach*, and *Tron* prototypes (all Figure 36) in order to increase our chances to find a form we could work with.

Figure 37 Creating different shapes in the *Wedge Formations* prototype.

As written earlier, the idea behind *Physical Separation* is to make the posts physically distinct from each other. Although we were working with multiple energy resources, it never occurred to us to work with a physically distinct artifact for each *Data Post*. This changed while working on the *Cardboard Scale Model* prototype (Figure 36 right). While building the prototype we realized that we could use the single wedges of the post and rearrange them to form different shapes. We wanted to use that idea and have the form of the post resemble the energy resource it is representing. We explored this idea in the *Wedge Formations* prototype (Figure 37) and thus moved *Physical Separation In Focus*. Unfortunately the possible formations were too limited and most forms didn't make use of the *Cracks* efficiently – which is why we dismissed this approach.

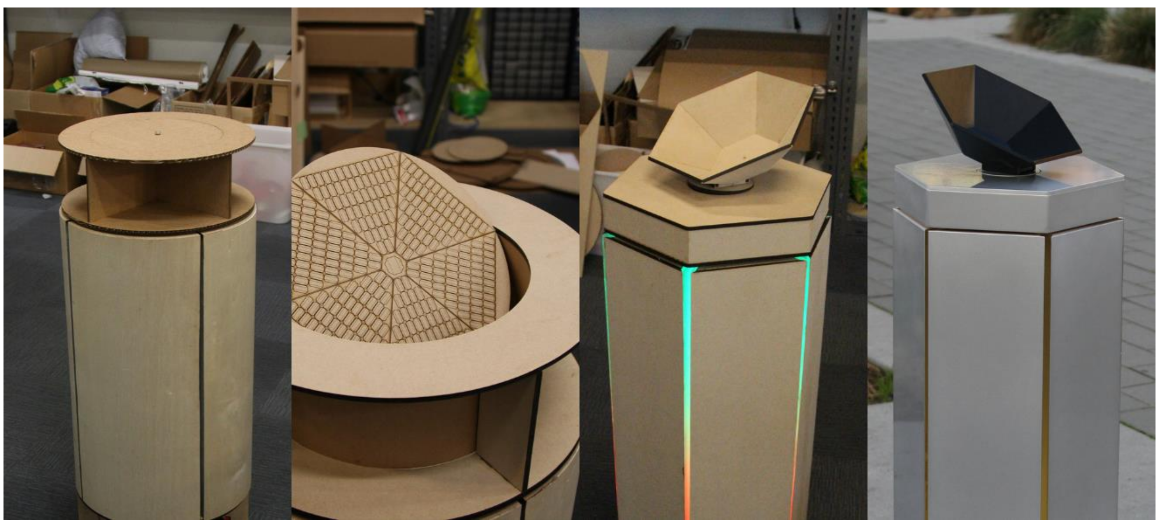


Figure 38 The *Visible Sensor* for solar energy in various stages in the design process.

However, the concept of *Physical Separation* was still very much alive and stayed *In Focus.* During the *Round Data Post* prototype we then developed the idea of *Visible Sensors* – a physical shape resembling a sensor used to measure the energy resource a Data Post is measuring. After the *Round Data Post* prototype (Figure 38 left), the *Physical Separation* was *Neglected* in the *Battery Test* prototype (Figure 38 second from left), but immediately came back *In Focus* and stayed there for the rest of the design process. In the *Visible Sensors* prototype we transformed the idea of a physically distinct form for each post into the *Visible Sensors* themselves. During the *Hexagonal Data Post* prototype (Figure 38 second from right) we improved on the *Visible Sensors* and the *Urban Data*

Posts Assembly prototype and the *Reactions + Animations* prototype (Figure 38 right) implemented their functionality with the rest of the installation.

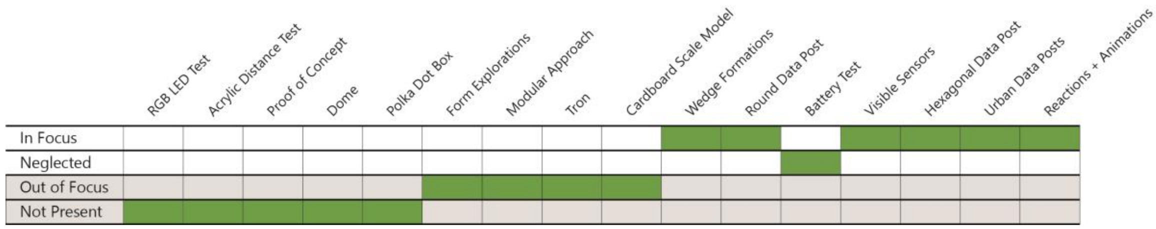


Figure 39 Overview of "Physical Separation" and its path in the design process.

In summary: the concept of *Physical Separation* was part of our designs midway through our design process (see Figure 39). This was due to the fact that we started to explore several shapes at once in order to increase our chances to find a form we wanted to work with. *Physical Separation* then moved *In Focus* after we had built the *Cardboard Scale Model* prototype and realized that we could have a physically distinct artifact for each energy resource instead of using the same shape for all. After the *Wedge Formations* prototype, the *Physical Separation* stayed *In Focus* for the remainder of the design process and was an integral part of our design. It was only *Neglected* while we were working on the electronics of our prototype in the *Battery Test* prototype.

The thread following the *Physical Separation* is a good example of how a prototype can immediately open up new possibilities. Although *Physical Separation* was present (but *Out of Focus*) in various prototypes before the *Cardboard Scale Model* prototype, it would have been difficult to recognize it. However, while building the *Cardboard Scale Model* prototype we almost immediately recognized its modular quality and therefore the possibility to rearrange the single wedges to different forms. This thread also show that a design anomaly can be positive and due to their positive nature, the creative possibilities within are almost immediately recognized.

5.3. Summary of the Focus Framework

As seen in the analysis of various design aspects in the Urban Data Posts project, *In Focus* and *Out of Focus* allows one to better understand the interplay between designer and prototype in the *Urban Data Posts* project. It creates an idea of what prototypes are capable of, beyond their intended purpose. The focus framework captures a prototypes potential towards opening up new design space, generating new design opportunities. Capitalizing on these design opportunities is then the task of the designer. She needs to engage in a conversation with her artifacts and closely listen to the feedback.

This conversation between designer and prototype is of course a very complex process. The designer is faced with a vast amount of information and she needs to navigate a complex web of possibilities. Not only does the current prototype offer her feedback in terms of its performance (the design aspect *In Focus*), but, as I just showcased, unexpected and unintentional design opportunities. On top of that the designer is probably still conscious of prototypes that were previously built. A good designer might even be able to take into account prototypes and experiences from other projects.

The analysis of the Urban Data Posts project with the Focus Framework is simply an exemplar showcasing how design anomalies can affect the design process. It also shows the reality of prototyping from a designer's perspective. Although simplified, the designer is constantly gauging which design aspects she wants to explore while at the same time looking for new opportunities, combining ideas and making decisions for the final design.

5.4. Summary

This chapter analyzed the design process of the Urban Data Posts project utilizing the lenses In Focus and Out of Focus. The two lenses can be seen as a tangent to the Anatomy Framework provided by Y.-K. Lim et al. (2008). *In Focus* and *Out of Focus* highlight a designer's intention when building a prototype, as well as design anomalies with creative potential. This allows one to better understand how different design aspects emerged through the prototyping process and how the designer engages in a conversation with her prototypes.

Chapter 6. Discussion

Prototypes are well established throughout all design practices. They are also well understood from a design research perspective. However, the interplay between designer and prototype received less attention from the design research community. In the previous chapters, I have illustrated how the Focus Framework can be used to understand how individual prototypes have (and could have) influenced the final design of the Urban Data Posts project. This answered the main research question of this thesis which is:

- How did the individual prototypes in the Urban Data Posts project influence the project's final design?

However, while unraveling the interplay between designer and prototype to answer this question, new questions arose, along with several opportunities and considerations. This section will summarize these thoughts, along with the limitations of this study.

6.1. So what? Contributions of this research

Based on the analysis of the Urban Data Posts design and prototyping process, the following section lists the contributions of this research. There are three different contributions.

First, I propose the Focus Framework as an extension of the Anatomy Framework. As written throughout this thesis, both frameworks capture a prototype's purpose (although with a different level of detail) and both provide an analytical perspective. While the Anatomy Framework is better equipped to understand the fabric of prototypes, it helps the designer plan the build of prototypes. It therefore has a strategic or planning character. The Focus Framework, on the other hand, is better equipped to capture the "back-talk" (Schön, 2000) of prototypes. It therefore has a generative character.

Secondly, I will propose a way for designers to better catch design anomalies in their prototypes. Prototyping itself is a very demanding activity, and as a designer one gets easily lost in planning, building the prototype, and understanding its implications. It is therefore easy to pay much attention to parts of the prototype that are not immediately connected to its intention. Moreover, some design anomalies are harder to catch than others. Based on the experience in the Urban Data Posts project, I will propose taking pictures as a way to capture both intentional and unintentional design aspects in prototypes.

Third, I will explain how purposefully designing for anomalies could be used in design projects. As the analysis of the Urban Data Posts project revealed, unintentional design aspects can have a huge impact on the final outcome of a design. They open up the design space by generating new ideas and creating new opportunities. While this is not applicable for a designer during the final stages of her project, my argument is that this is can be beneficial during the explorative stages of a design project.

6.1.1. Focus Framework as an extension of the Anatomy Framework

Throughout this thesis the notion of the Focus Framework was related to the Anatomy Framework introduced by Lim et al. (2008). This section will build on their relation and position the Focus Framework as an extension to the Anatomy Framework.

The Anatomy Framework – Strategic and Analytical

As mentioned in Chapter 5, the Anatomy Framework by Lim et al. (2008) consists of two main ideas. Prototypes can act as filters, and prototypes are manifestations of design ideas. Prototypes as filters describes the idea that prototypes do not need to include all five dimensions (Appearance, Data, Functionality, Interactivity, and Spatial Structure) at the same time. A designer can decide to solely work on the form of a prototype while disregarding the 4 other dimensions. This allows him to make decisions about the form of her design, without having to consider or resolve the other dimensions. Prototypes as manifestations build on the concept that prototypes are the externalization of ideas. The externalization happens through three dimensions: material, resolution (which corresponds to fidelity), and scope. These manifestation dimensions have an impact on how well a prototype performs – that is, how well it serves its purpose to explore the design space and generate ideas (Lim et al., 2008).

Thus, the Anatomy framework has a strategic and analytical character. Strategic because understanding the notion of filters and manifestations helps a designer plan what their prototype's purpose is, and how its manifestation (i.e. material, resolution, and scope) contributes to its performance. Analytical because it allows to examine the very fabric (purpose, material, resolution, and scope) of prototypes on a very detailed level.

The Focus Framework – Analytical and Generative

The Focus Framework, which was elicited from the analysis of the Urban Data Post design and prototyping process, is similar to the filtering dimensions described by Lim et al (2008). The similarity resides in the fact that both are describing a designer's intention when building a prototype. The Anatomy Framework does this on the level of the filtering dimensions (Appearance, Data, Functionality, Interactivity, and Spatial Structure) and the Focus Framework does it through describing actual aspects or features of the design (e.g. "d-pad"). However, the Focus Framework also includes unintentionality of prototypes. That is, design aspects or features that are part of the prototype not by design (intentional), but by happenstance (unintentional). I also referred to these unintentional design aspects as design anomalies. The designer is not necessarily aware of these design anomalies and it is up to her to carefully listen to her prototypes "back-talk" (Schön, 2000) to recognize them. After a successful recognition of a design anomaly, the designer then might have the possibility to use its creative potential to expand the design space, generate new design ideas and ultimately inform the design process.

Thus the Focus Framework has a generative and analytical character. Generative, because it captures unintentional design aspects of prototypes, the "back-talk" (Schön, 2000). This feedback can be used by an attentive and resourceful designer to expand the design space and generate new ideas. Analytical, because it can track intentionality and unintentionality of consecutive prototypes and highlight how the single prototypes have influenced the final design.

Anatomy and Focus Framework – a side by side comparison

Figure 40 – an excerpt of the full analysis matrix from Chapter 3 – exemplifies the strengths and weaknesses of both frameworks. The Anatomy Framework excels at analyzing the underlying structure of prototypes – their fabric (see rows Materials,

Resolution, and Scope). And like the Focus Framework, the Anatomy Framework also elicits a prototype's purpose (see Addressed Filtering Dimensions and Not Addressed Filtering Dimensions).

The Focus Framework on the other hand uses a less detailed lens to analyse a prototypes purpose (see *In Focus* in Figure 40). However, the Focus Framework excels by eliciting a prototypes “back-talk” (Schön, 2000). Next to a prototype's purpose, it also captures unintentional design aspects in prototypes (see *Out of Focus*). When applied to consecutive prototypes, the Focus Framework highlights the decision making of a designer and how intentional and unintentional design aspects inform the final design (e.g. *Cracks* switching from *Out of Focus* to *In Focus* in Figure 40).

Protoype	5 - Polka Dot Box	6 - Form Explorations	7 - Modular Approach
In Focus	Polka Dot Grid		
			Cracks
Out of Focus			
	Cracks	Cracks	
	Aura	Aura	
		Physical Separation	Physical Separation
Addressed Filtering Dimensions	Appearance: Resolution and size of mask, size of object, shape of object	Appearance: Shape of objects utilizing RGB LED strips differently	Appearance: 2D and 3D shape of artifact
	Functionality: Illuminating mask	Functionality: RGB LED strips illuminating objects	
			Spatial Structure: Relationship between single parts of the artifact
Not Addressed Filtering Dimensions			
	Data	Data	Data
			Functionality
	Interactivity	Interactivity	Interactivity
	Spatial Structure	Spatial Structure	
Materials	Arduino, RGB LED strips, Breadboard, Laptop, Jumper Wires, USB Cable, Frosted sheet of acrylic, Wood, Wooden Veneer, Screws, Capacitors, Resistors, Clear adhesive tape	Arduino, RGB LED strips, Breadboard, Laptop, Jumper wires, USB Cable, Capacitors, Resisitors, Clear Adhesive Tape, Aluminium Foil, Foam Board, Card Board, Pins	Clear Adhesive Tape, Brown Paper, Card Board, Pins
Resolution	Quickly built box made out of wood, Actual resolution and size of Polka Dot Grid, Smooth animations, RGB LED strips not properly attached	Rough and fragile artifacts made out of foam board and card board, smooth animations, RGB LED strips not properly attached	Rough artifacts made out of paper and card board
Scope	Test animation with physical artifact	Test animation on several physical artifacts	Physical artifact only

Figure 40 **Excerpt of the analysis matrix showing three prototypes through the lenses of the Focus and Anatomy Framework.**

Summary

The Focus Framework can therefore be seen as an extension to the Anatomy Framework, as they are complementary to each other.

The analytical character of the Anatomy Framework excels at understanding the underlying structure of a prototype, which is useful for a designer when planning a prototype. However, its use decreases during the build and reaches its low point after the prototype is built. The Focus Framework on the other side is not helpful during the planning stages of a single prototype. But its use increases during the build and is at its peak when the build is complete because a designer is able to elicit unintentional design aspects which can be used to advance the design or open up the design space.

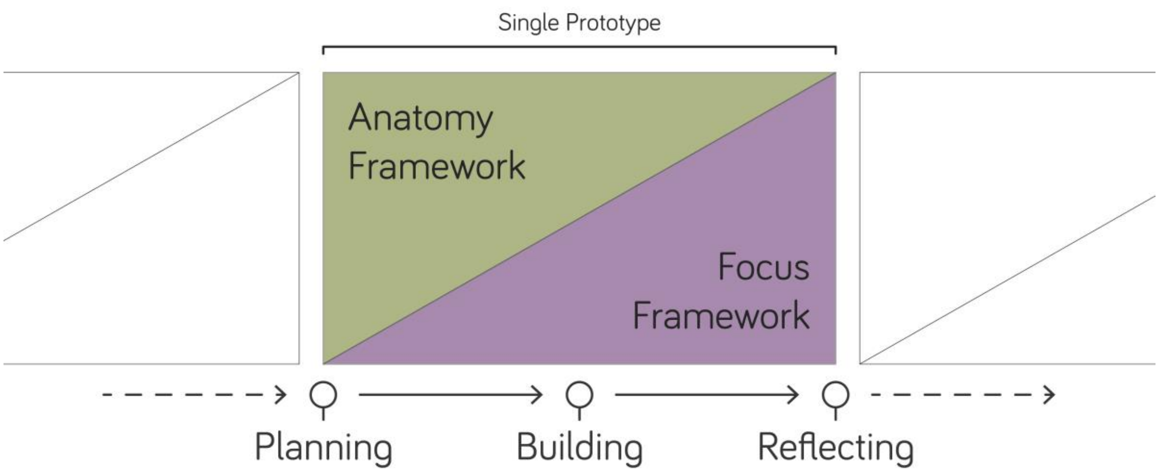


Figure 41 The Anatomy Framework and the Focus Framework as complementary tools for the planning, building, and reflection

Together, the Anatomy Framework and the Focus Framework can help a designer to better plan, build, and reflect on their prototypes.

6.1.2. Reframing prototypes

As outlined above, the Focus Framework has a generative character. That means it allows designers to track the unintentional design aspects in a prototype. But as written in Chapter 5, it is not always easy to recognize them in the first place. While some are easy to spot (usually the ones that have a positive annotation to them, like the modularity aspect in the *Cardboard Scale Model* prototype), others are hard to spot. Especially those who have a negative annotation to them and are considered as errors, flaws, or malfunctions. In fact, in the Urban Data Posts project, we didn't realize the *Aura* design aspect until after the project was already deployed. In hindsight, we would have liked to explore this possibility. It felt like a missed opportunity. So how can a designer find unintentional design aspects when he does not immediately recognized them? I will propose a solution/tool for this problem based on how we found the *Aura* design aspect.

The discovery of Aura

After the Urban Data Posts project had been deployed and I started to analyse the project for this research, the members who were part of the project occasionally talked about the outcome of the project. After I had collected the data for the Annotated Portfolio and looked for patterns, one of these conversations took place. We looked at all the data on the wall and after some time, we focused on the pictures of the single prototypes (see Figure 42). We talked about how it is almost possible to see how the design "naturally" evolved throughout the single stages of the design process. Especially because we could see the *Cracks* appear in more and more prototypes.

But we suddenly realized that some prototypes also have something else in common: a glowing quality which we eventually called *Aura*. Now, it is easy to say the prototypes have a glowing quality when the prototypes involved the use of lights. However, as described in Chapter 5, the glow we meant had a very subtle, halo like quality and the picture we had documenting this effect did the reality no justice. And the pictures not only helped us to remind us of the prototypes and their appearance, but, more importantly, to see this effect in the first place.

Stepping back

Looking at the picture of a prototype essentially 'pulled us away' from being designers and put us in the shoes of an observer. While prototyping, the designer is lost in her thoughts about the prototype and the design process. Since the prototype was built for a very specific purpose, the designer is more than likely occupied thinking about the prototypes performance and the resulting implications for her design. Her view of the prototype becomes different from her actual surroundings. While the prototype might include a messy table with breadboards, wires, micro-controllers, batteries, a DC power supply, and a multimeter, she might be seeing something completely different. In this scenario all she might be seeing is the multimeter, checking the power left in the batteries. She essentially looks at the parts in the prototype the currently matter to her. She is framing the prototype.

Figure 42 **The pictures of the single prototypes made us discover the unintentional design aspect *Aura*.**

The picture I describes above is similar to the situation we had while working on the Battery Test prototype (see Figure 43). The purpose of the prototype was to find suitable batteries for the Data Posts. We simply used four different batteries, connected each to a different wedge and checked how long they would last. However, by looking at a picture of that situation, as an observer, it is suddenly possible to appreciate the subtleties of the situation. Details about the prototype suddenly occur that were lost while immersed in the 3 dimensional space. The picture, literally, flattens the situation, thus allows the designer to step back, enabling her to oversee the whole situation. The eyes of the designer are then free to look around for new points of interests.

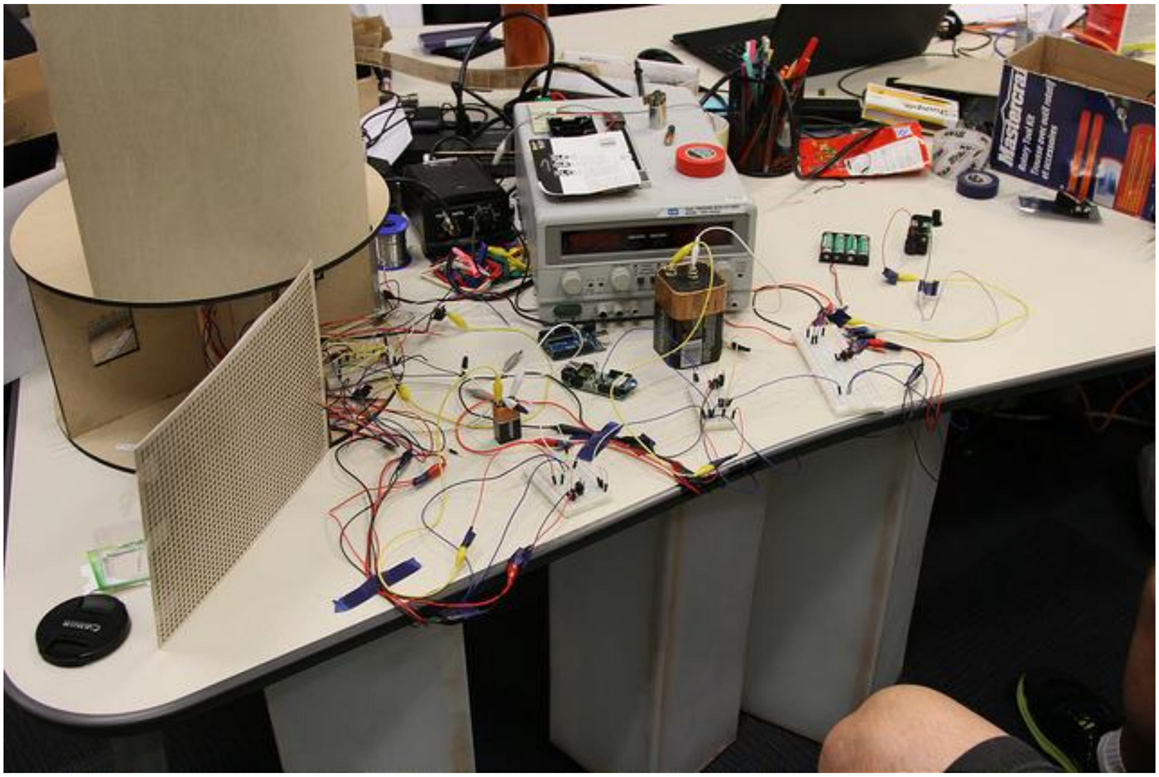


Figure 43 **The prototype setup of for the *Battery Test* prototype. The only thing of interest at that moment was the multimeter (not in picture) and time.**

Datacatcher

I observed something similar when browsing through the book Datacatcher (Interaction Research Studio, 2015). In this book, the Interaction Research Studio at Goldsmith University documents their work on the Datacatcher project. Midway through the book the various prototypes that were built throughout the design process are put next to each other and annotated with short texts. The annotations point towards the prototypes purpose and let us know what the designers were focusing on. Some of annotations read:

- "*Periscope prototype with rotational handle as physical dial, presenting data on a mirror rather than electronic screen.*"
- "*Exploring flexible material such as foam rubber and foam.*"
- "*A bounding box around the proposed hardware, illustrating scale and the potential for a single dial interface.*"

(Interaction Research Studio, 2015, pp. 74 – 75)

While reading the annotations and looking at the image, the reader gets an understanding of why the single prototypes were built. At the same time, the pictures allow the viewer to make her/his own observations, find points of interests, combine ideas and make new associations. The same is true for the designer. Although she designed the object, the prototype is no longer a 3 dimensional form that can be altered. The image changed the state of the artefact. The designer has no longer control over its form, weight, size, etc. The artefact is compressed into a 2 dimensional form, easily digestible showing the artefact as is, and successfully disconnecting the designer from her position as a creator, putting her in the position of an observer.

6.1.3. Purposefully prototyping for anomalies – Interactive Sketching

Laseau (2001) and Pugh (1991) visualized the design process using the notion of funnels (exemplified in Figure 44). The idea is that at the beginning of the design process, the designer starts with a specific intention or problem, indicated by a single point. On the other side of the design process is the final design, also represented through a single point as it is a very concrete and consciously designed artefact. But the design process in between these two points is not a linear line as one might suspect. The designer has a variety of ideas to consider, possibilities to explore and of course decisions to make. The elaborative and generative aspect of the design process is visualized through an expanding funnel - indicating that the designer is exploring different opportunities for her design. Decisions and refinements on the other hand are visualized by the design funnel getting narrower. The surface area in at any current point in time indicates they design space – that is, how many possibilities the designer has it her disposal as well decisions she has to make.

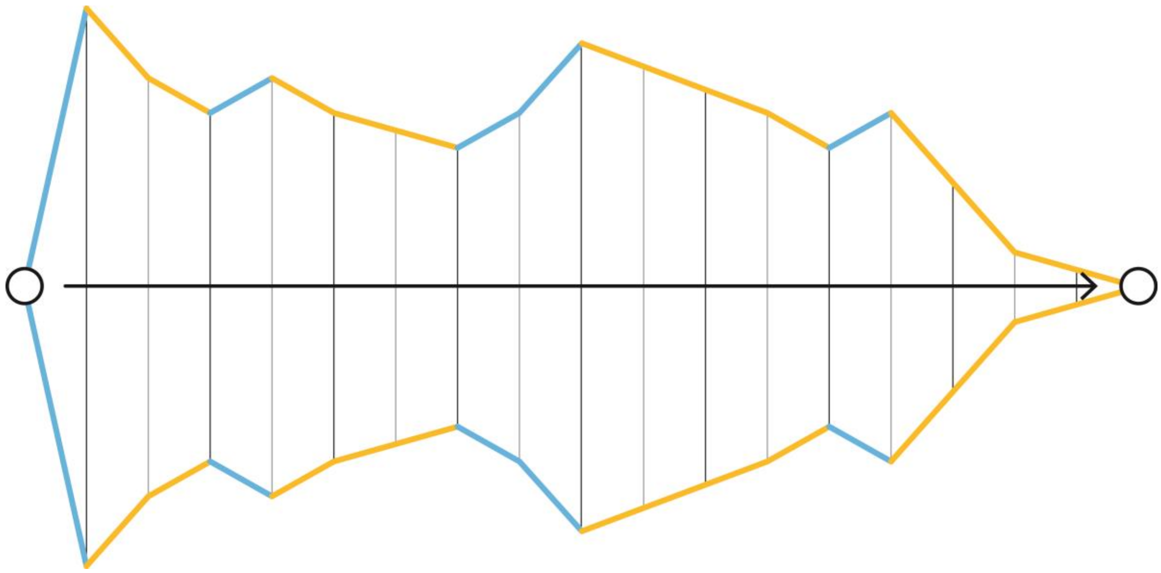


Figure 44 An exemplary design funnel, indicating exploration (blue) and refinement (yellow).

This is of course a very simplified model but it captures the very basic nature of design: as a creative practice in which the designer first generates as many ideas as possible, before carefully selecting and refining ideas. Exploration and refinement are likely to happen multiple times throughout the design process (as shown in Figure 44) but the funnel is eventually resulting in the final design where all the decisions and refinements have been made.

Sketching VS Prototyping

As shown in this thesis, design anomalies can be a powerful tool to alter the trajectory of a design project. They offer new possibilities and options in the design process which the designer can choose to explore. And as visualized in the design funnel in Figure 44, there is need for exploration (blue) and for refinement (yellow). And although prototypes can be used for both, exploration and refinement, a clearer distinction might be helpful.

Bill Buxton makes an insightful differentiation between a sketch and a prototype which I would like to quickly present at this point. In his book “Sketching User Experiences” Buxton (2011) includes a graphic (p. 140) that opposes the Sketch with the Prototype. Under each there is a list of attributes. Between these attributes there is an arrow, indicating that the space in between the two attributes is a continuum. Some of these attributes read (from sketch to prototype):

- "*Suggest > Describe*"
- "*Explore > Refine*"
- "*Question > Answer*"
- "*Propose > Test*"

(Buxton, 2011, p. 140)

What Buxton describes is a subtle distinction between sketches and prototypes. "*Sketches and prototypes are both instantiations of the design concept. However they serve different purposes, and therefore are concentrated at different stages of the design process. Sketches dominate the early ideation stages, whereas prototypes are more concentrated at the later stages where things are converging within the design funnel.*" (Buxton, 2011, p. 139). He further argues that the early stages of a design process are uncertain and therefore require design exploration. Sketches facilitate that as they are easy and cheap to make, but they are also disposable. During the later stages of the design process, where the design is converging and the designer is refining her design, prototypes are more frequent.

The reason why I explain this is the following. Based on Buxton's differentiation between sketches and prototypes, and the need for designers to open up the design space for exploration, I propose the notion of Interactive Sketching. Interactive Sketches are prototypes which are prone to design anomalies due to the amount of time spent building them, as well as the materials and tools used. They are quick and dirty representations of a design idea, made out of the tools and materials immediately available. They are purely meant for the designer to explore the design space, and can be disposed or repurposed for another interactive sketch afterwards. And unlike other "low-fidelity" prototypes, Interactive Sketches have a computational aspect – hence the word *Interactive*. In case of the prototypes for the Urban Data Posts for instance, the Interactive Sketches we built always had either a test animation running on the LED strip or were controlled by actual data. This interplay between testing a core digital component and having a rough physical representation of the artifact then allows the designer to test her idea while discovering new and unexpected opportunities at the same time.

The key for building Interactive Sketches are the materials and tools used, the time spent and including a computational aspect. To some degree, it can be compared with a physical “low-fidelity” prototype that already includes some degree of the intended computation. The idea with this prototyping approach is to stay away from perfection and allow the prototype to be scrappy. This will increase the chance of design anomalies to appear which can be used to further open up the design space. This is of course only useful when the designer is looking for exploration, and not for refinement.

Looking back at the design process of the Urban Data Posts, we relied on spare materials and easy to use tools in our surrounding whenever possible. Foam board and cardboard where often preferred over higher quality materials such as MDF. We used scissors, tape, carpet knifes as often as a laser cutter and power tools. And whenever possible, we addressed the computational aspect of the final design to some degree. And the imperfection of the “cheaper” prototypes often showed unintentional design aspects. This is not to say prototypes made out of MDF didn’t show them. The argument here is they are not as prone to have them because professional and precise tools and materials increase the chance that the designer’s mental image of the prototype will coincide with the actual prototype. Hence, there is less room for unintentional design aspect to appear.

6.2. Limitations

The following section captures some of the main limitations of this research. First, the Focus Framework was only applied to analyse a single design project and second, the findings are based on a project conducted in a research setting, and not in a professional design context.

6.2.1. Research based on single, personal design case

This research is based on a single design project, the Urban Data Posts. As a result, the findings of this thesis are not generalizable. Just because the Focus Framework was applicable to analyse the Urban Data Posts project, does not mean it is applicable to other interaction design projects as well. And even it is, it does not guarantee similar results. As mentioned at several points in this thesis, design projects are complex procedures, influenced by various factors from inside and outside the design project.

Other design cases would be needed to draw some more generalizable conclusions (see Future Research Opportunities). These cases could be rooted within an academic research context as well as in a professional design context, which brings us to the next, more significant limitation.

Moreover, the research does not analyze the design work or project of someone else. It analyzes a project in which the author of this work was heavily involved in. Thus, it doesn't follow the method of a more traditional research project, in which data is gathered through observations or interviews. The data is generated through knowing the project inside out. At the same time, this is a strong point of this work, as the author was able to rely on data and knowledge, which might have otherwise stayed hidden or could have been lost in translation.

6.2.2. Academic research context VS Professional design context

Another decisive factor which limits this thesis, is that it was conducted within an academic research setting although the thesis and the findings are directed primarily at the design community.

The Urban Data Posts project was a common design research project. The purpose was very open ended and new knowledge was pursued through the design of an artefact. The goal of the project was to find novel ways to engage the public with communal and urban data in a public setting and to explore new ways of displaying data. However, it is very unlikely that such a project would be conducted in a professional design context. And if so, it would be very rare.

The actual execution of the project was very much following a common design process. As described in Chapter 4, it started with a project brief, then going through a phase of secondary research for idea exploration, over concept creation, to various design iterations with prototypes, to the final build and deployment. This or a similar structure is what I would expect from most design processes. However, even here it is very likely that there would be substantial differences between the Urban Data Posts project, and a similar project conducted in a professional design context.

For instance, we would immediately have to ask the question who other stakeholders in this project are. Are we designing for someone? Science World? The City of Vancouver perhaps? What is the timeline? How much budget do we have? Are other stakeholder part of the project? Maybe for data mining, programming and manufacturing? What is the intention with this project? Who will it be made for? Are there any restrictions we have to consider? And so on.

These, and many more factors did not play a role in the Urban Data Posts project since we had the freedom to take how much time we needed. We could choose to work with other stakeholder or not. We had no one to design for except for ourselves. And our money for this project came from a NSERC Engage Grant. Of course there were limitations, but far fewer and less restrictive than the ones we could expect in a professional design context. This simply means, that the project executed in the "real world" would have probably looked very different from the one described in this thesis.

This is not to say the findings of this thesis are not applicable within a professional design context. I am very confident they would be, just not to this same extend.

6.3. Future Research Opportunities

This section highlights some future research opportunities that arise from this research as well as from the previously mentioned limitations.

6.3.1. Application of the Focus Framework in other design projects

One of the future research opportunities is to apply the Focus Framework to other design projects. This could be done within both, the academic research context and the professional design context.

There are several small differences to consider. First, the Focus Framework could be applied to the whole design process, like in this thesis. The results could then be compared with this research. On the other hand, the Focus Framework could be applied to specific prototypes in order to see if the designer is able to generate new design ideas. The analysis itself could happen through a different medium such as videos or text to see how they perform in comparison to analyzing pictures.

But the most interesting research opportunity is probably the application of the Focus Framework to design projects executed in a professional context and in various design disciplines. Research on the Focus Framework on a professional design context could yield information to how designers can successfully implement and use the framework in their everyday work. The application of the Focus Framework in other design disciplines opens up the question if it is applicable at all. Even within Interaction Design there are many project that work quite differently from the Urban Data Posts project. The Urban Data Posts project is of course a physical / tangible digital artifact. But what projects in Software Design? The design for mobile app? Service design? Emerging technologies? Prototypes, in one form or another, are almost always part of the design process. As a result, the Focus Framework can in theory highlight unintentional design aspects in these prototypes.

Other design disciplines like Communication Design and Industrial Design also work with prototypes. How would the Focus Framework perform in the design process of a piece of furniture? Or a brand identity? Because prototypes are so ubiquitous in design, the Focus Framework could be tested in many different ways. And that is not even considering the various other ways of making, testing and exploring that exist in design.

6.3.2. Use of Interactive Sketches

Another contribution of this research was the proposal of utilizing Interactive Sketching as a way to build prototypes that are prone to have design anomalies. Here it would be interesting to see a side by side comparison between two design processes on the same project. One team is utilizing Interactive Sketching while the other team is not.

A research team could observe both teams and collect qualitative data about each design process to compare them.

This is not to find out of Interactive Sketching is a required tool in the design process, but to gauge its usability and to possible add another tool into a designers toolbox.

6.4. Summary

This chapter looked at the contributions of this research as well as its limitations and future research opportunities.

In the first section, the Focus Framework was proposed as an extension to the Anatomy Framework by Lim et al. (2008). The Anatomy Framework allows a designer to understand how prototypes can be used as filters and how the manifestations dimensions influence its performance. This is useful knowledge for planning and building targeted prototypes that perform well. The Focus Framework on the other hand allows the designer to reflect on the prototype. Both intentionality and unintentionality are captured from the prototypes “back-talk” (D. A. Schön, 2000) and open up more design possibilities.

Next, taking pictures of prototypes we proposed to help designers step back from their prototypes to discover unintentional design aspects. While prototyping, the designer is often caught up in details and does not recognize lingering possibilities in his prototypes. Pictures helped to discover the *Aura* design aspect in the Urban Data Posts project, and an argument is made how pictures turn an immersive experience while prototyping in an observable and digestible form.

Third, the notion of Interactive Sketching is proposed. During the design process the designer is alternating between exploration and refinement. The argument is made that Interactive Sketching – prototypes purposefully build so they are prone to include design anomalies – are a way for designers to further open up their design space.

This chapter then looked at the limitations of this research. The main limitation is the fact that the Urban Data Posts project was conducted in an academic research context and not in a professional design setting. As a result, the findings of this research are likely not to be as useful in an actual design project due to restricted time and resources.

Lastly, various future research opportunities were introduced, which are based on the findings of this research.

Chapter 7. Concluding Remarks

Prototypes are ubiquitous in the world of design: from their use as a first artifact before production starts, to their use in formal design evaluations (e.g. usability test), to their use as a design tool for idea exploration and generation. Prototypes are hugely important in the world of design due to their versatility and usefulness. As a result, prototypes exist in many forms and variations, they are well defined and well refined tools and as a result, central to the practice of design.

But not only designers cherish prototypes. Researchers are attracted by the concept of prototypes as the countless methods, theories and definitions about prototypes coming from the research area testify. Especially RtD holds a special place for prototypes. After all, RtD generates knowledge through the act of designing. And as prototypes are a central element to design, so are they for Research through Design.

7.1. Summary of thesis

The purpose of this thesis is to shed more light on the nuanced interplay between designer and their prototypes. Especially how prototypes can (and could) influence the final design of a project. As the work of the Urban Data Posts project shows, even unintentional deign aspects (design anomalies), who were first mistaken for errors, can fundamentally change the outcome of the final design. This thesis set out to explore how exactly the design team of the Urban Data Posts project worked with prototypes, how they were built, how they performed, the feedback they provided and how this changed the trajectory of the project.

The thesis started with a literature review to situate the thesis in between research on ‘Design & Design Process’, ‘Prototypes’ and ‘Research through Design’. In each area, a single contribution was highlighted as it was closely related to this research. These contributions are: design as a reflective practice (D. A. Schön, 2000), the anatomy of prototypes (Lim et al., 2008), and Annotated Portfolios (B. Gaver & Bowers, 2012).

The next section explained the methodology underlying this research and how the thesis was conducted. The key methodologies in this research are Research through Design and Annotated Portfolios. The actual execution of this research is divided into two sections: a description of the Urban Data Posts project and a data collection and analysis.

The forth chapter explained the design and prototyping process of the Urban Data Posts project in detail. The focus of this chapter was on the development of very specific prototypes. This was done in preparation for the next chapter, which uses these prototypes as key elements in its analysis.

The fifth chapter explained the actual analysis of this research. The Anatomy Framework by Lim et al. (2008) is explained in detail to provide a grounded comparison to the Focus Framework, which is used for the project analysis. In total, three design threads are being investigated with the Focus Framework: *Polka Dot Grid*, *Cracks/Aura*, and *Physical Separation*. The analysis of the design process following these three threads answers the main research question, by visualizing how the single design aspects effected the design process, and ultimately the final design.

The sixth chapter provided a discussion of this research. After describing the three contributions, the chapter also points out what limitation this research faces, as well as future research opportunities.

7.2. Contributions

This research hopes to contribute in the fields of design and design research.

7.2.1. Focus Framework as an extension of the Anatomy Framework

The Focus Framework provides designers with an additional tool to monitor the evolution of the design and can provide the tools to open up the design space if needed. I consider the Focus Framework as an extension of the Anatomy Framework as I see them as complementary tools. The Anatomy Framework excels at providing knowledge for planning and building prototypes, while the Focus Framework has a more generative character and provides the tools to capture a prototypes purpose and “back-talk” (D. A. Schön, 2000). Both tools serve a specific purpose and can therefore co-exist.

7.2.2. Reframing prototypes

I propose the idea of utilizing pictures in order to help designers reframe their prototypes as a starting point for further design and research exploration. As described in the Chapter 6, prototyping is a complex and immersive activity. The designer, at the center of this activity, might miss valuable feedback from her prototypes because of the complex nature of design. This is not to say, missing valuable feedback is crucial to the success of a design project. It is merely a missed opportunity. But recognizing an opportunity when the designer is in need for inspiration or ideas helps to gain traction in the design process. Images could be an easy and cheap way for a designer to be able to step back from her designs to re-evaluate.

7.2.3. Interactive Sketching

I propose the notion of Interactive Sketching as a way to build prototypes that are prone to design anomalies. Using immediately available tools and materials, and executed in shorts amount of time, Interactive Sketches are likely to show unexpected behavior and include unintentional design aspects. As argued throughout this thesis, unintentional design aspects can be used to create new design ideas and create design opportunities. Especially during stages in the design process where designer want to explore, rather than refine, Interactive Sketches could be a valuable tool.

7.3. Limitations

This research has two main limitations.

7.3.1. A single, personal design case

The research is based on a single design case which was also conducted by the author of this research. As a result, this research does not follow a more traditional approach in which people are observed or interviewed in order to receive data. However, this is also a strongpoint of this research, as the author of this thesis was able to draw on genuine and in depth knowledge about the Urban Data Posts project without relying on interviews or observations.

A single design case also means that the contributions of this research are not generalizable. They are true to this project but not necessarily applicable to other design projects. The knowledge is therefore "*provisional, contingent, and aspirational.*" (W. Gaver, 2012, p. 938), a hallmark of Research through Design.

7.3.2. Academic Research Context VS Professional Design Context

The second limitation is that the design project, on which the study and contributions of this research are based on, was conducted in an academic research context. As a result, they are not necessarily applicable to projects conducted in a professional design context. This is mainly due to the fact, that a designer as less time, resources at her disposal in a professional design context. Moreover, she is designing for someone else in this context, whereas a designer in a research context can follow her own interests.

7.4. Summary

I do not propose these contributions with the intention to say they should be used in the design process, or are in any way superior to existing tools. I merely propose them in the hope that it will encourage other designers and design researchers to pick up these ideas, test and evaluate them, and build on them. I do believe that there is still much to learn at the intersection of design as a reflective practice (D. A. Schön, 2000) and prototypes – especially in all the nuances and often tacit knowledge a designer uses to advance her design. This thesis merely hopes to be a stepping stone to further our understanding in that area, to provide tools which might help us understand this process better, and to give tools to designers which help them to capture a prototypes purpose and feedback more entirely.

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