Designing for sketching to support concept exploration

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ISSN 0345-7524
ISBN 978-91-7519-009-9

Printed by LiU-Tryck, Linköping, Sweden, 2019

ABSTRACT

Sketching is a way of exploring early concepts through the act of externalization in a suitable material with the aid of a suitable tool. One could use paper and sketch with a pencil or go digital and sketch with code. What is appropriate to choose depends on the situation and on the skillset of the person who is going to sketch. When sketching is done successfully, the externalization can “speak back” and thus engage the sketcher, and others, in a conversation leading to a better understanding of the sketched concepts as well as new concept ideas. This is thoroughly documented in literature – a typical example would be an architect sketching a site plan on a flat piece of paper and being able to read into the possible movements in the third-dimensional space. Sketching generally works like this in familiar, that is, idiomatic situations for experienced sketchers. In unfamiliar or non-idiomatic situations, existing sketching tools are inadequate for expressing and exploring

early concepts. For novice sketchers, with limited sketching literacy, even attempting to sketch in an idiomatic situation can be challenging.

Through three cases, I design for concept exploration by enabling sketching to understand how this can be done in new situations. The first case deals with expert sketchers exploring non-idiomatic situations: professional creatives working with fulldome format for visual communication. The second case deals with novice sketchers exploring non-idiomatic situations: design students working with virtual reality. The third case deals with novice sketchers exploring idiomatic situations: air traffic controllers working with finding alternative routes for aircraft in the airspace with automation support.

I take a constructive design approach by making design examples and reflecting during and after the process. With the help of the design examples, I engage domain experts through participatory co-design workshops and elicit insights in order to inspire further design work. What I learn through this dynamic making-workshopping-and-reflecting process forms the foundation of the knowledge contribution. It is presented here as three design tactics on how sketching could be like to support concept exploration: 1) be responsive, 2) emulate salient material properties, and 3) be lightweight.

SAMMANFATTNING

Att skissa är ett sätt att utforska tidiga koncept. Det görs vanligtvis genom att externalisera koncepten i ett lämpligt material med hjälp av ett lämpligt verktyg. Det går likväl att skissa med papper och penna som att skissa digitalt med hjälp av kod. Vilket material eller verktyg som är att föredra beror på situationen och skickligheten hos personen som ska skissa. När skissning sker framgångsrikt kan externaliseringen “prata tillbaka” och på så sätt engagera skissaren, och andra, i en konversation som leder både till bättre förståelse för koncepten och även till nya konceptförslag. Det här finns utförligt beskrivet i litteraturen – ett typexempel är när en arkitekt skissar en byggnadskonstruktion på ett plant papper och utifrån det kan se hur möjliga rörelser kan te sig i en tredimensionell rymd. Skissning funkar generellt sett på det här sättet i alla fall i välbekanta, idiomatiska situationer för erfarna skissare. Däremot i obekanta, icke-idiomatiska situationer, är befintliga skissningsverktyg otillräckliga för att

kunna användas till att uttrycka och utforska tidiga koncept. För novisa skissare, med begränsad skiss-kunnighet, är det dessutom utmanande att skissa även i en idiomatisk situation.

I tre fallstudier, designar jag för konceptutforskning för att förstå hur det kan ske i nya situationer genom att möjliggöra för skissning. Den första fallstudien handlar om erfarna skissare som utforskar icke-idiomatiska situationer: professionella kreatörer som jobbar med domformat för visuell kommunikation. Den andra fallstudien handlar om novisa skissare som utforskar icke-idiomatiska situationer: designstudenter som jobbar med virtuell verklighet. Den tredje fallstudien handlar om novisa skissare som utforskar idiomatiska situationer: flygledare som jobbar med att hitta alternativa rutter för flygmaskiner i luften med automationsstöd.

Jag tar en konstruktiv designansats genom ett skapande av designexempel och reflektion under och efter processen. Med hjälp av designexemplen engagerar jag domänexperter i deltagande co-designworkshops och fram insikter som inspirerar fortsatt designarbete. Det jag lär mig under den här dynamiska processen av skapande, workshopande och reflekterande, formar grunden till kunskapsbidraget. Bidraget presenteras här som tre designtaktiker om hur skissning kan vara för att stödja konceptutforskande: 1) vara responsiv, 2) emulera centrala materialegenskaper, och 3) vara lättviktig.

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1. INTRODUCTION

In the past, creative people such as Einstein, Beethoven, and Leonardo da Vinci were treated like geniuses. They were few and far between and were thought to be born with a special gift. Nowadays it is a common belief that everyone can be creative, and it is an ability that can be practiced and enhanced by methods and tools. Some of us have nurtured and developed that ability and turned it into a professional skill as designers.

It is rumored that when the mathematician and inventor Archimedes submerged himself into a filled bath, he suddenly understood the volume of water displacement. At that moment he exclaimed “Eureka!”, which translates to “I found it!”. Eureka is sometimes attributed to signify the “creative leap” when a designer gets that breakthrough idea, but some argue that the creative leap is more like a creative bridge (Cross

& Cross, 1998). That seemingly spontaneous moment of enlightenment usually comes from a long process of experiments which created less preferable outcomes. Figuring out what doesn't work, helps in navigating toward other ways that might work better. That is like paraphrasing what Thomas Edison apparently stated "I have not failed. I've just found 10,000 ways that won't work".

Design problems do not simply have one single correct solution (Boyarski & Buchanan, 1994). A design can always be improved, meaning that a proposed design solution can just be judged as better or worse than something else. In a design process, designers create many alternatives to explore the design space in order to find alternatives that can lead to better designs. Another challenge with design problems is that they are ill-defined. The problem definition is fussy and incomplete. Designers are able to define the problem more clearly as they learn more about it while working on possible solutions (Maher, Poon, & Boulanger, 1996).

"[O]ur industry is organized around two all-too-common myths:

- 1. That we know what we want at the start of a project, and*
 - 2. That we know enough to start building it."*
- (Buxton, 2010, p. 77)

Producing many alternatives is also about gaining knowledge about the design problem. It is a process that is about exploring and understanding the design space in order to find better

solutions. This co-evolution of the problem space and the solution space is what Schön (1983) called “problem framing”, where insights are being fed back and forth between the problem and solution spaces.

It is necessary to start the exploration early on and it can be done through the act of sketching (Boyarski & Buchanan, 1994). I use the term “sketching” to mean the act of externalization of early concepts in order to explore them further. Without being able to sketch during the creative process, designers are hindered and might feel frustrated (Verstijnen, Hennessey, Van Leeuwen, Hamel, & Goldschmidt, 1998).

Due to the purpose of sketching, many sketches are produced in order to explore the design space before committing to an alternative that could lead to a better solution. This means that most of the sketches made will be dismissed, so it is more economical to choose to sketch with a reduced version of a final production material (Buxton, 2010). Therefore, sketching is usually not done in the material of the final design solution. Sketching can be done using pencil and paper, or any other types of appropriate tools and medium to express a fleeting idea. This act of externalizing an idea in an appropriate material enables the sketch to “speak back” and give the designer new insights that could not have been imagined before (Schön, 1983). This act is what Schön called reflection-in-action where there is a tight coupling between doing and reflecting.

“In the designer’s conversation with the materials of his design, he can never make a move that has only the effects intended for it. His materials are continually talking back to him, causing him to apprehend unexpected problems and potentials. As he appreciates such new and unexpected phenomena, he also evaluates the moves that have created them.

Thus the designer evaluates his moves in a threefold way: in terms of the desirability of their consequences judged in categories drawn from the normative design domains, in terms of their conformity to or violation of implications set up by earlier moves, and in terms of his appreciation of the new problems or potentials they have created.”
(Schön, 1987, p. 63).

In order for this reflection-in-action conversation to happen concepts need to be externalized in an appropriate material suitable for exploration. Sketching using pencil and paper works in some situations where the gaps in the sketch can be filled thanks to the designer’s previous experience and knowledge about the final production material. When designers are dealing with what is already familiar, we call these idiomatic situations. For example, the movie production industry is a field that uses static sketches to successfully explore temporal material properties. They have developed their own pictorial language using arrows to express certain types of transitions between cuts and movements of the camera. The director and the camera crew can also use these sketches to communicate and have a common understanding of the vision. This is a typical example of *expert sketchers* sketching in an *idiomatic situation*. In these cases, it is well-

	Idiomatic	Non-idiomatic
Expert sketchers	Well-known in literature	
Novice sketchers		

Figure 1. Sketching supports concept exploration for expert sketchers in familiar, idiomatic situations. It has been extensively documented in literature along with details on the benefits of sketching. This is only one corner of the space where sketching could enable concept exploration.

known in literature that sketching enables explorative work and has proven benefits. However, not much has been said about how to enable sketching for *novice sketchers* or in *non-idiomatic situations*. Taking those two factors into account creates a space that can be mapped out in a 2x2 matrix (figure 1). Expert sketchers dealing with what is already familiar is described extensively in the literature. On a closer look, this is a somewhat limited scope in terms of research area, and it exposes some uncharted territories that might be worth expanding into. For novice sketchers or when dealing with non-idiomatic situations, traditional and existing sketching tools may not be enough to support concept exploration. Nevertheless, it might even be more crucial to enable an explorative approach in these particular cases.

	Idiomatic	Non-idiomatic
Expert sketchers	Well-known in literature →	Full dome: case one ↓
Novice sketchers	Airspace with automation: case three	Virtual reality: case two ←

Figure 2. My work in the three cases focusing on designing for concept exploration beyond what is already well-known in literature.

It is plausible that the known benefits documented in literature could yield benefits beyond expert sketchers in idiomatic situations. My work aims to enable this back and forth conversation through the medium, where traditional pencil and paper sketches may not be enough in order to explore externalizations. I work within the field of interaction design, as in “shaping digital things for people’s use” (Löwgren, 2013b). Interaction design deals with digital material, which is a material with arguably less inherent qualities than traditional design materials such as wood, fabric, and other physical materials (Löwgren & Stolterman, 2004). While the materials and the design process might differ between fields, we have shared concepts such as sketching as a way to explore. Through three cases I attempt to stretch the boundaries on how sketching should be like to support

Figure 3. The half-spherical shape of a fulldome and its size make it non-idiomatic to design for. (Photo credit Visualiseringscenter C and used with permission.)

concept exploration beyond the realm of what is already known when it comes to expert sketchers in idiomatic situations (figure 2). The first case deals with professional creatives working with fulldome format, which is non-idiomatic because the shape and size of a fulldome make traditional design principles non-transferable (figure 3). The second case deals with design students working with concepts for immersive formats such as virtual reality. This is an example of novice sketchers in a non-idiomatic situation. The third case deals with air traffic controllers, working with automation support for airspace flows. Directing aircraft is their everyday job and thus idiomatic to them, but air traffic

controllers are novice sketchers. In all three cases my work has been to design for sketching to enable concept exploration. In the first case it was to enable professional creatives to explore alternative concepts for fulldome. In the second case it was to enable students to explore alternative concepts for immersive spaces. In the third case it was to enable air traffic controllers to explore alternative possible routes for aircraft.

1.1 Included publications

Paper one:

Tran Luciani, D., & Lundberg, J. (2016). **Enabling designers to sketch immersive fulldome presentations.** In Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems (pp. 1490-1496). ACM.

Abstract:

Sketching is an integral part of a designer's creative process, especially in the early phase of a project and in particular when exploring an unfamiliar medium. Traditional design principles does not seem to apply when designing presentations for a fulldome. Surprisingly, interviews with local creative professionals revealed that sketching was a challenge when designing fulldome presentations, which made it more difficult for them to understand the characteristics of this unfamiliar medium. This challenge has also been affirmed by the first author's own experience of creating a fulldome presentation. This paper describes the challenges in designing for a fulldome and discusses the work in progress by

imagining new variations of sketching media that are being created as early design concepts, which will be tried out by a reference group. The aim is to identify characteristics a sketching medium needs to have in order for a designer to successfully express and explore early ideas for a fulldome presentation.

Comments:

Summary of the challenges of sketching immersive fulldome presentations that I identified based on interviews and my own design attempts. My initial explorative design concepts on how to enable designers to sketch for fulldome are introduced. I wrote the paper with supervisory support.

Paper two:

Tran Luciani, D., & Vistisen, P. (2017). **Empowering non-designers through animation-based sketching.** In Proceedings of the 7th Nordic Design Research Conference (Nordes).

Abstract:

This paper asks whether it is feasible and valuable to facilitate early stakeholder involvement in the design process by applying animation as a common temporal sketching language. We build on the notion of sketching as an efficient activity for designers to think with and communicate ideas through. Not much research has sought to involve non-designers in the sketching process and assess which sketching media might be suitable for this purpose. We present the findings and learnings from a one-day workshop

of using animation-based sketching techniques with non-designers as a way to empower them in the early concept exploration phase. We then discuss whether animation could be a suitable mediator of the sketching mind-set in stakeholders with varying preconditions for participating in the early exploratory phase of design.

Comments:

Summary of a workshop held at the developer conference Øredev, where we introduced animation-based sketching to non-designers. The workshop was collaboratively organized and facilitated. The paper was collaboratively drafted and written.

Paper three:

Tran Luciani, D., Lindvall, M., & Löwgren, J. (2018). **Machine learning as a design material: a curated collection of exemplars for visual interaction.** In Proceedings of NordDesign.

Abstract:

Although machine learning is not a new phenomenon, it has truly entered the spotlight in recent years. With growing expectations, we see a shift in focus from performance tuning to awareness of meaningful interaction and purpose. Interaction design and UX research is currently in a position to provide important and necessary knowledge contributions to the development of machine learning systems.

Machine learning can be viewed as a design material that is arguably more unpredictable, emergent, and “alive” than traditional ones. These characteristics suggest practice-based work along the lines of research-through-design as a promising approach for machine learning system development research. Design researchers using a research-through-design approach agree that a created artifact carries knowledge, but there is no consensus on how such knowledge is best articulated and transferred within academic discourse. Knowledge contributions need to be abstracted from the particular to a higher level. We suggest curated collections, a variation of annotated portfolios, as a way to abstract and communicate intermediate-level knowledge that is suitable and useful for the research-through-design community. A curated collection presents thoughtfully selected and inter-related exemplars, articulating their salient traits. The insights collected in a curated collection can be used to inform future design in related design situations.

This paper provides a curated collection addressing the fine-grained details of interaction with machine learning systems. The examples are drawn from highly visual interaction, predominantly in the domain of digital pathology. The collection of interaction examples is used to elicit a set of salient traits, including the preservation of visual context, rapid real-time refinement, leaving traces, and applying judicious automation. Finally, we show how this curated collection could inform the design of a future system in a different domain. The insights are applied to a case of interaction design to support air traffic controllers in their collaboration with future agentive systems.

Comments:

The idea of a curated collection was developed collaboratively.

The designs presented in the curated collection for visual interaction are mainly previous works done by the second author and used to inform next possible steps for my, at the time ongoing, design work. The paper was collaboratively drafted and written, but I had the lead and wrote most of the content.

Paper four:

Vistisen, P., Tran Luciani, D., & Ekströmer, P. (2019). **Sketching immersive information spaces: lessons learned from experiments in sketching for and through virtual reality.** In Proceedings of the 7th Symposium Education and research in Computer Aided Architectural Design in Europe (eCAADe).

Abstract:

This paper presents the lessons learned from a design workshop exploring methods for early exploration of immersive information spaces, such as Virtual Reality (VR). The methods explored cover design situations both designing for VR, and designing through VR, in varying degrees of fidelity. The workshops shared the common factor of attempting to enable a feedback loop between sketching activities and the more didactic and time consuming prototyping processes. From our analysis, we found that to achieve true 'sketchiness' in an immersive VR settings, tool proficiency naturally becomes a decisive factor, since a lot of new techniques needs to be learned and gained experience with. Furthermore, it is evident that the mental shift, from flat to 360 degree design, was challenging, but also the enabler of new creative constraints

from which the designer can explore the boundaries of the design space. We conclude by arguing for the development of more formalized patterns, materials and tools to not just enable immersive sketching, but also enable grasping the immersive design space itself by motivating the explorations and happy accidents when 'doodling' in the immersive space.

Comments:

Summary of two workshops about sketching for and through virtual reality. I was present at the first workshop which was held by the first author. I organized and held the second workshop together with the third author. The paper was collaboratively drafted and written.

Paper five:

Tran Luciani, D., Löwgren, J., & Lundberg, J. (in press). **Designing fine-grained interactions for automation in air traffic control.** Accepted for publication in Cognition, Technology & Work.

Abstract:

Our work aims to explore novel approaches to the challenge of designing the interaction between people and automation. Through a case study within the domain of air traffic control, we focus on designing fine-grained human-automation interactions. We design a concept and develop an interactive lo-fi prototype of an assisted sketching system to enable air traffic controllers to interact with automation in a fine-grained manner and to

externalize mental images. Assisted sketching seems to offer a possible way to communicate different degrees of predictive certainty by using visual cues and interaction. Our insights further suggest that externalization through assisted sketching could encourage exploration of future scenarios, and support communication and collaboration between air traffic controllers and between air traffic controllers and pilots. The explorative benefits for the individual decision-making process might be more evident in situations where air traffic controllers have more time for reflection, for example during planning or debriefing and in educational settings.

Comments:

A thorough summary of a project that ran for three years. It resulted in design concepts for fine-grained interactions through assisted sketching for air traffic controllers. I drafted and wrote the paper with supervisory support.

2. SKETCHING: THEORETICAL FRAMEWORK

My research focus is sketching, and more specifically how it supports concept exploration. It is an area that is in a sense already very well-documented in the literature. Sketching is the act of externalizing ‘what ifs’ in order to explore many possible futures. It is a way to explore ideas that are not yet completely formed. The word sketch comes from the Greek *schediazō* meaning off-hand, and the Latin word *schedium* meaning hastily made. Sketching is often defined as something that is done quickly, with inexpensive resources, and produces something disposable (Buxton, 2010). “The advantage of sketching is its dynamic nature: A sketch may be transformed by adding to it, by deleting parts or by drawing over it. The designer is not confined to a single sketch: He or she may generate as many sketches as required before satisfactory images emerge [...] Sketching [...] does not stop when the idea

is triggered but continues in order to develop, test, and refine it.” (Goldschmidt, 1991, p. 130).

Sometimes sketches are categorized and are even labeled as a thinking sketch, a talking sketch, or a prescriptive sketch (Ferguson, 1992; Kirsh, 2010). The thinking sketch supports the individual thinking process. The talking sketch is meant to be shared in group discussions and builds a shared mental model. Lastly, the prescriptive sketch aids in communication outside the immediate design group and can be used, for example, to persuade someone of one’s idea. It has been pointed out that a single sketch can fit into all the categories depending on the scenario in which it is being used (Goel, 1995; Van Der Lugt, 2005). Thus, a categorization of a sketch is not necessarily final, and a sketch can move from one category to another.

An alternative way of defining what is sketching is to focus on its purpose. “Sketching in the broad sense, as an activity, is not just a byproduct of design. It is central to design thinking and learning. Sketches are a byproduct of sketching. They are part of what both enables and results from the sketching process. But there is much more to the activity of sketching than making sketches.” (Buxton, 2010, p. 118). Sketching is an essential part of the designer’s creative process. A layman sketches to externalize images that already exist in the mind, but a professional designer seems to sketch as a way to think and explore (Goldschmidt, 1991). A designer sketches to express and evaluate early concepts. Most designers embrace the fuzziness in early sketches, drawing and redrawing until they can see something useful in the messiness (Goldschmidt, 1991). Sketching enables interactive imagery, that is an

interplay between seeing-that and seeing-as meaning that it triggers a ping-pong effect between seeing what is already there in the sketch and what *could* be there (Goldschmidt, 1991). It is recognized as a tangible way to frame a design problem in parallel to creating possible solutions, a sense-making process. Sometimes, it is even described as having a conversation with the sketch (Schön, 1983; Tversky, 2002).

Sketching is essential to the design process and there have been various experimental studies, mostly in cognitive science and psychology, providing evidence on the benefits of sketching. For example, Van der Lugt (2002) compared sketching to written notes during a collaborative idea generation session. Participants were asked to sketch their own ideas and then present them to the group. The process was repeated to encourage participants to transform or build upon each other's ideas. Based on the outcome, the author concluded that sketching supports the individual thinking process and helps in retrieving earlier generated ideas. Schütze, Sachse, and Römer (2003) invited industrial designers to design a backyard barbeque grill that had to meet some specified requirements. Some of the participants were prohibited to sketch, some had limited time to sketch, and some were allowed to sketch freely. The result was then judged by an expert panel. The experiment showed that the participants that were allowed to sketch experienced the problem-solving process as less challenging and came up with designs that were deemed to have higher functional quality. Heiser, Tversky, and Silverman (2004) found that sketching is beneficial for collaboration. In an experimental study they asked some participants to find routes from point A to point B on a map. Some participants got to work together face-to-face and others got to work remotely.

Participants who got to sketch collaboratively found it easier to communicate because they had a shared externalization. They were able to generate more efficient routes and in less time.

2.1 Sketching works in idiomatic situations with sketching literacy

When sketching is done in an explorative way, it is typically not done using the materials of the final artefact. Sketching can be done using pencil and paper, but it can also be done using digital software and input devices – they are just different tools of the trade enabling the sketching activity. What tool to pick depends on the circumstances and it needs to match the fidelity of the experience that one wants to explore. The fidelity of the experience does not necessarily correlate to how advanced the sketching tool is, nor how intricate the sketch turns out. The chosen sketching medium does not even have to emulate all of the properties of the final implementation materials. This can allow for quicker, easier, and cheaper sketching iterations during early concept design work. For sketching to have the thinking and communication benefits mentioned earlier, it is precisely the properties quick, easy, and cheap that are necessary (Buxton, 2010). For example, a web designer could be sketching by making wireframes in order to explore possible flows of a website. Even if the wireframes do not show the animation or pacing inherent in an interaction

flow, they seem to be quite adequate for exploring and assessing potential connections and movements between pages of a website. Animated use sketches or animation-based sketches are other examples of exploring and conveying temporality in interaction design through narration (Löwgren, 2004; Vistisen, 2016). Sketches are also commonly used in architecture. What an architect sees in a sketch differs from person to person and the ability develops with experience. Experienced architects can extrapolate information not explicitly depicted, such as potential movement flow and lighting conditions inside the buildings (Menezes & Lawson, 2006; Suwa & Tversky, 1996).

These and other examples show that designers who are experienced with the kind of design situation presently at hand can obtain the benefits of sketching, even though the sketching media used are not very close emulations of the final implementation materials. In order for this to work, the designer must be able to fill in the gaps between sketching medium and envisioned result by drawing on experiential knowledge. For instance, the motion pictures storyboard artist draws a stylized panning arrow in a scene layout to codify a rather deep, rich and precise expressive intent. Moreover, the storyboard artist rightfully expects the director, the photographer and all other parties involved in the movie production to share similar experiential interpretations. This ability to use and interpret a sketching medium both individually and collaboratively may be called *sketching literacy*.

The starting point for the work reported here is that sketching literacy requires experiential knowledge of the design situation

at hand, the available design expressions and the effects of those design expressions in the final product. In other words, in order for designers to benefit from sketching literacy, they must be familiar with the particular design idiom to employ (Cooper, 2004). This is by far the most common situation in everyday design practice; we may call it an *idiomatic design situation*.

2.2 Sketching is challenging in non-idiomatic situations or without sketching literacy

Within interaction design there are situations, non-idiomatic design situations, where traditional sketching techniques do not sufficiently capture the designer's intention. It can be because the design situation is unfamiliar to the designer in the sense that there is a lack of previous experience pertaining to final material properties, available design expressions and what effects to be expected. By extension, we call them *non-idiomatic design situations*. It has been shown that explorative conversations with design materials are conducive to innovative design also in non-idiomatic situations (Löwgren, 2016). It is clear that non-idiomatic design precludes sketching literacy and hence the sketch might have to more closely emulate the salient properties of the intended final artifact. It seems plausible that sketching in non-idiomatic situations could yield benefits analogous to sketching in

	Idiomatic	Non-idiomatic
High sketching literacy (expert sketchers)	(Well-known in literature)	
Low sketching literacy (novice sketchers)		

Figure 4: The highlighted areas show the gaps in the literature, where sketching is challenging because it deals with a non-idiomatic situation or there is a lack of sketching literacy.

idiomatic design situations, whether it be for individual performance or communication with others.

The two dimensions of idiomatic and non-idiomatic together with sketching literacy define a space, like a matrix. What has been described in literature so far mainly covers a limited area, namely where the sketching literacy is high, and the situation is idiomatic (figure 4). Within this space where expert sketchers are dealing with familiar design situations, previous research has been able to describe how to enable sketching and proven what the benefits are. However, this still leaves other areas in the matrix quite uncharted and that is where my work aims to start filling in and contribute with some examples on how sketching could be like.

3. CONSTRUCTIVE DESIGN RESEARCH: METHOD

Design is a future-oriented activity. It is about “changing an undesired situation into a desirable one” (Fallman, 2003) by imagining possible futures. For it to not only be a philosophical exercise, practitioners make new things to be introduced in order to answer *how?* “Theory has a role in explicating why design works, but it does not tell how to create good design” (Koskinen, Zimmerman, Binder, Redström, & Wensveen, 2011, p. 121). If you just study people using what already exist, you might notice where there is room for incremental improvements, but it is not an optimal way of finding breakthrough ideas. The gap is filled by the designer’s imagination based on design experience and design skills (Koskinen et al., 2011; Schön, 1983; Stappers, 2007). It has

been pointed out by others that designed things often come before the theory, and that experimentation leads to knowledge rather than the other way around (Carroll & Kellogg, 1989; Cross, 1982). For example, direct manipulation interfaces, which was a breakthrough innovation and not an incremental improvement of command line interfaces, was first demonstrated in the form of a concept called SketchPad made by Ivan Sutherland as his doctoral thesis project (Sutherland, 1963). About twenty years later the term was coined and explained why it works based on cognitive theory (Shneiderman, 1982). In other words, you sometimes need to make before you understand, because “invention comes before theory” (Pye, 1978). Thus, making is essential to design and making has been recognized to bring value to design research as well.

Design research through practice is “not about trying to explain the world, but to imagine new worlds and building them” (Koskinen et al., 2011). It centers around making and it is through the process of making that new knowledge is gained. The practitioner is usually an experienced designer, who adapts generative design methods found in design practice, but the making itself is mainly informed by imagination (Sanders, 2005). Designers are skilled in imagining possible futures and making things to let people experience them to see if they work. Researchers carefully document and reflect on the process to learn and communicate the knowledge to the broader community. In summary, a designer-researcher makes, reflects, and communicates.

There have been many attempts to describe various types of design research and Frayling’s definitions (1993) are often

cited. He makes distinctions based on the influence design has on the knowledge formation and whether the research is about analyzing an existing design or if the designerly activities are more in focus. He describes one type of design research where *making things* plays a central role. It is what now is more generally known as research-through-design. In research-through-design, designerly activities such as making artifacts lead to knowledge formation (Stappers & Giaccardi, 2017). Making artifacts is a core research activity in generating knowledge and knowledge is gained through an iterative process of making, framing and reframing (Cross, 1982). Some even state that making and reflecting are two activities that are not just connected but inseparable (Gaver, 2012; Zimmerman, Forlizzi, & Evenson, 2007).

The artifact is often considered the embodiment of the knowledge produced in the way that it embodies all the choices made by designers that relates to its purpose, functions, social implications, and aesthetics (Cross, 1982; Zimmerman & Forlizzi, 2008). It is a physical reification of abstract concepts. While designers certainly get inspired by others' works such as artifacts, an artifact on its own is to some extent a black box; it does not present itself in an open and decoded way. How do we make the box more transparent or unfold it to highlight important experiential qualities? One way is through abstraction of knowledge from the particular examples by pinpointing and highlighting interesting features of the artifact to populate the intermediate space between the particular artifact and general theory (Löwgren, 2013a). The knowledge contribution can be the combination of artifacts and the annotations, forming an annotated portfolio that deals with a specific design space (Bowers, 2012; Gaver & Bowers, 2012).

These kinds of intermediary forms of generative knowledge that can inspire future design work is the type of knowledge that can be expected from research-through-design (Gaver, 2012).

While a designed artifact is an embodiment of theory, what is also shaping the designed thing is the designer's design values such as subjective insights and interpretations. To non-designers the designing part might seem like magic, which is pretty much as far from research as you can get. Designers are partly to blame for this misconception because focus is often placed on presenting the resulting design rather than making the process transparent by sharing the reasoning behind design decisions. Many well-cited academic works from the research-through-design community showcase polished artifacts, which could easily be mistaken as intended products. The publications describe the artifacts in detail and how the final resulting artifacts were experienced by people who fit the targeted future audience, which puts a focus on communicating the end-result. The process of making gets lost in the way. What is not commonly communicated is the messy designerly activities that led to the formation of the artifacts and what was learned during the process of making. Constructive design is a variation of research-through-design with more focus on the making; the iterative and messy design process that generated insights along the way and fed back into the continuation of the design process. The knowledge produced are descriptions and explanations of these designed things and the process of making them. (Koskinen et al., 2011)

A criterion for successful constructive design research is if it is generative. The design does not need to have the intended

effects in the specific context, nor does it need to be commercially viable, because that is outside the scope for a designer-researcher (Koskinen et al., 2011). However, the insights from the design can definitely be useful for industry as inspiration for product development as the designs “can open up possibilities and prepare actions” (Koskinen et al., 2011, p. 46). Another way of thinking about the quality of generative knowledge is whether it is evocative enough to spark new concepts and if it invites other to join the discussion. Following this, the knowledge contribution should benefit from being presented in a way that is “open to multiple interpretations and reinterpretations” (Löwgren, Svarrer Larsen, & Hoby, 2013, p. 96). However, an obvious critique on the criterion of being generative is that it can only be assessed long after the fact. Since only time can tell if something turned out to be generative or not, it becomes quite impossible to assess with certainty whether new knowledge is “generative enough”. There are also no directions on how to make something that *will be* generative. Despite this unsatisfying realization, generativity is nevertheless something that practitioners and designer-researchers agree is of value. For now, perhaps what we can do at best is to present the knowledge contribution in a way that *can* be used in a generative way by making the black box transparent and untangling the messy designerly process and present it all in an accessible format.

3.1 Taking a programmatic approach

Programmatic design research mainly consists of two parts; the program that depends on a certain worldview based on assumptions and design experiments that express and challenge the program (Redström, 2017).

For example, consider a program based on the following statement: “Design is the use of the basic geometrical shapes of the circle, the square, and the triangle to express the functionality of everyday things.” Through design experiments, we would then explore what designing would be like according to this program through the (re)design of various everyday objects. To find out what the design space of this program is like, our experiments would probably initially explore issues such as how objects with more complex forms could be reduced to these elementary geometrical compositions. (Redström, 2017, p. 96)

Some design experiments can provide insights that supports the program’s rigor, while other design experiments might be formulated to challenge it and cause it to evolve and unfold over time. The programmatic approach originates from Redström’s (2011) definition of how a program is formed based on earlier works with colleagues (Binder & Redström, 2006; Hallnäs, Melin & Redström, 2002; Hallnäs & Redström, 2006). In the original definition a research program is somewhat more rigorously structured from the beginning

and realized through design experiments. Since then Redström himself has been pointed out that the relation between a program and the design experiments is more complex and dynamic (Redström, 2017).

I approached three very different cases. Because of my experiences from the industry and background in interaction design I naturally started with engaging with domain experts and experimentations. The three cases ran in sequence slightly overlapping each other timewise. About halfway through the first case I discovered that I could formulate my work as a program, which shaped the framing of the experimental work done in the following engagements in all three cases. This organic and retrospective evolvement of a research program is in line with the dynamic and hermeneutic approach to design research described by Löwgren and colleagues (2013) and illustrated in figure 5. It usually starts with engagements, which are the various design activities, or design experiments as Bang and Eriksen calls them (2014). They used their experiences from their own PhD studies to tentatively map out different roles of design experiments, exemplifying how these engagements can initiate and drift a research program, and build knowledge contributions (Bang & Eriksen, 2014). The optics stands for the “ways of seeing and ways of thinking” (Löwgren et al., 2013, p. 87). By looking through the optics it affects how findings through the engagements are interpreted. Through different types of engagements, the optics are enriched, which in turn changes the framing and scope of the program, which is symbolized with the circle around the loop between engagements and optics. Programs are ongoing and drifting as indicated by the arrow pointing towards the right. At any point in time a snapshot of takeaways can be elicited to

Figure 5. This illustration of a programmatic design research is a version of the model found in Löwgren et al. (2013).

take an appropriate form in order to be shared and communicated with others as a knowledge contribution as indicated by the arrow pointing upwards. This thesis is an example of such a snapshot highlighting the insights gained up to this point of writing.

The work presented here are the current takeaways from a programmatic approach in doing design research. I started off with one case dealing with enabling local designers to participate in the creative process of creating productions for a fulldome. I found that a challenge was in the inability to sketch and explore this non-idiomatic format. It made me curious about how to enable sketching in non-idiomatic situations. Then I was introduced to another domain of airspace

Figure 6. The work done in the different cases shaped the framing and scope of the program.

management and worked on this new case in parallel, using the optics of sketching to empower air traffic controllers in their daily work of planning future airspace flows with automation support. This time I got curious about how to introduce or enable sketching for non-expert sketchers. Throughout the time I did work in the domain of virtual reality and how to introduce a sketching mindset to non-experts. The program unfolded and developed over time. It was not until the third year of design engagements that I

started formulating the research program to be about sketching to support concept exploration (figure 6). The drifting happened along with the work I was doing in these different cases, which shaped the framing and scope of the program. It seems to be a rather common approach for researchers in our field to identify the abstractions and formulating the program in a reflective manner and Hoby's program about designing for Homo Explorens is another example of this approach (Hoby, 2014).

3.2 Making design examples

There are different kinds of prototypes. Some are prototypes of proposed new things used in usability or field studies to lay the foundation for incremental improvements. Houde & Hill (1997) describes the different roles a prototype can have depending whether the focus is on its functions, appearance or implementation. Some use prototypes as a way to speculate about the future as in research-through-design where the role of prototypes is in generating alternatives to explore the design space (Buxton, 2010; Lim, Stolterman, & Tenenber, 2008; Sanders & Stappers, 2014). Buchenau and Fulton Suri (2000) emphasize the importance of people being able to try out the prototypes for themselves as opposed to just being shown a demonstration. They define "experience prototypes" as something made to understand, explore, or communicate what is being designed.

The definition of a prototype is somewhat ambiguous and can lead to a misunderstanding of having the sole purpose of evaluation or fine-tuning a product proposition. In order to avoid any possible misconception and to emphasize the exploratory use of the things I have created; I have chosen to call what I make *design examples* instead of prototypes in the remainder of the thesis to make a clear distinction. It echoes Redström's (2011) line-of-thoughts on using the term design examples instead of prototypes, to point out that what is being made later in the process may not necessarily be more advanced.

The design examples I have made in the cases are unfinished and open for experimentation (Sanders, 2005; Stappers, 2013). They are purposefully “sketchy” to make it obvious to people experiencing them that they are not intended to become actual products. The animation-based design examples are either crude stop-motions with few keyframes or hand-drawn. Even the design examples that are developed with working interactions are obviously unfinished in other aspects, such as having an unpolished look. Apart from making it clear in communication with others that the design examples are not final design proposals, the scaled-down aspect has been a choice to filter away unnecessary qualities that are not currently being explored (Lim et al., 2008), such as the graphical interface.

I make design examples as a way to gain insights about an imagined future. Thus, my design examples are used in the process of generating knowledge in an iteratively explorative approach. The design examples I make are both manifestation

of design ideas and generators of new design ideas as I gain more insights (Lim et al., 2008).

“They are design-thinking enablers deeply embedded and immersed in design practice and not just tools for evaluating or proving successes or failures of design outcomes” (Lim et al., 2008, p. 7:2).

3.3 Facilitating explorative co-design workshops

In the work described here I start off as an outsider in each domain. It is necessary to understand the organization of activities in a situation before knowing what to design for it. Analytic ethnographic studies require additional resources and competencies that I as a designer-researcher do not possess. Moreover, even though ethnography is a great approach to describe current culture, it might provide limited use for suggesting a possible future that is of value to a designer and not result in facts that can directly be translated into “implications for design” (Dourish, 2006). I start with various types of fieldwork that focus not only on data-gathering but serve as a source of inspiration for design.

To address the uncertainty of not having a first-hand experience in each domain, I facilitate co-design (Mattelmäki, Vaajakallio, & Koskinen, 2014) workshops with selected

participants to bring in their expertise directly in the design process. The co-design workshops take advantage of the participants' tacit knowledge, expertise, and skills. Each participant is therefore chosen accordingly to the specific domain and are exemplary future users of the intended design. The design examples are used to facilitate the participatory workshops to explore "use-before-use" (Redström, 2008).

The main goal of the workshops is not to evaluate or persuade, but to collaboratively explore and learn in order to continue the design process in a promising direction. The participants get to experience the design examples, make their own interpretations of them, and are encouraged to share their opinions and ideas, which also become sources of inspiration (Boyarski & Buchanan, 1994). Since the participants are not professional designers, I also reinterpret their feedback. Their concerns, values, and abilities are taken into account and influence the decisions I make during the continued design process. I use design examples in co-design workshop mostly generatively to explore the design space, but judgements are part of the exploration that guides the next steps, so some evaluative aspects come into play as well.

Figure 7. An example of data sorting in progress using printed transcripts of co-design workshop sessions.

3.4 Abstracting insights from co-design workshops

Whenever possible, the co-design workshops are recorded and transcribed to free me from excessive note-taking while being the facilitator. The unstructured qualitative data collected from participants during the workshops are analyzed using a thematic analysis described by Tesch (1990). The transcripts, and other means of documentations, are carefully read through and interesting passages are highlighted and get assigned a “topic” in the margin (Tesch, 1990, p. 119). Based on the topics the data is sorted and grouped into appropriate categories (figure 7).

4. CASES

For now, the program consists of work done in three cases to expand the boundaries of what is already well-documented in literature about how sketching should be like to support concept exploration. In all three cases I seek to enable concept exploration by introducing tools and techniques, either existing ones or as new design examples, to the participants. The first case takes a step into the non-idiomatic realm of fulldome and deals with professional designers exploring concepts for fulldome productions. The second case continues within the non-idiomatic in the context of virtual reality but deals with non-professional designers exploring concepts for virtual reality. The third case deals with air traffic controllers exploring future airspace flows with automation support, something that they already do on a regular basis but without using tools for externalization. Figure 8 shows the cases mapped out into the gaps depicted earlier in figure 4:

	Idiomatic	Non-idiomatic
High sketching literacy (expert sketchers)	(Well-known in literature) →	Full dome: case one ↓
Low sketching literacy (novice sketchers)	Airspace with automation: case three	Virtual reality: case two ←

Figure 8. Engagements in three cases designing for concept exploration to expand the boundaries of what is well-known in literature about enabling sketching and its benefits.

In the following subsections, I will describe the domain of each of the three cases, the engagements and the design examples or tools and techniques used.

4.1 Fulldome: case one

Fulldome:	Expert sketchers in non-idiomatic situation.
Collaboration:	This project was supported by the Norrköping fund for research and development and was conducted in close collaboration with Visualiseringscenter C through C-research.
My role and contributions:	I conducted, transcribed, and analyzed the interviews. I created all the design examples. I collaborated with a research engineer to make interactive design examples. I organized and facilitated the workshops.
What has been published from this case:	An analysis of the initial interviews framing the challenge of sketching for fulldome can be found as Paper one.

A fulldome theater is a dome-shaped 180-degrees space for projecting visual media. The projected image completely fills the viewers' field of view (figure 9) providing a sense of digital immersion created by technology, as described by Slater and Wilbur (1997). Historically, fulldomes stem from planetariums, so it is not a coincidence that the early and still most dominating fulldome content centers around astronomy. With technological advancement it is now possible to not only

Figure 9. Audience immersed inside a half-spherical fulldome. (Photo credit Visualiseringscenter C and used with permission.)

project pre-rendered movies, but also use the fulldome as a canvas to showcase 3D content, captured footage, and a place for artistic expressions, in addition to real-time and interactive shows.

As of now, the fulldome production scene is technology-driven. This has been pointed out along with a wish for more content-driven approaches, because the format introduces artistic challenges (Lantz & Thompson, 2003; Thompson et al., 2009). Not only are the characteristics of a fulldome non-idiomatic for designers “only” experienced in traditional media, the format for fulldome productions are unfamiliar as well. Fulldome productions are typically implemented in the final execution environment as 2D “fisheye” images (figure

Figure 10. A “fisheye” still-frame. (From the fulldome film “Spacetrrip 3D” produced by Visualiseringscenter C and used with their permission.)

10), even though the user experience is contingent on immersive 3D projection. It is not obvious that what is pictured in the center of the fisheye will end up projected at the top highest point in the fulldome. What is even more difficult to grasp is that the top part of the fisheye will be projected behind the audience in the fulldome. In addition to that, it will be up-side-down *and* mirrored inside the fulldome.

Experienced fulldome production teams tend to use 2D fisheyes for sketching, relying on their experiential knowledge to bridge the gap between flat fisheye images and immersive dome projection. Storytelling for traditional film uses sequences of rectangular frames that are predefined. Storytelling in dome also uses sequences of frames, but these frames are spherical, and the format is fluid since the viewers can independently choose to turn their head to look around. Also, the seating arrangement in a fulldome affects the viewer's perspective, making every viewer's experience slightly different from the rest.

Another type of barrier exists as well. The software for making fulldome visualizations requires programming skills and a physical connection to the fulldome theater to preview the production in making. There are free tools, for example DomeTest (Warnow & Ruszev, 2010), that make it possible to view images and videos projected in a dome-shape. However, there are still no tools to enable a sketching approach to fulldome production. Sketching using available tools that designers are familiar with, such as pencil and paper or Adobe Photoshop, is not enough to explore the unique characteristics of a fulldome (Tran Luciani & Lundberg, 2016). Thus, without programming skills, designers need to rely on others to implement their early ideas. In addition to that, the production must be rendered before it can be previewed and projected in the actual fulldome. It is sometimes done overnight to "save" time. Understandably, this prevents the designers from freely exploring early design concepts and makes them dependent on individuals with technical knowledge and access to the fulldome. One way to make the fulldome production scene more accessible for

designers is to create new tools for exploring creative concepts. If these tools are not bound to the physical location of the fulldome, then designers could potentially sketch independently of others (Tran Luciani & Lundberg, 2016). In a recent work, Brien and colleagues introduced a creation tool that enables using a fulldome as a place for exploration and experimentation (Brien, Durand, Soria, Seta, & Bouillot, 2017). Using handheld controllers, the tool allows you to import premade 3D models into the fulldome and modify the content. It is an example of an initiative aiming to improve the workflow and enable a more explorative approach.

4.1.1 The engagements

Because I had no previous experience in fulldome production, I started with establishing an understanding of the domain and the creative process. I interviewed local creatives, such as designers and producers, who had worked with fulldome productions. I also attempted (but failed) to make a fulldome presentation in order to get first-hand experience of the process. What I learned from these activities helped to identify a lack and a need of sketching tools for sketching early concepts. It has been found in other studies that sketching has a correlation with design outcomes and it is important to generate many concepts, but even more so to do it early in the design process (Yang, 2003). Because of the shape and size of a fulldome, design know-how for traditional visual media is not directly transferrable to the fulldome environment. The formative phases started with conceptualizing some sketching tools. Some concepts were exemplified and made into

interactive design examples. The design examples were used in a co-design workshop with creatives to elicit feedback to inform further designs. Next, co-design workshops with creatives sketching in virtual reality helped to further define desirable qualities of a sketching tool.

4.1.2 The design examples

Five concepts attempting at enabling a sketching approach were used as design examples in co-design workshops. The first concept lets the designers sketch on a flat surface and see the sketch projected on a fulldome model on a screen in real-time (figure 11a). This made it possible to get a sense of how the flat sketch would actually be projected on a curved dome-shaped surface. In the second concept, the designer sketched on a flat surface while wearing a head-mounted display to see a virtual full-size fulldome with the sketch projected on it in real-time (figure 11b). The third concept allowed the designer to sketch straight to the fulldome by drawing on a screen that projected in real-time to the fulldome surface (figure 11c). These three concepts all required the designer to draw fisheye sketches, which is in itself an unfamiliar format. For instance, it is not obvious that sketching on the upper part of the fisheye results in something behind you, upside-down, and mirrored inside the fulldome. The fourth concept was an attempt to address this confusion. What would it be like to sketch on a miniature fulldome and have the result displayed in a fisheye

Figure 11a-e. Illustrations of design examples to enable concept exploration for fulldome.

on a flat screen (figure 11d)? A fifth concept explored the possibility of sketching inside a virtual fulldome inside virtual reality using head-mounted display and hand-held controllers (figure 11e). Three of the design concepts were executed as interactive design examples (figure 11a-c), one as an animated stop-motion video (figure 11d), and one was initiated as a Master's thesis (figure 11e).

4.2 Virtual reality: case two

Virtual reality:	Novice sketchers in non-idiomatic situation.
Collaboration:	This project ran in conjunction with a studio-based course called Immersive Information Spaces held at Linköping University for students in their second year of the Design Master's program.
My role and contributions:	I co-taught the course and helped planning it. I co-organized and co-facilitated the second workshop.
What has been published from this case:	A detailed description of the design experiments and design examples, along with learnings on sketching for and through virtual reality can be found as Paper four.

Figure 12. The person wearing a head-mounted display will be immersed in a visual projection. With handheld controllers the person can interact with the virtual world. Movements are tracked through sensors in the devices.

Using a head-mounted display a person can be immersed visually in a computer-generated environment, called virtual reality or VR (figure 12). Sound can be added with headphones, and with handheld controllers and sensors in the worn devices, movements and interactions can be tracked and triggered inside the virtual world. Virtual reality is not a new phenomenon per se, but it has recently gained attention due to technical advances and more affordable devices being made available to consumers. A variation of VR applications has emerged ranging from professional use for health treatments

and surgical training (Huber et al., 2017) to manufacturing (Seth, Vance, & Oliver, 2011), industrial design (Berg & Vance, 2017), and architecture (Portman, Natapov, & Fisher-Gewirtzman, 2015), and of course entertainment and games (Pallavicini et al., 2017; Rosa, Morais, Gamito, Oliveira, & Saraiva, 2016).

We are still only seeing the beginning of the full potential of virtual reality as a design material. Virtual reality is especially interesting if the applications are designed beyond merely trying to mimic the real world and its physical constraints (Shneiderman, 2003). Great design makes use of the material's unique properties. In order to enable designers to explore the characteristics of virtual reality, sketching is necessary. To sketch an immersive space, such as virtual reality, traditional design tools are usually insufficient to explore the unique characteristics of the material (Jerald, 2015). Virtual reality is also a space that is mainly driven by technology. Without proper tools to enable designers to be significantly involved in the content creation, they will only be able to take a supportive, but passive, role giving suggestions in a critique-like setting (Keefe et al., 2008). There are tools attempting to enable sketching in virtual reality. One example is *Spacedesign*, which aims to let the artist conceptualize using a head-mounted display and an input device held like a pencil (Fiorentino, De Amicis, Monno, & Stork, 2002). In a case study the authors found that industry designers appreciated the tool's simplistic way that did not require interaction with mathematical controls, like curves or anchor points (Fiorentino et al., 2002). However, the tool was still lacking functionalities in terms of editing options to fully support the designers' way of working exploratively. Another example is

Surface Drawings, where the sketch is created by using hand gestures in virtual reality (Schkolne, Pruett, & Schröder, 2001). It lets the artist make organic shapes through repeated hand movements to mimic the repeating pencil strokes that is common when sketching on paper. Different input devices are used in order to make modifications to the sketched model. Modifications can be made with a pair of tongs to move objects, two pairs of tongs to scale, or a magnet to make a slight bend in a shape. Some technical and design related challenges remain, such as how to fine-tune these devices to make them more natural parts of the sketching activity. For example, the magnet was perceived as frustrating to use because it caused involuntarily effects (Schkolne et al., 2001). *SymbiosisSketch* is another example and it aims to combine the freedom of sketching in 3D with the control and precision of sketching in 2D (Arora, Habib, Grossman, Fitzmaurice, & Singh, 2018). It supports freeform sketching in mid-air and offers the ability to map out canvases for precise sketching on a tablet. While their evaluation shows promising opportunities, it was also highlighted that the editing capabilities needed improvements in order to support iterative design. It is worth pointing out that these examples all focus on tools used for sketching *in* virtual reality and not much research has been done on sketching *for* virtual reality.

4.2.1 The engagements

We facilitated two workshops for design students who took a course in immersive information spaces with a goal of developing their own concept for an immersive experience.

The first workshop focused on sketching for virtual reality using analogue tools and video editing software. The second workshop focused on sketching through virtual reality, using different VR apps. During the workshops the students were introduced to tools and techniques that had the potential to support concept exploration. We selected the tools and techniques based on their different abilities and what was feasible to acquire on a limited course budget. After the workshops the students continued their individual projects throughout a whole semester where I assisted in supervising their work and could follow their progress. We analyzed the students' process of developing the concepts based on informal observations, field notes, and the students' own sketches and written reflections. The analysis provided insights on what characteristics might be valuable to enable a sketching approach.

4.2.2 The design examples

At the time of the study, there was no single tool or technique that could by itself enable a sketching approach for designers, let alone novice sketchers, to explore their early concepts for virtual reality. However, there were various emerging tools and techniques that aimed to enabling designers to sketch for or in virtual reality. I choose to treat them as design examples made by others to be used in my engagements.

Figure 13. An equirectangular coordinate system for sketching virtual reality with the focus and limited field-of-view marked out. (Created by Volodymyr Kurbatov and used with permission.)

An equirectangular coordinate system can be used to map what under normal circumstances is a rounded surface onto a flat surface. The effect of this mapping is a distortion on certain parts of the flat surface. This kind of distortion is characteristic of projections from non-Euclidian to Euclidian systems. Using an equirectangular projection one can make two-dimensional hand-drawn sketches and transfer them into a three-dimensional virtual reality environment (Araújo, 2018). For instance, an equirectangular projection is sometimes used to map the Earth's surface from a sphere onto a flat world map. What many might not have reflected on is that this results in unintuitive non-linear distortions in the higher latitudes. Greenland typically ends up being as large as nearly all of Europe after being projected this way. Due to the limited field-of-view of a head-mounted display it is also necessary to consider the fact that the viewer will never see everything that

is on the equirectangular sketch at any one point in the virtual world (figure 13). The distortion of shape and field-of-view on the equirectangular coordinate system is more prominent at the top and bottom edges in the flat format which is exemplified here using the equirectangular artwork created by Olivero (Olivero & Sucurado, 2019), who is devoting his Ph.D. work to spherical drawings (figure 14).

Figure 14 (right). Here we see the same artwork viewed from two different perspectives. The canvas at the bottom was created by an artist intimately familiar with equirectangular projections. In it is “Elizabeth’s green eye”, which is impossible to find by merely looking at the original canvas. However, it is easily spotted in virtual reality when the viewer looks straight up, as evidenced by the image above the canvas. What looks like an ordinary green eye in virtual reality, ends up looking like a long smeared out green blob in an equirectangular coordinate system. The black line along the top is what makes up the pupil of the eye. (Artwork by Lucas Fabián Olivero and used with permission.)

Figure 15. Screenshots of the application Storyboard VR.

We picked four commercially available applications that can be used for sketching in virtual reality; Tilt Brush, Gravity Sketch, MasterpieceVR, and Storyboard VR (figure 15). Tilt Brush is an application that lets you paint in 3D in virtual reality with the whole space being the canvas, almost transforming a painter into a sculptor. You can move around and paint from different directions and view the sculpture from different angles. Gravity Sketch lets you sculpt three-dimensional models in virtual reality and MasterpieceVR introduces collaborative 3D sculpting. Storyboard VR, as the name suggests, lets you create storyboards in virtual reality. Assets, such as texts and images, are created elsewhere on a computer and imported into Storyboard VR to be placed onto a background canvas of choice. The assets can be resized and aligned along the X-, Y- and Z-axis to create the environment and visually perceived depth. Using frames, the storyboard can be arranged. Pressing the triggers on the handheld controllers steps through the frames. The storyboard is to be viewed from a standing position and does not really support moving around or interacting with assets that have been placed out.

4.3 Airspace with automation: case three

Airspace with automation:	Novice sketchers in idiomatic situation.
Collaboration:	This project was supported by the Swedish Traffic Administration (Trafikverket) and was conducted in close collaboration with the air navigation services of Sweden (Luftfartsverket).
My role and contributions:	I conducted the field studies. I organized and facilitated the workshops. I transcribed and analyzed all the recordings. I created all the design examples. I collaborated with a research engineer to code-sketch the interactive design example.
What has been published from this case:	A detailed description of the design experiments and design examples, along with learnings on how to design for automation in air traffic control can be found as Paper five.

Air traffic controllers direct aircraft by giving verbal instructions to the pilots. To maintain safe and efficient airspace flow conditions air traffic controllers must take into account constantly changing factors that depend on current traffic situation, weather conditions, and time of the day. In

Figure 16. Air traffic controllers at work in the area control. (Photo by Torbjörn Andersson, used with permission.)

their workspaces they have systems that show real-time information on various display screens (figure 16). They also have so-called “flight strips” with aircraft identification, status, and manually added notes. Attempts in modernizing the current work situations have been focusing on touch sensitive screens with digitalized paper strips (Bos, Schuver-van Blanken, & Huisman, 2011; Mertz, Chatty, & Vinot, 2000) and in introducing integrated systems that show labels with information attached to each aircraft on a radar display. With only the aircraft identification number, the air traffic controllers can draw conclusions about the characteristics of the aircraft. For instance, they can conclude the size of an aircraft which affects the amount of turbulence it creates. That, in turn, will affect the minimum amount of separation air

traffic controllers work to maintain between the aircraft due to safety regulations.

Another approach to designing complex systems that has gained attraction is a theoretical framework called ecological interface design (Vicente & Rasmussen, 1992). As its name suggests it is focused solely on designing the interface, without taking into consideration of designing the overall user experience. The ecological interface design framework aims to create an interface based on a formalized workplace analysis defining functionalities, constraints, and relationships between people and the environment (Vicente & Rasmussen, 1992). The workspace analysis is based on current situation and already existing relationships, which then results in an abstraction hierarchy (Rasmussen, 1985) that is supposed to inform the interface design. This process of creating an ecological interface design is very formal and structured up until the design phase. It has been pointed out that a big gap exists between analysis and how to actually decide the look of the interface design (Van Dam, Mulder, & Van Paassen, 2008). The interface design usually results in overlays for visually showing constraints and boundaries (Klomp, Riegman, Borst, Mulder, & van Paassen, 2019), which might lead to visual clutter and information overload.

Most of the decision-making process take place inside the air traffic controllers' own heads relying heavily on "mental images" (Shorrock & Isaac, 2010). They combine the real-time information from the various sources and imagine possible outcomes based on previous experiences. They quickly choose a preferred outcome and try to achieve it by giving verbal directions to pilots over radio. This has not been

a problem *per se* – in general, air traffic control works quite well – but new challenges are being posed by projected developments towards growing volumes, which in turn motivates the development of increase in automation. Free flight has also been proposed as a future scenario where predefined airways will not be used as strictly as they are today. To address these challenges on the levels of individual thinking processes as well as coordination and work management, there might be benefits in a sketching approach to externalize and explore the dynamic nature of airspace flows with automation support.

4.3.1 The engagements

With no prior knowledge nor experience of air traffic control, my first step was to gain an understanding of the domain. It was done through fieldwork such as informal observations and interviews with air traffic controllers in area controls and towers. To get a deeper understanding of the quick reasoning that happens inside the air traffic controllers' head, I organized a co-design workshop using physical props to identify factors that affect their decision-making process. The learnings laid the ground for the initial design concepts on how to enable air traffic controllers to have an exploratory approach when planning airspace flows. Selected design concepts were developed into an interactive design example (see chapter 6.2 for reflections about code-sketching) and was used in an exploratory workshop with air traffic controllers.

4.3.2 The interactive design example

The main concept was to use a stylus as an input device. This allows air traffic controllers to interact with a responsive surface to externalize their mental images of aircraft flows with automation support (figure 17). The interactive design example aimed to support exploration of factors that affect the air traffic controllers' decision-making process such as time, traffic situation, and environmental changes. The collection of features is presented in figure 18: With a slider the time can be manipulated to see how future scenarios might evolve based on current plans. Ghosts-of-the-future are transparent shadows of each aircraft showing their future positions. Any ghost-of-the-future can be dragged to change its planned route and dragging also triggers the movement of the other ghosts-of-the-future showing the evolvement of the whole traffic situation. A red transparent circle indicates possible collision detection. Varying sizes of dots on the planned route indicates changes in altitude (which can be manipulated using a vertical slider while dragging a ghost-of-the-future). Visual inertia is experienced when trying to direct a ghost-of-the-future towards obstacles. Pushing a button captures a screenshot and annotation can be made using freehand drawing. The interactive design example also supports the ability of adding objects and saving scenarios for later use.

Figure 17. The interactive design example allowed the air traffic controller to use a stylus to draw on a responsive surface to externalize imagined aircraft routes.

Time	Timeline	Ghost of the future	
Traffic	Aircraft	Collision detection	Altitude
Environment	Moving obstacle	Static obstacle	
Other	Inertia	Screenshots	Freehand drawing

Figure 18. An overview of the features that were implemented in the interactive design example.

5. DESIGN TACTICS: KNOWLEDGE CONTRIBUTION

The program, as of now, is about designing for sketching to support concept exploration and is grounded in that explorative sketching works in idiomatic design situations. Engagements have been made through design work in three cases in different domains combining the making of design examples and facilitating explorative co-design workshops with participants. Design examples were used for generative and participative purposes as opposed to using prototypes for testing or evaluation. What is presented here as the knowledge contribution is not an immediate summative version of the included publications, but rather a reinterpretation of the included works with additional reflection and analysis of the whole. Some insights have been extracted from empirical setups while others are “merely” the result from my own reflections-on-actions. I have also highlighted some “failed”

design attempts that gave me insights into what does not work. Failures usually do not feature in published research, but they do carry learnings and I have drawn insights from making and figuring out why they did not succeed that well.

With my current optics I have taken a snapshot of takeaways and formulated them as three *design tactics*. I have chosen to call them design tactics as opposed to the more familiar term design guidelines, because to me guidelines means something that has been repeatedly fine-tuned and validated to give an expected result, like a recipe. Design tactics is what can be elicited from experimental work, and a design tactic can turn into a design guideline over time with numerous engagements supporting the desirable outcome. Also, by using the word tactic I want to emphasize their relation to the overarching strategy, which is how to design sketching to support concept exploration. The tactics could work based on practical experiments and reflections, but like any other strategy, simply following the tactics does not always guarantee an expected or planned outcome.

So, based on the lessons learned through my various engagements in the cases so far, I have started articulating how sketching could be like to support concept exploration. The three design tactics are: 1) be responsive, 2) emulate salient material properties, and 3) be lightweight. The first two design tactics are very closely related, but there are some distinctions that make it interesting to discuss them separately. The first design tactic, be responsive, focuses on shortening the back-talk loop regarding time and response, while the second design tactic, emulate salient material properties, focuses on the importance of enabling distinctive material properties to have

that backtalk with. In the next three subchapters I describe and reflect on each design tactic and connect them to examples found elsewhere both in academia and industry.

5.1 Be responsive: design tactic one

Interaction design is temporal, which means it unfolds over time. It is hard to simply imagine how an interaction will unfold and be experienced. Thus, when we are sketching possible experiences it becomes valuable to be able to engage in the interaction and get some sort of feedback in order to explore its complexity. One way to do that is through engaging with responsive real-time externalizations (Löwgren, 2015). It has been pointed out previously that interacting with externalizations helps the thinking process; the backtalk from the externalization helps in finding the next step in the explorative process (Kirsh, 2010). The first design tactic is about shortening the distance between input and output to make the feedback loop more direct and immediate, in other words enabling the sketching medium to *be responsive*.

In their daily work, air traffic controllers rely on radar displays to see the current positions of aircraft. What is visible on the display is the separation in space at any given moment. However, it is the separation in *time* that is more important in

Figure 19. Dragging a ghost-of-the-future automatically triggers the response from the system to show planned movement of the other ghosts-of-the-future.

order to know when to make those turns efficiently while still maintaining the minimum separation for safety reasons. Air traffic controllers manage to do it quite well by using their eyes to gauge the distance and make judgements based on years of accumulated experience. In the interactive design example made for the airspace case (see chapter 4.3), the route of an aircraft can be manipulated by dragging its ghost-of-the-future. Doing so simultaneously triggers the planned movement of all the other aircraft's ghost-of-the-future, moves the timeline forward and unfolds possible future traffic changes (figure 19). It is an example of a responsive real-time externalization that evokes an immediate backtalk from the system. Making future scenarios visible and tangible for manipulation seemed to facilitate exploration of alternative paths. During co-design workshops with air traffic controllers

I could see that the air traffic controllers readjusted the route while they were sketching as they saw how other aircraft's ghosts-of-the-future moved (Tran Luciani, Löwgren, & Lundberg, in press). This is an example of being responsive in the sense that the sketching moves literally yield backtalk that help the air traffic controller make progress in sketching the route.

With the interactive design example we made it possible for air traffic controllers to use a stylus to explicitly draw the routes and externalize the imagined routes, which otherwise are only kept as mental images inside the air traffic controllers' own heads. Using a stylus is a more direct and immediate way of interacting than using a computer mouse to control a cursor on the screen, which separates the input and output by physical distance. By drawing the routes the air traffic controllers' intentions and plans are also fed into the system, which makes it possible for the system to respond to and potentially learn from them (Tran Luciani, Lindvall, & Löwgren, 2018). The system can respond to the input by continuously updating the drawing surface and providing instant visual feedback depending on the stylus input and other external factors, such as changing weather conditions. This collaborative act between the air traffic controller and the system could be a way for the system to guide the air traffic controller towards preferable routes in a non-intrusive manner (Tran Luciani, Löwgren, & Lundberg, in press).

We explored visual inertia as a way for the system to guide in a non-intrusive manner. If an aircraft is directed towards an obstacle, such as a thundercloud, visual inertia is triggered. That means that the ghost-of-the-future will start lagging

Figure 20. Screenshots from an animation-based sketch of when visual inertia is triggered as an aircraft is being directed towards an obstacle. Despite the resistance, the aircraft will nonetheless follow the direction of the stylus, more or less.

behind the stylus and show increasing resistance the closer it is being pulled towards the obstacle. I discovered afterwards that others have done experimental work on optically simulated haptic feedback, which has shown promising potential and even performed better than real haptic feedback in some conditions (van Mensvoort, Hermes, & van Montfort, 2008). The way the system is giving feedback through the visual inertia is showing guidance through responsiveness. The system is hinting that this may not be an optimal path, but the air traffic controller can still force through the obstacle and lead the aircraft through the thundercloud if one chooses to do so (figure 20), which they did during co-design workshops. This is a way of loosening up on the control without making the air traffic controller lose control over the aircraft. It could be a non-intrusive way of giving guidance to nudge towards exploring other alternatives.

Another feature in the interactive design example was the circle that marks a point to indicate risk of possible collision (figure 21). During the workshops I noticed a difference in behavior between how the air traffic controllers chose to act when they

Figure 21. Transparent circles are used to indicate collision risk to avoid occluding the surroundings on the radar display.

encountered visual inertia compared to the collision circles. As soon as air traffic controllers created a route that prompted circles that marked risk of collision, they would redraw the route until there was no circle alerting risk for collision. However, in many instances despite the obvious resistance from the visual inertia, air traffic controllers would push ahead and continue with the aircraft lagging behind. It seems to be possible to establish a variation in the strength of enforcement by differentiating ways of being responsive.

The interactive design example from the airspace with automation case had a feature that could capture screenshots of what was currently showing on the screen. The screenshots are static images and they are automatically saved to a folder on the computer. The screenshots were not integrated into the

experience of using the design example and the screenshots were not accessible for real-time refinements. That might explain why they were never used as a means to explore by the air traffic controllers during the co-design workshops, even though they know about the functionality and where the screenshots could be found. However, air traffic controllers suggested that these screenshots could be useful as reference aids during debriefing with colleagues after a work shift (Tran Luciani, Löwgren, & Lundberg, in press). This feature with the static screenshot images turned out as an example of *not* being responsive, and perhaps that was a reason why it did not support concept exploration.

In the fulldome case (see chapter 4.1), local fulldome productions in the Norrköping Visualization Center were created using software that requires programming skills and a physical connection to a fulldome in order to view the rendered projection. I found that these requirements prevent a sketching approach and make it difficult for designers to get an understanding of how objects placed on a fisheye are translated into the shape of a fulldome (Tran Luciani & Lundberg, 2016). A recurrent theme among the different design examples I created was to get real-time projection while sketching. In a co-design workshop, local designers got to try out some interactive design examples. They all expressed with relief how great it was to get this immediate feedback from laying down a pen stroke and seeing it projected in its intended shape (figure 22). By being responsive and enable instant rendering of the pen strokes gave the designers a way to quickly figure out the relations between the fisheye and the rendered projection.

Figure 22. Designers sketching on a fisheye on a flat screen and seeing the immediate real-time projection on a fulldome model on the screen (left), in a 1:1 scaled fulldome model in virtual reality (middle), and in the actual fulldome theater surface (right).

When students were introduced to the equirectangular coordinate system in the virtual reality case (see chapter 4.2), they were initially excited about the possibility of using familiar tools such as pencil and paper to “sketch” a virtual reality concept. However, they soon discovered that it requires mental exercise in translating the drawn strokes to the actual format of virtual reality or using a rendering tool, which breaks the immediate feedback loop that is necessary for a quick sketchy approach. This was probably why some students preferred using Storyboard VR with placeholder assets to bodystorm in virtual reality (Vistisen et al., 2019). With Storyboard VR they got a rough, but immediate sense of the experience.

To summarize, in non-idiomatic situations or for novice sketchers, it seems to be advantageous for the sketch to be more responsive and “talkative” in nature in order to speak back immediately in real-time. It should be responsive in the sense that the sketching moves yield backtalk that help with exploring the concept to make progress, like as if you are

sculpting something that is immediately reactive and directly changeable. It goes in line with the concept of pliability that describes the “tight coupling between action and outcome, a pseudo-tactile sense of manipulating a malleable digital material” (Löwgren, 2007). This quality is also exemplified in a seminal demonstration by Victor (2012) of a coding environment that enabled fine-grained interactions with temporal features in code that was tightly coupled with direct visual output on the same screen. It enabled tweaking of pacing as well as experimentation with the extremes of effects. The tweaking is not just about fine-tuning for perfection, but rather quick exploration of different alternatives. To be responsive is about reducing the distance between input and output both when it comes to time and effect.

5.2 Emulate salient material properties: design tactic two

The previous design tactic was about shortening the distance in latency and granularity of feedback between the act of sketching and the sketch, emphasizing the importance of sketching to be responsive. Now let us continue this line of thought to discuss *how* it needs to be responsive. It is not enough for the sketch to be talkative and speak back, but what it says and how it says it is just as important. Design tactic two focuses on the material properties and points out that not all properties need to be expressed in the sketching media, however, it is essential to *emulate salient material properties*.

In the fulldome case (chapter 4.1), the real-time projection enabled designers to immediately see how the strokes on the flat sketch became warped onto a curved dome-shaped surface. The immediate projection on the intended shape, or even on the actual surface, helped the designers get a sense of the translation of strokes from a flat format to the fulldome format. The shape is one of its salient material properties that makes the fulldome unique and unfamiliar compared to a traditional flat and rectangular screen. It is these types of salient material properties that need to be emulated in the sketching medium in order to support concept exploration.

One design example I made for the fulldome case came from me being critical about introducing the fisheye format as an additional unfamiliar variable in the process of sketching fulldome productions. I wondered what would happen if the input and output was flipped and it was somehow possible for designers to sketch inside a fulldome model and get a fisheye image rendered in real-time. I made a crude animation-based stop-motion using what I had available in my immediate surrounding at my kitchen table, which also serves as my work area when I work from home (figure 23). This example elicited positive response from designers and made me decide to continue along the line of enabling sketching directly in this unique shape, which is a salient material property of a fulldome. The design example that followed focused on sketching in virtual reality for a fulldome.

Figure 23. A still-frame from the animation-based sketch of drawing strokes inside a fulldome model and having the flat fisheye image projected on a separate screen.

When designers were able to sketch directly in virtual reality inside a virtual fulldome they explored the “sweet spot” for the actual design concept for a fulldome production. A salient quality of a fulldome production is that it is not streamlined like a regular video production. Each person in the audience of a fulldome can choose to look at different places inside the immersive projection space, so the format becomes fluid and unique for each person in the audience. This puts a bigger responsibility on the production to design for attention while using the peripheral space for ambience. In order to do so the field-of-view needs to be experienced. This gave me the idea to incorporate seating in the virtual space. With this it becomes possible to take into account the different views the audience might have based on the seating and see the sketch through

the audience's eyes and reducing the distance between intention (input) and effect (output).

In the virtual reality case (see chapter 4.2) one of the techniques the students got to try out was the equirectangular coordinate system printed on paper. While it did let the students draw using familiar tools such as pen and paper, the format is different, just like how the fisheye format for the fulldome is different. To get a straight horizontal line anywhere else but on the horizon of an equirectangular coordinate system, you have to draw a curve. It is difficult to figure out the perspectives and a student exclaimed that she had “wasted a day” trying to understand the equirectangular grid, but still did not manage to get the perspectives right in order to use it for sketching. The fact that you have to invest time in learning a tool in order to use it as a sketching tool is a challenge worth mentioning, but for now this example points out a translation gap between the sketching medium and the output. It required some mental work to translate the flat and distorted equirectangular image into a 360-degree immersive experience, similar to the fulldome case with the fisheye coordinate system. The gap was too wide to be bridged entirely in the head of the student. It was not until the students could view their sketches in virtual reality or sketched directly inside virtual reality with the help of the app Tilt Brush that the placement and sizing of assets could be explored. Tilt Brush was constrained to one room and for some of the students' concepts it was enough to sketch for placement and sizing. One of the students, who had spent a lot of time imagining and planning with physical material by laying out paper on the floor, realized when she used Storyboard VR that showing detailed data visualization information on the floor was

distracting. It was not conducive to natural head movements because of the limited field-of-view in a head-mounted display. These examples are contradictory to what has been repeatedly found in studies on sketching graphical user interfaces where designers preferred to sketch freehand before moving into digital sketching, where they would add the details (Gross & Do, 1996). Sketching for non-idiomatic situations, such as virtual reality, seemed to not follow the same progressive process where the unfamiliar aspects are not easily translatable from the paper sketch and the experience is difficult to imagine for non-expert sketchers. This illustrates a difference between idiomatic and non-idiomatic design situations.

In the airspace with automation case (see chapter 4.3), the ghosts-of-the-future was my attempt at emulating the salient material property of time. By making it possible for air traffic controllers to sketch with time, future traffic scenarios could be explored, which was noted during the co-design workshop with air traffic controllers (Tran Luciani, Löwgren, & Lundberg, in press). Changing weather conditions, such as wind is another important factor to take into account when air traffic controllers direct moving aircraft. The wind affects the aircraft's ground speed, which is the speed relative to the ground. An aircraft with a tail wind will have an increased ground speed compared to an aircraft keeping the same speed with a head wind, which causes it to have a lower ground speed (table 1). Strong crosswind is notorious for its ability to cause dangerous situations (Fujita & Caracena, 1977). The strength and direction of wind can change on short notice, sometimes requiring quick adjustments to the flight paths. In current systems, weather information is shown on a separate display.

No wind:	Ground speed = speed of the aircraft
Head wind:	Ground speed = speed of the aircraft - wind speed
Tail wind:	Ground speed = speed of the aircraft + wind speed

Table 1. Wind affects ground speed of an aircraft depending on the direction of the wind in relation to the aircraft.

This means that it is up to the air traffic controller to stay up to date on changing weather conditions and make a prediction of its effects on the current traffic situation.

I saw an opportunity to make wind more tangible and intertwined in the sketching experience. My experimental attempts were not integrated into the interactive design example. They were being explored as separate interactive work-in-progress concepts on the side because they were not fleshed out enough to be included in the interactive design example yet. In one of the interactive work-in-progress concepts, the wind was implemented to affect the visual inertia reflecting the real change in ground speed. Head wind caused an increase in the visual inertia, while tail wind caused the ghost-of-the-future to gain speed and pull away in front of the

stylus. Informal feedback from air traffic controllers showed that this kind of interaction could be perceived as “buggy” because sometimes the ghost-of-the-future would lag behind, and sometimes it would race ahead of the stylus. This change in behavior could happen in the act of a single stroke making it confusing. I concluded that this work-in-progress concept was disruptive rather than helpful in sketching routes. It was a reminder that simply emulating a salient material property as closely to reality as possible is not always better, and further experimentation in finding an appropriate way of emulating wind is needed.

Another salient material property within airspace planning is altitude. Air traffic controllers often use vertical separation in order to maintain the minimum separation in distance between aircraft. On the radar display a number is shown next to each aircraft representing its current altitude. An arrow either pointing up or down indicates current ascent or descent. It might seem like a natural improvement to implement three-dimensional perspective views on the flat radar display to make altitude more visible. Attempts have been made and introduced to air traffic management systems, however, studies have shown that two-dimensional perspective views are preferred for judging relative positions between objects (St, John, Cowen, Smallman, & Oonk, 2001). The reason is because a two-dimensional perspective view is clear in terms of what it presents, while a three-dimensional perspective view adds an ambiguous mapping because of the viewing angle (figure 24). This is an example that emphasizes that literal emulation of a salient property is not always the right way to go. In addition, it has been pointed out that studies that have found benefits with three-dimensional perspective views might

Figure 24. A comparison of ambiguity between two-dimensional perspective views and three-dimensional perspective views based on an illustration found in Smallman et al. (2001, p. 52). With a two-dimensional perspective x and y are clear while z is ambiguous. With a three-dimensional perspective view x , y , and z are all ambiguous.

not have been because of the format, but rather due to information availability in the actual interface design (Smallman, John, Oonk, & Cowen, 2001).

I tried another approach to make the change in altitude visible at a glance without adding another dimension and at the same time reduce clutter. I decided to incorporate altitude information into the actual path of the route by using varying sizes of the circles to indicate change in altitude (figure 25). This concept was not appreciated, and it received an unanimously negative response from all air traffic controllers who tried it. The main reason was that it was perceived as messy – so I failed at reducing clutter. Another reason was that the sizing was not precise enough – a number is very exact. The air traffic controllers also said specifically that they missed

Figure 25. A concept of visualizing altitude changes using varying sizes of circles on the actual path.

the numbers. This turnout does not mean that they do not want anything else. It just means that the numbers are their preferred alternative amongst the ones they have experienced so far. I still think altitude changes can be externalized in a way that can give information at a glance. My specific example just shows that this was not the way to do it.

Another example that emulated salient material properties is Sketchflow, which I worked with in various projects when I got employed at Microsoft in 2009. Sketchflow was a dynamic prototyping tool for interaction designers to explore animation and interaction for early designs of applications. Sketchflow was part of Expression Blend, which was a complementary tool integrated with the mainstream development tool Visual Studio. This was seen as an advantage, because it meant that designers could sketch in Sketchflow and developers could augment the sketches with functionality to bring them to life. The same project file could be opened in either Expression Blend or Visual Studio. It was even possible to have the project opened in both programs at the same time, switch between the

two depending on the task, and the project would stay in sync. Sketchflow had a short distance to the production material with respect to the aspects that were in focus, i.e. it emulated the salient material properties animation and interaction.

To summarize, per definition, a sketch does not need to be rich in all aspects and have all the properties of the final artifact. The design tactic to *emulate salient material properties* emphasizes that it is the unique, and perhaps non-idiomatic, that is necessary to emulate in order to enable sketching. Other properties that are familiar can remain unexpressed or inexact. This goes in line with how designers within the car industry often make full-scale mockups using solid materials in order to explore and communicate the complex three-dimensional shape of the vehicle (Cross, 1990). The full-scale mockup of the car is usually made in clay to explore the conceptual aesthetic design such as the angles and shape. By taping on the full-scale mockup, the designers can get the lines correct by making sure the tape does not end up with unwanted creases. It is not always a direct emulation of all properties that enables a sketching approach. Finding an appropriate way to emulate the salient material properties might need some experimenting to avoid being too literal while still being precise enough.

5.3 Be lightweight: design tactic three

The previous design tactic was about emulating salient material properties more closely in order to support sketching for non-experts or in non-idiomatic situations. It might be vital to point out that it is not desirable to strive for emulating all material properties. The emulation must be carefully and selectively limited in order to avoid resulting in a tool for making things that are too detailed and production ready. That would be counterproductive to sketching. This leads us to the third design tactic; *be lightweight*, to highlight the actual experiential quality of a sketching approach for concept exploration. However, lightweight can mean different things.

For the interactive design example in the airspace with automation case (see chapter 4.3) I chose to have a stylus as the input device. It allows for a more fine-grained interaction of direct manipulation, while at the same time being less exact than typing in a specific number to direct the degree of turning of aircraft, for example. Sketching is not about expressing the details; it does not have to be precise. By intentionally leaving out details and concentrating on the larger strokes, you might say that being lightweight can mean to be unprecise. A stylus is also more inviting to a “doodling” approach compared to using a computer mouse to control a cursor, which is the common input device used in current air control systems for exactness. During a co-design workshop session an air traffic controller was obviously doodling and making wiggly and

Figure 26. Still-frames from a recording of a co-design workshop session with an air traffic controller who was doodling with the stylus.

swirly routes after completing the task of steering aircraft away from nearby obstacles (figure 26).

To doodle is to set the mind free from expectations and just see what happens. It is more like a side-activity without any clear intentions, as opposed to trying to externalize or convey a concept that already exists inside your head. There might be parallels between doodling and serendipitous discoveries. Doodling is sort of a playful, non-meticulous way of exploratory sketching and could lead to stumbling upon these serendipitous discoveries or “happy accidents”. Others have criticized computer aided design tools for not supporting doodling and thus hindering serendipitous discoveries (Bilda & Demirkan, 2003). I think it might be because many digital tools tend to be advanced and require full attention to operate, which contradicts mindless doodling that you do to keep your hands busy, for example while you are talking on the phone.

In the virtual reality case (see chapter 4.2), one of the students was working on a VR experience trying to convey what discrimination in everyday life can be like for minorities. The concept was to emulate the sense of unjustified surveillance from other people in public spaces, which would cause a feeling of being constantly observed and “trapped”. While the student was sketching on her concept in the VR app Storyboard VR, she kept moving outside the boundaries of the physical virtual reality space which would prompt a grid to show up in the head-mounted display to indicate the limitations. It caused frustration because she felt the grid kept interrupting her while she was trying to sketch. She continued using Storyboard VR despite this annoyance when she suddenly realized that she could use this grid in her own concept to recreate this feeling of frustration. So, the sense of being “trapped” in a socially stressful situation in public spaces was symbolized with an actual cage, which caused frustration in the virtual reality experience (figure 27). This is a wonderful illustration of serendipitous discovery through sketching, which was prompted by a specific property in Storyboard VR. The grid was of course not implemented with the intention to promote this type of discovery; it was just a usability feature meant to signal the boundaries of the virtual reality space. The student encountering it happened to have the mindset to turn her initial frustration into a serendipitous discovery.

Figure 27. The grid in Storyboard VR unexpectedly became part of the concept for this virtual reality experience to show discrimination. The grid was a cage to symbolize the feeling of being trapped and observed in public spaces, for example in the park or at a supermarket. (Screenshots from a virtual reality concept video by Meike Remiger used with permission.)

Figure 28. Dragging an aircraft pulls out its ghost-of-the-future, which looks like a lightweight shadow of the aircraft and very distinguishable from the representation of the actual position of the aircraft.

Another aspect of being lightweight is to make an obvious distinction between the tentative sketch and the intended solution. Different tools give different impressions of permanence in the marks they make. It is no wonder that a hand-drawn sketch is usually made in pencil or coal rather than in acrylic paint. Rough marks made with pencil or coal are more tentative in nature, or more lightweight. An example of this type of lightweightness can be found in how the future positions of aircraft are visualized as ghosts-of-the-future in the design example made for the airspace with automation case. The ghosts-of-the-future are represented as shadows of each aircraft making it visually obvious that they are just possible future scenarios and not actual real-time representations (figure 28). This distinction was made to encourage air traffic controllers to interact with the ghosts-of-the-future to explore alternative paths for the aircraft before committing to a decision.

While Sketchflow was not lightweight when it came to functionality, it was lightweight in the visual appearance. In SketchFlow the visual look of the components is made to resemble hand-drawn sketches with their wiggly lines giving

Figure 29. The visual style of the components in Sketchflow in Expression Blend was “sketchy” to make it obvious that it was a sketch despite it being interactive and possibly fully functional. (The fonts were said to be based on Bill Buxton’s handwriting.)

it a more playful appearance (figure 29). The “sketchy” look encourages a more explorative approach when using the tool by steering away from focusing on finalizing the visual details. This type of sketch also helped steer conversations with stakeholders towards discussing the interactions and flow rather than tweaking colors or pixel-perfect alignments. Others have also used rough sketches to present early concepts to avoid stakeholders getting distracted by details or mistaking it for a final design (Lin, Newman, Hong, & Landay, 2000; Wong, 1992). In a similar manner the graphics for the

interactive design example in the airspace with automation case was intentionally left very sparse to emphasize that the focus was on the interaction and not the user interface design. Thus, being lightweight does not mean it has to be inferior in all its features. Both SketchFlow and the interactive design example made for the airspace with automation case are very rich in functionality, but the visual style is lightweight.

“If you want to get the most out of a sketch, you need to leave big enough holes” (Buxton, 2010, p. 115). “Leaving holes” as in literally leaving gaps or empty spaces in the externalization is another way of slimming down and making it more lightweight by being abstract. Sketching leaves out unimportant details (Black, 1990) and thereby welcomes alternative readings of the sketch. By being ambiguous a sketch can spark different interpretations of it. Most of us are probably familiar with the common components that usually make up a traditional playground. It has swings, a slide, and maybe some monkey bars. Each part is self-explanatory in how to play with it. Children swing on the swings, slide down the slide and hang on the monkey bars. The architect and sculpture artist Isamu Noguchi reacted to these constructions that sort of constricted the forms of play that took place. To counter it he created a concept called Play Mountain, which is more like a giant abstract landscape sculpture. It had no obvious instructions on how to play there and he envisioned that the abstract forms would be more inviting to open free play where children’s imagination could find creative ways of playing. While his concepts were dismissed in the early 1930s, we are seeing more of these types of playgrounds in contemporary areas. With this said, thinking of lightweight as a form of abstraction can invite different readings and

interpretations. I tried to incorporate this into the interactive design example made in the airspace with automation case. One of the features was the ability to place out obstacles to interact with. In addition to thunder clouds, other obstacles where in the shape of a triangle, square, or freeform area. The size and rotation of the obstacle could be modified, and it was an attempt to give freedom in using these shapes to symbolize anything meaningful. I did not notice any air traffic controllers making use of these more abstract obstacles during the co-design workshop sessions, but they did mention the possibility of using the freeform area feature to mark out a no-fly-zone.

In their current display systems, air traffic controllers get various alerts and warnings that compete for their limited attention. To reduce the complexity and graphical clutter I introduced the concept of visual inertia to inform about less desirable routes. It is triggered when an aircraft is being directed towards an obstacle and makes the aircraft drag behind the stylus. Visual inertia is just an alternative label for lag, which is usually met with annoyance and is unwanted. However, in this context visual inertia felt novel. When an air traffic controller first discovered the feature, he giggled and exclaimed “yes, that was pretty funny!”. The visceral pleasure of feeling simulated haptics was experienced as something playful and surprising, but easy to grasp. Visual inertia was a way to be lightweight in order to counteract the visual complexity, but it also provided a more playful, lightweight, experience.

I noticed the importance of being lightweight, as in playful, in a previous collaboration described elsewhere about a workshop involving self-proclaimed novice sketchers (Tran Luciani &

Figure 30. Participants in the middle of animation-based sketching during a workshop. Analogue materials and lightboxes were used to make stop-motion images as assets, which were later imported to Adobe Premiere to create the animations with additional effects.

Vistisen, 2017). The participants explored early concepts in an unfamiliar situation using different types of sketching tools and techniques. In the workshop, the participants were making animation-based stop-motions using analogue and digital tools and techniques. In the first stage they created assets for the stop-motion by cutting out hand-drawn images, which they arranged in a lightbox and took photos using their cellphones (figure 30). This part of the process was very playful in nature and participants approached the task with a sketching mindset; the created props were discarded and replaced as the participants explored different ideas. It all took a different turn as soon as they imported the assets into Adobe Premiere to put together the animation-based stop-motion.

This part of the process was meant for sketching the temporal aspects of the concepts. However, the unfamiliar software created friction so the participants were not able to use it as a sketching tool. Adobe Premiere is not intended for this kind of sketching approach and its interface presents many advanced editing features that are not relevant in a sketching process even though it does enable temporality to be expressed. We noticed the same challenge in the virtual reality case (see chapter 4.2) with tools that were advanced enough to enable creation of immersive visualizations. They too required a lot of effort to get familiar with and the students felt invested in the “sketches” they managed to produce. Thus, a tool that produces outcomes in a particular expected medium does not automatically enable explorative sketching for that given medium (Vistisen et al., 2019). In addition, simply introducing a new “sketching” tool can make it more difficult to sketch because it is necessary to master the tool before you can sketch with it freely. However, a new tool or technique that has the perception of being lightweight can invite a more playful attitude to “learn as you go along”, like with creating the assets for the stop-motion.

A common definition of sketching is that it is lightweight in the sense that the activity produces many disposable sketches (Buxton, 2010; Goel, 1995). Sketching on paper easily results in many sketches because the material is inexpensive. It is more convenient to make changes on a new piece of paper rather than trying to edit the drawn lines already made on an existing paper sketch. Using digital sketching media, erasing is usually as quick as pushing an undo-button and it leaves no messy traces. Exploring and editing while sketching in digital media is less traceable and might look like just fine-tuning details

although it is not. Quantitative sketching in digital material can be deceptive if you base the quantity on just the number of produced, as in manually saved, digital sketches. When rapid real-time refinements are being made with the purpose of exploring the different options, many digital sketches are being produced. They are just instantaneously being replaced and previous ones are therefore disposed in a fast-paced manner and not visible anymore. I noticed this when air traffic controllers were sketching with the interactive design example. Using a timeline the air traffic controllers could go back and forth in time to see how their actions affected the outcome and see the changes unfold. The air traffic controllers used this feature to backtrack their changes, almost like a rewind-button, but it only supported capturing the latest “sketch”. When changes happen instantaneously it can be easy to forget previously explored states. A way to incorporate states could be to make previously drawn routes visible and then make them fade over time, as the concept of leaving traces described elsewhere (Tran Luciani et al., 2018). Another idea not implemented could be to show traces of historical data from other aircraft flying similar routes. These lightly visible historical traces could act as guides or inspiration, as if the air traffic controller was to ink a pencil sketch, or rather an opportunity to read and reflect on the variations. However, it should be taken into account that the air traffic controllers were more inclined to make instant changes using the stylus in the interactive design example, than sketching routes using pencil on paper printouts during the earlier workshop sessions. The resistance to use those analogue tools might have been because they leave behind messy pencil mark traces. Air traffic controllers are very sensitive to clutter, which might speak against overlaying layers of historical routes.

To summarize, to *be lightweight* highlights the importance of not emulating all material properties, but intentionally leaving some gaps in order to support a sketching approach. Lightweight can mean different things. It can mean to design for lightweight sketching as in mindless, unprecise doodling and being playful to open up for serendipitous discoveries. It can also mean designing to work with lightweight sketches as being abstract and have a clear distinction from the final artifact to welcome different readings and interpretations. It can also mean designing for inexpensive and tentative sketching of many possible variations. All these different manifestations of being lightweight serve to promote a carefree approach to sketching in order to support concept exploration.

6. CONCLUSION AND DISCUSSION

This thesis is a snapshot of the takeaways abstracted at the time it was written, and I have formulated three design tactics. The three design tactics are: 1) be responsive, 2) emulate salient material properties, and 3) be lightweight. The first design tactic emphasizes the need for sketching to speak back. However, it is not enough to just be talkative, but it is equally important to pinpoint what should be said and how. That leads to the second design tactic, which highlights the need to *emulate salient material properties*. The third design tactic points out that everything should not be emulated, and it is necessary to leave room for gaps. Thus, it is desirable to *be lightweight* in order to support a sketching approach.

I do not intend these design tactics to be prescriptive, but rather more of a way to think about how sketching could be like to support concept exploration, especially for non-experts and in non-idiomatic situations. Hopefully, when someone wants to learn about it, they will have a glance at this work.

6.1 About method

I have mainly been designing and making things on my own, especially in the beginning where I perhaps could have benefited the most from collaborations. In a more optimal setting, I would have been part of a larger team of peers working on the cases and everyone would contribute with different skillsets. Having more manpower could mean the possibility of making more complex (or just more variations of) things. As a designer-researcher there are challenges that come with having multiple roles. As a designer I imagine and create things, and as a researcher I need to document and reflect on the process and the results. This requires a balance. Another aspect that also requires divided attention is that I have been working on different cases with different external funding running in parallel. Each case has different stakeholders in different domains. It all adds to the complexity. It has been a challenge to align stakeholders' expectations and manage the separate cases to make progress in all of them. Not only do I need to focus on making progress in the individual cases that is satisfactory to stakeholders due to external funding, but I also need to keep in mind my own research goal, which each case should contribute to. I did not

personally select the three cases described in this thesis. I did, however, (re)define their scope and continued to align them with my research interest that drifted into designing for sketching to support concept exploration. If I had had the luxury to define my own cases, I would probably have chosen to only take one step outside what is already well-known in literature and worked solely with designers in non-idiomatic situations. It would have made the scope more focused. On the other hand, you could also say more limited. By venturing outside the conventional design situations, I found an interesting and still fairly unexplored area that deals with non-designers that might also benefit from a sketching approach. Just like how “design thinking” has gotten attention outside the immediate field of design, perhaps the sketching mindset and skillset is useful to non-designers as well.

As a result of using a constructive design research method my knowledge contribution takes the form of the design examples along with reflections. They are presented in this thesis mainly in the form of abstracted intermediate-level knowledge contribution as three design tactics. I suggest this work to be evaluated based on the criteria suitable for this type of knowledge, which are *contestable*, *defensible*, and *substantive* defined as the following:

“Contestable means that the contribution proposes a position that not everyone in the academic community already believes. Defensible means that members of the community can accept the new position, given the arguments or evidence given. Finally, a substantive contribution is one that is worth the time and effort of the

researcher making it and community members engaging with it.” (Höök & Löwgren, 2012, p. 8)

The takeaways are contestable in the sense that it is new knowledge about areas that have not been well-documented in existing literature, which was covered in chapter 2.2. It goes beyond concept exploration within the idiomatic and expert sketchers.

I hope this work is defensible, or trustworthy, in the way the content of this thesis has been presented. Beck and Stolterman (2016) point out the differences in knowledge claims made in design research compared to other more established research areas, for example in natural sciences or social sciences. In design research claims are usually not used in order to discover a unified truth about one possible future, instead they can point to many different possible futures. This kind of knowledge contribution may not be reproduced simply by following the same methodological steps. Some might look at this as lack of evidence or proof to ground the knowledge claims, but the claims are instead grounded in design judgement.

“Judgement is a form of decision-making that is not dependent on rules of logic found within rational systems of inquiry. Judgement, however, is not irrational because it follows its own form of dialectic. In lieu of judgement being founded on strict rules of reasoning, it is more likely to be dependent on the accumulation of experienced consequences of choices made in complex situations. Learning to make good judgements is therefore not a

matter of learning to follow the steps of a technique, or to follow directions dictated by a method or algorithm, or to impose the a priori constraints of a theory". (Nelson & Stolterman, 2003, p. 24).

My intentions have been to present the provisional takeaways in a structured and transparent way, so that they can be traced back through the insights to the work done in the cases. It is an attempt to explain the reasoning behind my design judgements. By creating something new and introducing it to stakeholders, the potential usage can be studied using more traditional analytical methods, such as data sorting of transcripts from co-design workshops. In order to create something new that could be "studied", I had to implement the unconventional interaction designs so they could be experienced. I call this code-sketching and it enabled me to explore possible futures through a making process that was essential in order to figure out the interaction design features. It also made the making more transparent and enabled me to invite others into the process. I think code-sketching is a concrete example of how one can do explorative work in interaction design. For me it turned out to be of essence and I will therefore discuss it further in detail in the next section.

For a knowledge contribution to be substantive it has to be valuable for fellow designer-researchers within the field. What is valuable in imagining alternative possible futures is inspiration that exemplifies *how*. Through experimental work of making concrete design examples, design guidelines can be formulated to offer more prescriptive guidance in design work. Concrete design examples, both successful ones and less successful ones, can in combination with reflection be valuable

knowledge contributions as in being inspirational. Failed attempts can sometimes be greater learning opportunities than successful ones. Therefore, I chose to include some of those design examples as knowledge contribution as well, since I think it is possible to learn from others' mistakes.

Once again I want to emphasize that the purpose of the design examples was to explore possible futures. By imagining possible worlds instead of trying to create incremental improvements of existing systems, the design examples might be more novel and more conducive to spur new ideas. Thus, a way to evaluate how substantive this contribution is could be to determine its generativity. It is a tricky one, since it requires an *a posteriori* assessment of the influence, so only the future can tell whether something really was generative. However, there are other indications that something is substantive, with one being that it is accepted for publications and exposure in various academic journals and gatherings. This means that at least some of the experienced researchers in the field are able to make a judgement whether a contribution is worth the attention of others within the community.

6.2 A note on code-sketching

There are various forms of knowledge contributions that can be elicited from a constructive design research. One thing that has not yet been highlighted, but was a very profound insight during the making process, was the importance of sketching

with code. I call it *code-sketching*. Code-sketching turned out to be necessary for me to do explorative work and I would like to take a moment to elaborate on this note.

In the airspace with automation case, I was working on a future system for air traffic controllers to enable a different way of collaborating more continuously and closely with automation. The main concept during a certain phase of the design process was to enable directing aircraft through collaborative drawing. Using a stylus, the air traffic controller would be able to draw routes on a touch-sensitive surface overlaying a radar display and get guidance through continuous feedback from the system. I needed to explore this concept in order to grasp its qualities and potential.

The conceptual work started with imagining different examples of interaction in different types of scenarios. I explored early ideas through hand-drawn sketches and selected potential ones that I turned into more presentable illustrations to be used in communication with others. However, I found some of the static illustrations insufficient, for example the illustration of the interaction concept of visual inertia. When an aircraft is directed towards an obstacle, visual inertia is meant to be triggered and make the aircraft reject the pull and thereby guide the air traffic controller towards a more preferred direction. The air traffic controller would experience visual inertia for example when an aircraft is being directed too close towards another vehicle, towards a thunder cloud or in the opposite direction of a strong wind. I made simple animation-based sketches (Vistisen, 2016) that could fill in the gaps of pacing and explain how the concept would work more

Figure 31: Screenshots of an animation-based sketch showing the concept of visual inertia. The aircraft is showing some resistance to be directed too close to a thunder cloud.

clearly (figure 31). The animation-based sketches worked as a way to communicate the concept but was not enough for me to explore what it would feel like to interact with the system using a stylus. I decided to start code-sketching.

I quickly realized that I had to act as a developer and a designer, and also needed time to reflect and document the process as a researcher. I made the decision to team up with a research engineer with strong programming skills to allow myself to focus on being “only” a design-researcher. We used Git as our version control system to manage the code and to facilitate our collaboration over distance. In close collaboration, but from afar, we continuously made changes to the different concepts as they were implemented and could be experienced. The code branched out. Some branches were left behind while others were cloned and tweaked into new variations. Everything evolved like the roots of a plant and it was messy, just like it should be in the early explorative phase of a designerly process. It went against the professionalism of the developer to not engage in restructuring the code and optimizing for performance, but we established a common

ground for this project to leave things as they were as soon as they were functional. The code was neither structured nor thoroughly documented in any way. It was just a means to an end; to make it possible to sketch exploratively.

Through the collaboration with the research engineer we implemented visual inertia to explore it further. While we were code-sketching, more questions arose like how strong the visual inertia should be and whether it should be adjusted depending on the distance to the obstacle. How should the aircraft behave if the air traffic controller pulls through a thunder cloud despite the visual inertia and what happens when the stylus has passed through to the other side of the cloud? Will the aircraft still lag behind or catch up with the position of the stylus?

Another concept that was also first expressed through hand-drawn sketches and illustrations was ghosts-of-the-future. It was meant to externalize possible future scenarios by showing “shadows” of future position of the aircraft. It also quickly reached a point where I felt the need to start sketching it in code to explore the closer fine-grained interaction details. An initial idea for ghosts-of-the-future was to play an animation of a possible future scenario as soon as a route for an aircraft had been drawn. In other words, the animation would be triggered immediately when the stylus was lifted from the drawing surface. In order to make changes to the route while drawing, one would have to retrace backwards without lifting the stylus and redraw a new route before lifting and “committing” to see the future scenario being played out. When there were several aircraft to be directed, this meant that the animation would trigger as soon as all aircraft’s routes had

Figure 32. Code-sketching to explore the interaction details for ghosts-of-the-futures. The source code is peeking out behind the application window.

been committed. This was experienced as inconvenient and confusing, so we added a Start-button to control when the animation should be triggered. By having the Start-button, routes could now be edited after the stylus had been lifted by simply redrawing the route, which would immediately replace the previously drawn route. For a while I spent a lot of time tinkering with various ways of editing parts of a route without having to redraw the whole route. One concept was to have the current actual position of the aircraft and its final arrival destination as static points and have curves that you could manipulate by manually adding anchor points. However, I eventually realized that we were trying to implement the functionality of the Pen tool found in Adobe Illustrator, and

it is a feature that most laymen find very difficult to master (and air traffic controllers are not expected to be proficient in Adobe Illustrator). Instead we continued exploring a new branch by adding a time slider, like in common video playback applications. While drawing a route everything would automatically move forward in time and give a preview of how the specific scenario might unfold in the future (figure 32). With this in place, the Start-button became superfluous and could be removed. To edit routes, one would use the time slider to move back to the point where the change should start and redraw from there.

At one specific point in time, selected branches of the code were merged into one interactive design example so the different parts could be experienced as a set. The interface of the design example was intentionally very sparse. It was meant to leave room for interpretation and to make it obvious that this is not something to be evaluated as a proposed system. Four professional air traffic controllers were invited to participate in individual workshop sessions. During the sessions, I noticed that the air traffic controllers were not simply following instructions or evaluating the available features that were introduced to them. For example, at different points during the workshop sessions the air traffic controllers found a way to reset the route they had drawn by tapping on the aircraft. It happened to work because it was the equivalent of drawing a one-pixel path, which would replace the previously drawn path. I had not anticipated the need of “wiping the slate clean”, so I had not thought of a reset feature, but they all found the same way to achieve it and continued doing it. Another interesting thing I noticed during a workshop session was when an air traffic controller was placing

an obstacle and wanted to change its orientation. The function we provided for rotation was to first use the stylus to tap on the position to place the obstacle and then tap again on the side of it to choose which way the obstacle will be facing. This interaction pattern was actually the same for placing and rotating aircraft. We had an alternative idea to change the rotation by holding and dragging the object, but that would have interfered with the actual drawing of a route for an aircraft. However, an air traffic controller tried another way of rotating a placed obstacle; he tried to spin the stylus to see if the obstacle would rotate. I found it interesting and made a note of it for future implementation. I took these observations as signs of how a truly interactive design example seems to draw the user into the interaction and stimulate experimentation.

To conclude, others have pointed out the importance of making in interaction design (Löwgren, 2016). I would like to add that code-sketching is one approach and it is a useful, and sometimes necessary, component for explorative work in interaction design. A designer needs to be familiar with the sketching material in order to use it in an explorative manner. Therefore, to be able to code-sketch requires programming skills. How can you go about code-sketching in a fast-paced explorative manner if you do not happen to be a developer-designer knowing both how to program and design? An obvious way is to collaborate with others who have the skillset you lack or wish to have support in. It is possible to make it work in a constructive process, but I believe it is essential to be a skillful developer, designer, and researcher. If one does not possess all three skills and the ability to shift focus between the different roles, collaboration is key. Successful collaboration is

not guaranteed simply by putting together a skilled developer, a skilled designer, and a skilled researcher. What made the collaboration work in our case was that we immediately embraced a sketching mindset and emphasized that the focus of the coding was to make things work quickly, and not necessarily perfectly. By having a shared goal, it enabled us to code-sketch. Code-sketching itself enabled me to engage in a conversation with the sketch. It also enabled formative assessments and creative participation by the air traffic controllers.

During my research process code-sketching turned out to be necessary for me to do explorative work. It was responsive in the sense that we could experience the non-idiomatic interactions such as visual inertia and ghosts-of-the-future, which prompted further questions about their behaviors that we could continue to explore. It emulated salient material properties that enabled spontaneous creative input from others, for example when an air traffic controller tried to change the rotation of an obstacle by rotating the stylus. It was lightweight in the sense that we kept the code messy and deliberately had the mindset of just making things work and not focus on maximizing performance or defining a robust structure. In other words, code-sketching supported my concept exploration by being responsive, emulating salient material properties, and being lightweight.

6.3 Future work

It is undisputed that designers need to build experiential knowledge about the material they work with. Understanding the (im)material properties of interaction design is not an exception. The material turn (Robles & Wiberg, 2010) within interaction design has been addressed by several design researchers emphasizing the conversational relationship between designer and the material as a way to express and design with them (Arnall, 2014; Hallnäs & Redström, 2006; Löwgren, 2015; Vallgård & Redström, 2007). Some have pointed out the advantage of starting from the material properties to guide the design when working with novel technology (Fernaes & Sundström, 2012). My work in the three cases could possibly be a starting point to develop knowledge about even more specific non-idiomatic materials and their material properties, for example looking at fulldome as a unique material with its salient material properties such as immersion. In the cases described here I have begun to fill the collection and other designer-researchers can continue to evolve this collection and expand it. By growing this catalog, perhaps a pattern will emerge that makes it possible to better understand and even foresee what kinds of salient material properties need to be emulated and be responsive in order to design for sketching.

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Papers

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FACULTY OF SCIENCE AND ENGINEERING

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Dissertation No. 2013, 2019

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