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Perceptive Qualities in Systems of Interactive Products

Eva Deckers

Perceptive Qualities in Systems of Interactive Products

Doctoral Dissertation Eva Deckers

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Perceptive Qualities in Systems of Interactive Products

PROEFSCHRIFT

ter verkrijging van de graad van doctor aan de Technische Universiteit Eindhoven, op gezag van de rector magnificus, prof.dr.ir. C.J. van Duijn, voor een commissie aangewezen door het College voor Promoties in het openbaar te verdedigen op vrijdag 3 mei 2013 om 14.00 uur.

door

Eva Josephina Lambertus Deckers

geboren te Heerlen

Dit proefschrift is goedgekeurd door de promotoren:

prof.dr.ir. C.C.M. Hummels
en
prof.dr.ir. L.M.G. Feijs

Copromotor:
dr.ir. S.A.G. Wensveen

In this first sentence I will once-only renounce my phenomenological position: although you are without a body I can see you seeing me.

In memory of the late prof.dr. Kees Overbeeke, who initiated and gave guidance to this project. Thanks to dr.ir. Pierre Lévy, the daily supervisor in this project, and dr.ir. Rene Ahn who had an important role as expert in this project. Thanks to the committee members, prof.dr. Charles Lenay, dr. John Zimmerman and prof. Ad van Berlo for their consideration.

thank you

Kees,
Je wordt gemist. Vooral op momenten als deze. Het is bijzonder om iemand te kennen die zoveel voor je mogelijk maakt en die zoveel vertrouwen in je heeft. Ik troost mij met de gedachte dat je ook nu zou glimmen van trots.

Stephan,
Haptic Interfaces, RMIT, afstuderen en toen mijn promotieproject. We kennen elkaar ondertussen al een hele tijd. Samen met Kees maakte je het mogelijk dat ik mijn eigen project kon voortzetten. En dan is hij er opeens niet meer. Dank voor je vertrouwen, aandacht en zorg. Niet alleen voor mijn werk, maar vooral voor mij.

Pierre,
I'm sure you are the only one who finds it as funny as I do that Word, after three years, proposes that I might mean: I perceive you perceiving you and me perceive me perceiving you. Thank you for sharing your insights, for all the times we philosophised together about phenomenology and its implications for designing, for your help with more practical issues, for caring.

Rene,
Het is tegelijkertijd jou schuld, als dat ik het aan jou te danken heb dat ik een nerd geworden ben. We zijn een goed team. Waar de een ietwat voorzichtig is, is de ander zichzelf misschien af en toe net een stapje te ver vooruit. Een goede balans om ver te komen!

Caroline,
Soms zijn het hele verdrietige situaties die ervoor zorgen dat mensen elkaar beter leren kennen. Hoe verdrietig en heftig de week ook was, het was ook mooi, bijzonder. Dank voor je vertrouwen, dat je me mijn werk gewoon liet afmaken.

Loe,
Het is ondertussen alweer een hele tijd geleden dat ik bij je kwam met de eerste versie van mijn theoretisch model. Toen, en ook meer recent, was het je rust en scherpte om dingen eens echt goed te bekijken die mijn werk beter maakte.

Colleagues,
We concluded on several occasions that it is really nice when your colleagues are your friends. Next to be blest to work with a very intelligent and fun group of people, I cherish our social gatherings. A wedding in Italy, paella in the sun in Strijp, drinking too much in the Trafalgar, snails for Kees' birthday at the Usine, weekend is Denmark, laugh fit to burst in Alghero, 'Sinterklaas' and meatballs, enjoying Korean foot in Canada, daily cola at three, the commemoration for Kees. Thank you and your families for all the good times we had and I'm looking forward to the ones to come! Ambra and Remco, I am honoured to have you as my paranymphs.

Students,
As everybody can judge from the third chapter of this dissertation your input is of great value to my work. On many occasions, your explorations, questions and ideas brought new insights. Thank you for your creativity, enthusiasm and interest. I enjoyed working with all of you!

Papa, mama, ik ben niet zomaar geworden wie ik ben. Lieve zussen, familie, vrienden, ik ben blij met jullie. Sjors, ich ving dich leuk.

preface

In the second semester of my master's education, early 2008, I chose a design-research project on how perception gets emotional value through the use of an object. At that moment, I could not have envisioned that this project would inspire my final master's project and lead to this doctoral dissertation.

I met Kees Overbeeke on several occasions before this initial design-research project, but I had never worked with him over a long period of time. Kees was inspired by French researchers at the Compiègne University of Technology, which led to the proposition for the design-research project. At the start of the semester Jurgen, Milou (my friends and colleague-students), Kees and I drove to Compiègne, France, to meet Charles Lenay and his peers. I don't think I will ever forget how Milou and I took turns behind the wheel, while Jurgen listened to the endless historical facts and stories that every corner we turned elicited, which Kees knew by heart. And of course we were nitwits for not knowing all these facts and being unable to answer the questions he posed to us.

In this semester, the descriptive theoretical model, which I describe later in this dissertation, got its first form. It was a successful semester leading to a publication in 2009. In this design-research project I focused on inter-subjective interaction. Why do we feel involved, or not, in a situation? The thesis in this project was that we can only feel present in an environment when there are other people who share (or could share) one's way of perceiving, (inter)acting through the same means of access. The initial focus was on how perception, in mediated social interaction, gets emotional value through the use of an object. My focus shifted from mediated to direct interaction. How can a person who perceives tactually, perceive the perceptive activities of a person who perceives dominantly visually?

I liked my project, the topic and working with Kees. I started to wonder if the phenomenon of perceptual crossing –*I perceive you perceiving me and you perceive me perceiving you*– could also happen between person and artefact. I related my work to the work of Stephan Wensveen on feedback and feedforward. I met Stephan during my bachelor's course. He was my coach in a design project on haptic feedback. Could I consider feedback and feedforward as perceptive qualities of an artefact? Could I design for perceptive qualities in artefacts for person and artefact to engage in a strong reciprocal interplay of perceiving and being perceived? Kees became the client of the project, Stephan my coach. Not long after, Rene Ahn joined: I was in need of some help to translate my ideas to the algorithm that determined the behaviour of the artefact. In my final master's

project I designed and evaluated the first iteration of *PeP*, short for 'perception pillar'. This design-research artefact is also at the core of my doctoral work and described extensively in this dissertation. One can only imagine how many hours I spent standing and walking around this pillar with Kees, Stephan, Rene, Pierre (my daily supervisor in the PhD project) and my teachers/colleagues in the Designing Quality in Interaction Group.

The final master's project was a flying start for the three-year doctoral trajectory. From the initial design-research project onwards, Kees hinted that a PhD position was a serious option. Although I did wonder if a change of scenery was desirable, I quite quickly came to the conclusion that this was my chance to do exactly what I like for three more years. A better playground, although a serious one, does not exist. After the world for half a year, I started my doctoral project in April 2010. It was also then that I first met Pierre Lévy, my daily supervisor, with whom I share a more than healthy interest in phenomenology and its implications for designing. The leading question of my work is 'How to design for perceptive qualities in systems of interactive products?'. I endeavour to give an answer in this dissertation.

Time flies when you have fun. Although from a phenomenological point of view, considering the experience of traveling by plane, one comes easily to the conclusion that time does not fly (quote by Pierre). Moreover, I learned that also in more troublesome periods, time does not stand still.

about this work

for ease of reading

general

In this three-year doctoral project, I investigated whether and how to design for perceptive qualities in systems of interactive products from a phenomenological point of view. I set out to form and frame a new perspective on designing an artefact's intelligence from a quality- and action-centric approach, rather than a functional approach. Artefacts and the systems they create become increasingly intelligent and disappear to the background of our environment. How do we understand all these intelligible connections that systems create in our environment when they are invisible and highly flexible? Moreover, how do we design for such systems of intelligent and interactive artefacts? I am convinced that if we want to design for successful intelligent systems that are perceptible to and evolve around its user, the artefact's intelligence has to build on the direct interaction with its user(s). I show that, by designing for perceptive qualities, the system's activity becomes meaningful to its users. Moreover, I show that user activity becomes meaningful to the system in the course of the interaction.

I am inspired by and directly synthesise from theory. The theoretical starting point and the generated design-relevant knowledge, in the form of design notions, are a leitmotiv through this work. I structure three main chapters of my work around this connecting thread. In each of these chapters, designing plays an essential role. In the first chapter, I follow a minimalist approach in context and in implementation to bring forward fundamental knowledge for designing. In the second chapter, I investigate the added value of the generated knowledge for designing, and make a step towards design practice. In the third chapter, a third-person perspective corroborates my first-person approach and findings. For me it is crucial that these three chapters feed into each other to inform, inspire and validate.

objectives

The main objective of the first chapter is to investigate whether and how it is possible to design for perceptual crossing between person(s) and artefact(s). Perceptual crossing is the reciprocal interplay of perceiving while being perceived. By designing for perceptive qualities in the artefact, it hypothetically can engage in this reciprocal and participatory interplay of perceiving and being perceived with person(s) and their shared environment. The artefacts in the first chapter are particularly designed to flesh out and evaluate theory. I very deliberately chose the minimalist approach to address the theoretical implications in depth.

In the second chapter, the added value of the theoretical findings (of the first chapter) for designing is investigated. In this chapter, the findings are applied in intelligent interior textiles. Textiles surround us; they define the space we live and work in; we allow the material very close to our bodies; the physical qualities of textile support the aesthetics of the designed perceptive behaviour. The added value for designing is investigated in two directions. Firstly, the collaboration with an industrial partner explores the feasibility and added value of the findings for design practice. Besides exploring how the theoretical findings can be applied in our daily surroundings, the development of intelligent textiles is a live topic in the world of design and technology. The textile industry has shifted its focus over the last few decades. Dutch textile companies are niche-players, who focus on specialist and innovative textile products and applications (Modint, 2013). This is a development my project seizes and sets out to enhance. Secondly, the spatial qualities of these artefacts inspire system thinking and designing for systems. The work concludes in a proposition for systems of interactive products.

In the third chapter, I set out to corroborate my findings. Student projects and shorter assignments are initiated and described. By doing so, my first-person perspective of the first and second chapters is validated and added to by a third-person perspective. The main objective is to explore and show whether and how the students are inspired by and synthesise from knowledge generated in the other chapters. The projects are considered valuable iterations and valid argumentations for the relevance and extensibility of generated knowledge. Different aspects of the overall project, such as context, functionality, aesthetics and technology, are explored in depth. Moreover, it portrays the breadth of the theoretical exploration and its relevance when designing for different contexts. The contributions of the students are input to develop the design notions further.

I wish to elaborate on the societal implications of this project: on the apparent lack of placing the research in context. In order to conduct a study that brings forward fundamental design-relevant knowledge, I retrenched the context and functionality. To make it possible to grasp the theoretical implications and to be able directly to synthesise from theory, my focus is on theory. Adding complexity in context and functionality means that the requirements for designing and researching diverge from the initial theory. Choosing this set-up for my project results in a varied, rich and widely applicable set of design notions. The student work is an argument for this latter claim. Next to the examples in the perceptive qualities portfolio, numerous students address me as an expert for their projects. Supporting rehabilitation, pretended play, physical activity and wayfinding are a

few examples that show the variety of fields that students address in their projects, and in which they use my work as inspiration. To bring forward a new perspective to form and frame an artefact's intelligence from an action- and quality-centred approach, rather than a functional approach, the research pivots around these actions and qualities.

audience

The project follows a Research through Design approach. In the iterative process, several artefacts are designed, built and tested. Formulating, applying and refining the generated design-relevant knowledge throughout the process strengthens the argument of her relevance (Forlizzi et al., 2008; Zimmerman et al., 2010). In several publications and in this dissertation, the generated knowledge is elaborately described to provide for extensibility in and outside the academic world. The project yields knowledge of different fields. Most important is the interaction between theory and implementation. How to synthesise from theory and the role of synthesising in theory development are central topics in this work. By iterating in and over several artefacts, a set of design notions and a wealthy collection of examples have developed. These inform design-researchers and design-practitioners on designing for perceptive qualities. This process serves as an example for the community interested in the Research through Design approach. It not only is an example where the process and outcome are critically analysed and examined, but also has a declared intention to develop theory.

The project has a firm starting point in theory. The dissertation is a clear example of how (experimental) philosophy can inform design. Furthermore, it investigates in depth the implications of this starting point for designing. It shows not only how phenomenology is very suitable to describe and understand how people are acting in the world, but also how to synthesise directly from it. It makes the theoretical framework operational. The project comes full circle with a reflection on how the outcomes feed back to the initial theoretical framework. It poses new questions and proposes new means of investigations in the field of experimental phenomenology.

Throughout the work, the practical implementations for designing are discussed. This provides the reader not only with insights on why to design for perceptive qualities but also a way to do this. This ranges from more abstract insights, in the form of design notions, to the description of, for example, algorithms and the techniques used. It will especially provide design-practitioners and design-students with enough handles to work from the more theoretical findings. The

collaboration with an industrial partner, described in the second chapter, serves as an example for design-practitioners of how a rather theoretical starting point is valuable in the multidisciplinary innovation process.

The theoretical starting point, the generated fundamental knowledge for designing in the form of design notions, and the reflection on theory is the leitmotiv of this dissertation. This connecting thread appears throughout the dissertation. These parts are all labelled with 'Leitmotiv'. The design notions are presented on dark -coloured pages. Around this thread three main chapters are structured, namely: Generating Fundamental Design Knowledge, Applying Design Knowledge to Design Practice, and Applying Design Knowledge to Design Education.

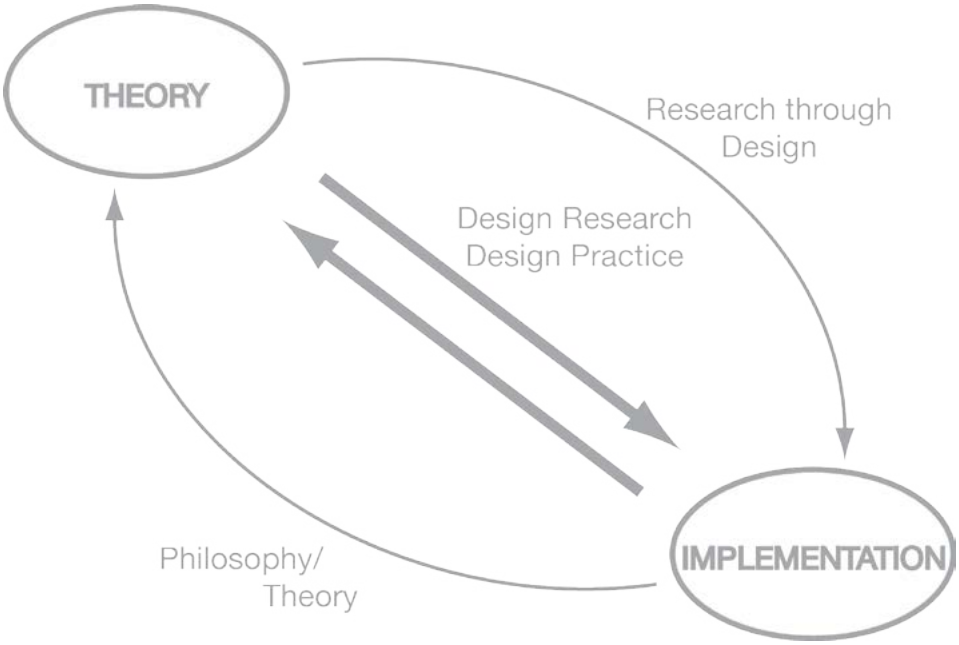

Figure 1. Overview of relevant areas.

Each of the three chapters is divided into sub-chapters. Both the content and set- up of the chapters and sub-chapters are introduced on the title page. QR-codes on these title pages will guide you to all the relevant digital information concerning this chapter. The main sections of each sub-chapter are also stated in the table of contents. To navigate easily you will find these sections on the right side of each spread. QR-codes that are placed next to the text will direct you to relevant accompanying movies.

For ease of reading, the table of contents also indicates which parts are most interesting for which audience. There is a distinction between Design-Research, Design-Theory, Design-Practice and Design-Students. For example, the practical implementations might especially interest design practitioners and students. On the other hand, discussion and reflection on the process might be of more interest to design-researchers. Behind each sub-section I recommend the part to a specific audience. Note that these recommendations only serve as guidance. Furthermore, the table of contents indicates the relevant publications for each section.

Figure 2. Three chapters are structured around the leitmotiv.

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The 'Leitmotiv' parts are a connecting thread through this dissertation. The current part introduces the theory and the process. I show that the theoretical background is relevant for designing, as it places the body at the centre of perception. Furthermore I elaborate on how the approach and the structure of this work mean that I can build a body of knowledge that is credible academically, relevant to practising designers, and of societal relevance.

leitmotiv: introduction

an introduction to theory and process

In this first sub-chapter of 'Leitmotiv: Introduction', I work towards the proposal of a descriptive theoretical model on perceptual crossing between person and artefact. The general introduction considers the active and reciprocal nature of perception. These qualities are the core of the design-research, as they allow me to design for activity and to invite people in an active engagement with the artefacts I design. I elaborate on the phenomenon of perceptual crossing. I show that the beauty of it is that it makes me experience my own intentionality. The discussion of several experiments by Lenay et al. (2007) makes the theoretical background operational. The proposal of a design-relevant descriptive model on perceptual crossing between two human subjects concretises the theoretical background further. Through several examples, I explore and explain the person-to-person descriptive theoretical model, and conclude with the proposal of a descriptive theoretical model on perceptual crossing between person and artefact.

theory

The research focuses on designing for perceptive qualities in artefacts, and is inspired by and grounded in phenomenology of perception (Merleau-Ponty, 1945) and ecological psychology (Gibson, 1979). Both bring forward the active nature of perception and put the body at the centre point of perception. This differs from a more traditional, Western line of reasoning in which perception, building on Descartes' heritage, is considered a rather cognitive matter (Abram, 1996; Dourish, 2001).

From this point of view, our body enables us to sense the world, and is not a programmed machine but an active and open form. If it would be possible to look at the body as something truly objective, as if it exists out of closed predetermined mechanisms, it could never experience something truly new. If all the experiences and responses we have would be predetermined by objective mechanisms, we would be like pre-programmed machines (Abram, 1996, pp. 34-35). Obviously we are not. It is exactly the limitation of modern electronic devices and the reason for design-researchers to explore more natural and intuitive interactions.

Edmund Husserl (early 20th century) introduced the discipline of phenomenology. The basis of all his ideas was that phenomenology would bring forward the '*things themselves*'. He proposed phenomenology as a method for examining the nature of human experience and perception (Dourish, 2001, p. 104). Our direct experience of the world is at the core of his ideas, and phenomenology does not set out to explain the world but as closely as possible to describe the way the world makes itself evident to us. The emphasis is on how things appear to us in our direct, sensorial experience (Abram, 1996, p. 35).

At that point, following the Cartesian line of thought, Husserl considered the body and the mind as two separate qualities, and described his notion of phenomenology as a non material dimension. He struggled to explain how, if this perception was purely non material, it enables us to recognise other subjects with a direct perceptual experience. It is only in his later work that he starts to recognise the importance of the body for the direct sensorial experience. In this approach, an experience is not completely transcendental (buitenzintuiglijk), but also, as the natural sciences assumed, not completely objective. This inter-subjective world of life he called the '*life-world*' (*Lebenswelt*). Husserl defined the *life-world* as the world of our immediate lived experience. It is the world as we perceive it before it is liable to our thoughts about it (Spurling, 1977, p. 9; Abram, 1996, p. 40).

Martin Heidegger, a student of Husserl, stressed the role of the body. Central to Heidegger's work is his notion of '*Dasein*', meaning that we actually are **in** the world and this is the only way to experience the world. We understand the world in terms of possibilities, and the world itself is always a structural component of '*being in the world*' or '*Dasein*' (Dourish 2001, p. 108). Objects in this world are presented to us as '*present at hand*' (*vorhanden*) or '*ready at hand*' (*zuhanden*), describing the relation between person and artefact. When '*present at hand*', we perceive the object as it is in the world, the *body-image*. When '*ready at hand*', we perceive the object not longer as it is, but we 'care' for it and establish a relation in which the object becomes a tool (*zeug*). The hammer lying on the table is an object in space; when '*ready at hand*' the hammer is an extension of my body. Glasses on someone's nose are glasses, but are part of my body when they improve my seeing (Heidegger, 1927).

In line with Husserl's work, Maurice Merleau-Ponty took a more radical position. Like Martin Heidegger, Merleau-Ponty tries to describe and understand the worldly experience by looking beyond the mind-body or object-subject divide (Carman, 1999). Merleau-Ponty rejects the assumption of a division of mind and body; that a human in essence is self-subsistent, disembodied and transcendental. He argues that if we have no body there is no possibility to experience the world (Merleau-Ponty, 1958, pp. 125-131). The body is the true subject of experience and therefore the so-called 'experiencing self' is the body (Abram, 1996, p. 45). Awareness is in the first place not a matter of 'I think that', but of 'I can' (Merleau-Ponty, 2009, p. 203).

The *active* nature of perception is also a profound notion of Gibson's (1979) ecology of perception. *My*[1] perception of the world is predominantly dependent on *my* body. The *affordances*, acts or behaviour permitted by objects, places and events of the world are actually what *I* perceive (Michaels and Carello, 1981, p. 42). In first instance *I* do not perceive a chair as the concept of a chair as *I* have been told. In a first preconception *I* perceive the 'sitability' of the chair. *I* perceive the place to sit, and whether *I* perceive something as 'sitable' depends on *my* body.

By considering perception as the *affordances* the world reveals to us, perception becomes a very active and personal matter. Perception can only be valuable to us if we undertake appropriate and effective actions in relation to the environment

1 In some cases, the first person perspective is used to describe a phenomenon. When 'I' does not refer to the author an italic font is used.

(Merleau-Ponty, 2009, p. 107). And, in turn, our actions should be guided by an accurate perception of the environment for them to be appropriate and effective (Michaels and Carello, 1981, p. 47). To experience the surface of the table top *I* will not just touch it but also move my fingers over it in an exploratory fashion. In a similar way, our eyes are always in action to perceive (micro-saccadic movements of the eyes) and when immobilised we are not longer able to see (Ditchburn, 1973; Steinman et al., 1990, cited in Lenay et al., 2007). Perception is active: *I* and the world are both part of it. It is 'out there': in front of *me* (Figure 3).

Lenay et al. (2007) show the active nature of perception in a simple experiment. A blindfolded subject tries to perceive a luminous target with a single photoelectric cell that triggers a one-bit tactile stimulation. Over time, the subject no longer notices the sensory input (*vorhanden* versus *zuhanden*), but perceives the target in front of her. The subject constantly acts to maintain the perception of the target. Holding still will result in a continuous on or off signal that does not contain any spatiality. Perception is not an internal representation built upon the sensory input we gain. Perception is the result of dynamic coupling between the person's actions in relation to her environment and the sensory input this environment provides.

The active nature of perception is at the core of my work. Perception is considered the result of the actions we undertake and the sensory feedback these result in, and the other way around. We access the expressive qualities, that is the meaning of the world, by means of our body. Meaning cannot be detached from action (Overbeeke, 2007). For me this is fundamental for my design-research, as I can design for actions and invite people in an active engagement with the artefacts that I design.

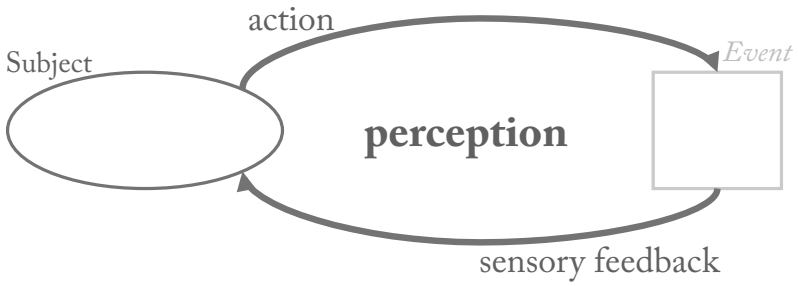


Figure 3. Perception is considered the result of the actions a subject undertakes towards an event and the sensory feedback she receives, and the other way around.

The discussion of Merleau-Ponty's investigations brings forward that perception is inherently interactive and participatory. Perception is an active, reciprocal interplay between the perceiver and the perceived (Abram, 1996, p. 89). Our direct sensorial experience, our direct perception, is only meaningful because of its reciprocal nature. We are only able to touch because our body is a touchable thing; to touch is also to feel oneself being touched. To see is also to feel oneself being seen.

In the phenomenological description of the body of a subject, two aspects are described. (1) The *lived-body* is the body as we experience it; it is our ability to perceive. (2) The *body-as-an-image* is, as it were, the object we are in space; our physical appearance to others (Lenay, 2010). It is in the reciprocal nature of perception that *I* recognise others as intentional subjects, that *I* distinguish their *lived-body* from their *body-as-an-image,* and that the other recognises *my* presence as intentional subject. This phenomenon, called *perceptual crossing,* is the interplay of perceiving while being perceived. In simpler words: *I can see you seeing me and you can see me seeing you*. We attract and escape from each other's perception. We catch each other's sight to let go of it again; our perception of each other crosses. We share a common space in which we can build a history in the course of our interaction (Lenay, 2010). This constitution of the other's viewpoint is essential to get a feeling of sharing the common space: *to feel involved*.

The beauty in the phenomenon of *perceptual crossing* is that I experience my own intentionality; it shows *me* that *I* affect the sensitivity of the other. It shows *me I* am involved in the situation. When *I* touch, *I* discover *I* am touchable and when your eyes catch mine *I* understand that I am seeing. I cannot perceive my own body in the way *I* perceive that of others. *I* might perceive the tip of my nose, but *I* do not see my own face, my own eyes (Merleau-Ponty, 2009, p. 152). In the other's perceptive activity *I* recognise that *I* affect the sensitivity of the other person. And it is the other's perceptive activity that shows *me* that the environment affects her sensitivity. These phenomena are respectively referred to as primary and secondary inter-subjectivity (Gallagher and Zahavi, p. 187).

When we engage in *perceptual crossing* this reassures us of ourselves, and we can feel involved with the other and the situation we are in. We all experience how weird it can feel when laughing out loud with no one else present. Or how a mirror urges you to look at yourself. You get vulnerable in situations where you are not aware of your own body. There is nothing more sincere than a child

playing without her knowing she is being watched. The child does not see herself as long as perceptual crossing does not occur, and you understand that what the child expresses is not under her control and is therefore sincere (Lenay, 2010). In the reciprocity of our perception of each other we share this vulnerability which makes the moment that we touch or catch each other's eyes so powerful.

The following discussion on research into Sensory Substitution Systems shows what it means for people not being able to engage in perceptual crossing. Since the 1960s, Paul Bach-y-Rita (1997, 2003) has worked on the topic of sensory substitution. His research includes the invention of the Tactile Vision Sensory Substitution (TVSS) system. The system transforms visual stimuli into tactile stimuli for blind people. Various studies showed that blind subjects developed spectacular capacities to recognise shapes. The blind subjects perceived the objects in the environment and, no longer noticed the tactile stimulation on their skin (*zuhanden*). The experiment of Lenay et al., (2007), described next, is a very simplified version of such a sensory substitution system. Although the studies showed convincing functional results, the TVSS was an economic and social failure for two reasons. Firstly, people felt uneasy about appearing as a 'cyborg' in the eyes of others. Secondly, the emotional content, or 'qualia' as Bach-y-Rita named it (1997), of the sensory experience appeared to be missing. In Bach-y-Rita's studies, when well-trained subjects explored the face of a wife or girlfriend they were deeply disappointed. Although they could describe the faces in detail, the image lacked any emotional content.

Building upon the work of Bach-y-Rita, Lenay et al., (2007) put the following hypothesis to the test: "The emotional value of the lived experience only emerges through a common history, built in the course of interaction between several subjects in a common environment defined by the *same means of access*". In simpler words: one can only feel present in an environment when there are other people who share (or could share) one's way of perceiving, (inter)acting through the same means of access. It is because people have similar perceptual bodies that we feel ourselves to be part of the world. By 'similar perceptive bodies' I do not refer to the fact that they have to look similar. Our bodies should be similar in the way that we can perceive each other's perceptive activity; to feel present in the world our perceptual bodies have to enable us to engage in *perceptual crossing*. When you access a situation with dissimilar perceptive bodies, like the subjects using the TVSS, this disables you to perceive the perceptive activity of the other, causing you to feel less involved.

Lenay et al. (2007, 2010) performed different experiments that deliberately show that a person is able to recognise the *presence*, the *intentionality*, of another person because of her perceptive activity. In one of the experiments ,two persons, separated in space, interact with each other in a one-dimensional virtual space. Both persons can act in this world by moving a mouse on a horizontal plane, and they gain sensory input by tactile stimuli on their fingers. Participants do not see this space. In the virtual world they can encounter either each other, a static object or a moving object. The moving object is connected to the other person and exactly follows the movement of the other on a fixed distance. Subjects click on the mouse when they feel they encounter the other (Figure 4).

The majority of people click at the moment they indeed encounter the other. They click when they engage in *perceptual crossing*. The person distinguishes the other from the moving object, because when she encounters the other a play of attraction and escape starts. The person understands that the other's sensitivity is affected by her presence. They engage in an explorative interaction in which they attract and escape from the other's sensitivity. There is a force between them. The experiment shows that the involvement in the interaction is dependent less on the richness of the sensory input than on the reciprocity of the interaction.

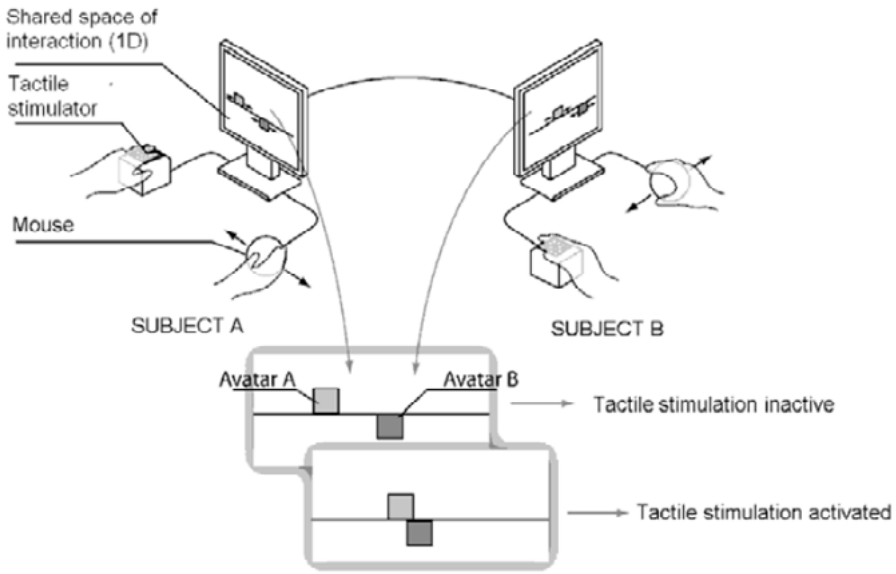


Figure 4. Experimental set-up, Lenay et al., 2007.

When meeting the other in this one-dimensional virtual world, the subjects engage in *perceptual crossing,* reassuring each other of their presence. In a second experiment, Lenay et al. (2007) investigate if the person can recognise her own *body-image* in the activity of the other. In the activity of the other *I* discover that *I* have something on my nose. For many people it feels awkward to close their eyes when surrounded by others as you not longer understand what you look like. In the experiment, that has the same set-up as the previously described experiment (cf. Figure 4), the participants do not know their own body as presented to the other. Moreover, only part of this body that is presented to the other is actually gaining sensory input. The question is whether the persons can recognise their own *body-image* that they offer to the perception of the other. The study shows that indeed it is in the participant's active perception of the perceptive activity of the other that she recognises her own body-image. You reassure yourself by the activity of the other: "it is the other who, by her way of looking at *me* (the way she is exploring my body-image in the experiment), helps *me* to constitute an image of myself, to recognise my face" (Lenay et al., 2007).

To explain perceptual crossing in a more concrete manner, I propose a descriptive model of perceptual crossing between two persons. The model in Figure 5 shows the reciprocal interplay between two persons. The perception of each other is considered the result of actions the two people undertake towards each other and the sensory feedback they receive, and the other way around. The dotted lines in the model show that the actions one person undertakes to perceive the other are part of the perceptive activity the other perceives. For example, when one person turns her head to look at the other, the other perceives this action as part of the perceptive activity of the first person. This also works the other way around; *their perception of each other crosses*.

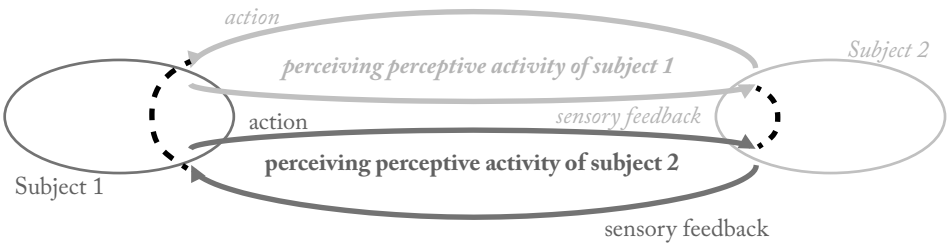


Figure 5. Descriptive theoretical model on perceptual crossing between two subjects.

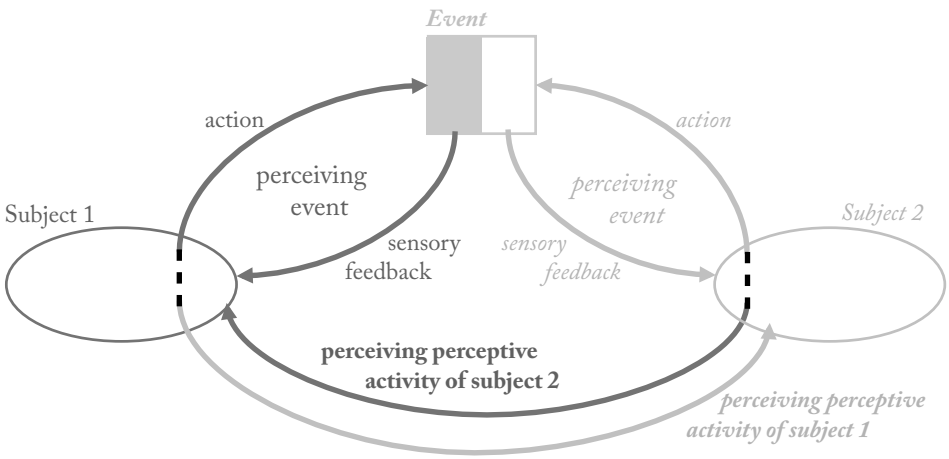


Figure 6. Descriptive theoretical model on perceptual crossing between two subjects, their common space is sketched by their perception of an external event.

To concretise the phenomenon of perceptual crossing further and to support the start of the design-research project, perceptive activity is set out in three components: (1) *perceiving presence*; (2) *perceiving perceptive actions;* and (3) *perceiving expressivity* (Deckers et al., 2009). The *perception of presence* refers to perceiving the other's ability to perceive, to the presence of the lived-body. Even if the other has not yet perceived *me*, *I* perceive her intentionality in the way she is engaged with the environment, how she affects it and how it affects her (referred to as partial perceptual crossing: Lenay, 2010). The *perception of perceptive actions* is the perception of the exploratory actions the other undertakes to perceive *me* and our common space. These perceptive actions, like looking in my direction, turning your ear towards the acoustic event or moving the finger in exploratory fashion over the table top to discover the surface, tell us what the other perceives. The other's expressivity is also in these perceptive actions. By *perceiving each other's expressivity* we come to appreciate how the other feels or thinks about what she perceives. If the other rubs a surface to the sensitive skin of the cheek, this reveals to *me* that the surface feels soft or pleasant.

Besides affecting each other, both persons also affect and are affected by the environment. Figure 6 sketches this common space by the addition of an external event. The perception of this event is again the result of actions they undertake towards the event and the sensory feedback this results in and the other way around. This perceptive activity towards the event is also part of the perceptive activity the other perceives (the dotted line in the model). When, for example, one person brings her nose close to a flower to smell it, the other perceives this activity towards the olfactory event. The lower part of the model in Figure 6 is a simplified representation of the model in Figure 5.

The picture in Figure 9 serves as an example. The picture shows two persons hiking. The two persons perceive each other's presence. They perceive each other's ability to perceive. The woman in the picture (the person on the right) undertakes specific perceptive actions in relation to their common space: she looks up in the direction of the tree and points in that same direction. The fact that she expressively points reveals to the man (the person on the left) that there is something, an event, up in the tree that is interesting to look at. Following her perceptive activity, the man looks in the same direction, exploring what she perceives and is pointing at. It is her perceptive activity that makes him undertake these perceptive actions. They will both look up and then try to find each other's eyes again. As their perception crosses, they can build a common history in the course of their interaction, in which the event in their common space plays an active role.

In a previous study (Deckers, 2009), I compared two situations, based on the work of Bach-y-Rita. (1) In the first situation, both subjects perceive with similar perceptual modalities; they both perceive visually. (2) In the second situation, one subject perceives dominantly visually and the other only perceives tactually. In this situation, for the subject that is only able to get tactile input, to perceive the other she should touch the other. In most common situations this is awkward or inappropriate, which leads to the fact that this subject is unable to perceive the perceptive activity of the other. Like the subjects using the TVSS, this subject does not perceive the *lived-body* of the other. This subject is unable to engage in *perceptual crossing* and so the emotional content or 'qualia' of the perception of the other is missing. These two situations are sketched in Figures 7 and 8.

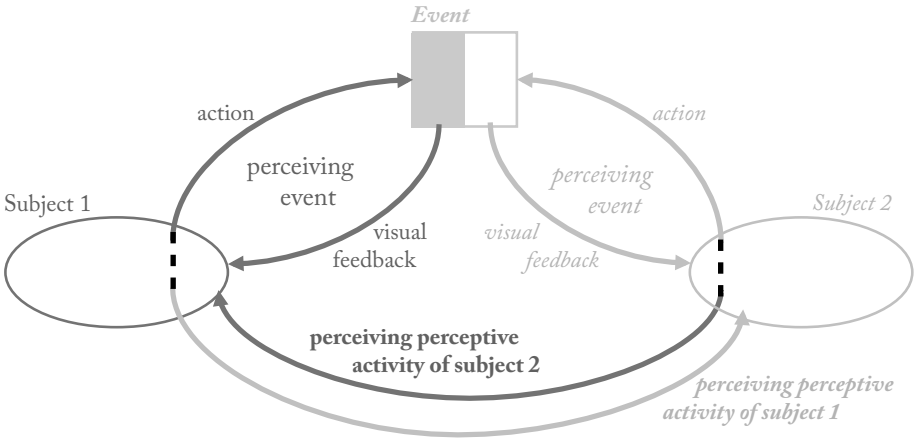


Figure 7. Theoretical model on subjects perceiving with similar perceptive bodies.

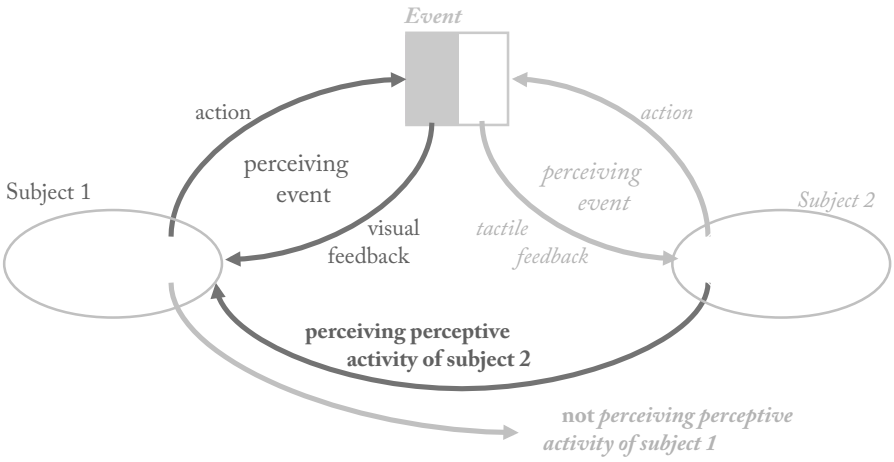


Figure 8. Theoretical model on subjects perceiving with dissimilar perceptive bodies.

Figure 9. Example

The experiments of Lenay et al. (cf. Theoretical Background, p.8) show that people are enabled to engage in perceptual crossing through the designed artefact. Figure 10 shows the design-relevant model of such a mediator. Perceptual crossing can happen through the object as it allows the persons to freely explore and perceive each other's perceptive activity. In a previous study (Deckers et al., 2009), I designed and investigated an artefact that enables a person who perceives tactually to perceive the perceptive activity of the other who dominantly perceives visually. This artefact is no longer a mediator, but facilitates direct interaction between the two people. This situation is sketched in Figure 11.

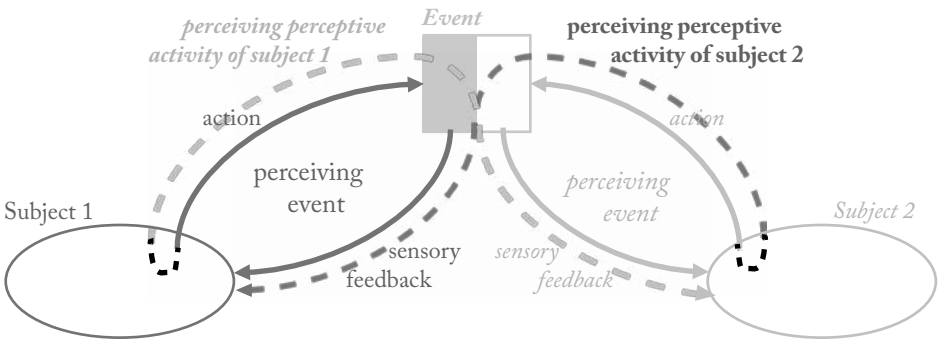


Figure 10. Perceptual crossing mediated through a designed artefact.

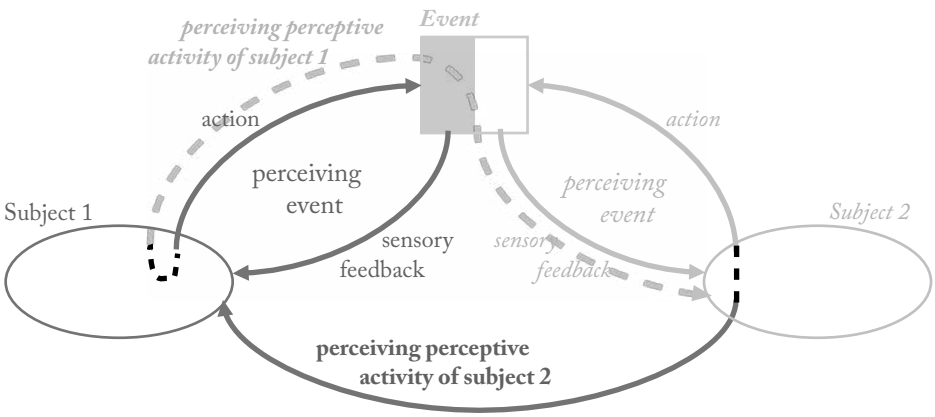


Figure 11. Restoring emotional content in perception through the use of an object.

About a lot of products surrounding us nowadays: "…To the sensing body these artefacts are, like all phenomena, animate and even alive, but their life is profoundly constrained by the specific 'functions' for which they were built. Once our bodies master these functions, the machine made objects commonly teach our senses nothing further; they are unable to surprise us, and so we must continually acquire new built objects, new technologies, the latest model of this or that if we wish to stimulate ourselves…" (Abram, 1996, p. 64)

So far the discussion has focused on person-person interaction and how objects enhance this inter-subjective interaction. My doctoral work focuses on person-artefact interaction. Designing for perceptive qualities in artefacts presumably means that people can engage in a more meaningful interaction with the artefact. The artefact is enabled to engage in a reciprocal, perceptive interplay with a person(s). Although, in other work, design-researchers do not explicitly refer to perceptive qualities, the introduction of these kinds of qualities is not new. For example, Wensveen (2004) proposed a framework for tangible interaction relying on several types of feedback and feedforward. Wensveen describes different characteristics to couple a person's actions and the artefact's reaction. The actions the artefact allows to control it and the actions it undertakes as a result of this are meaningful to the person. The artefact clearly shows what it is able to perceive: feedforward. Besides, the person understands whether her action was effective, as the artefact perceivably reacts to this: feedback. Considering feedback and feedforward in this light, the artefact becomes a perceptive body, sensing the person's actions and acting upon them. Nonetheless, in this framework, the actions of both person and artefact are related to direct control: it does not necessarily adapt or evolve over time.

To design successful intelligent systems that evolve around its user and are embedded in the background of our environment, the question becomes inevitable as to how to perceive and understand these systems (Frens and Overbeeke, 2009). Our perception of any artefact is reciprocal even if it is only because it can be touched or seen. A network of artefacts or systems, however, can loose its reciprocal nature when its activity is not made evident to its users. The challenge for designers is to create dynamic interfaces for more than one function that evolve over time and adapt to multiple users and events. Ultimately, if the artefact is able to detect perceptive activity of the person and show meaningful perceptive activity in relation to this, both person and artefact perceive intentionality.

Intentionality refers to the idea that perception is inherently participatory and interactive. Awareness is always awareness of something that is part of the world and oriented towards the world (Spurling, 1977, p. 17). Intentionality is the directedness of meaning (Keller, 2001; Dourish, 2001). Artefact and person can engage in reciprocal interaction, and the activity of both becomes meaningful to the other. They build a common history in the course of their interaction; they come to appreciate what things mean for the other. The person comes to appreciate that she and the environment they are in affect the artefact. And, in turn, the artefact comes to appreciate that it affects the person by its activity. It is in this activity, the expressivity, that both person and artefact can appreciate each other's viewpoint, their intentions towards each other and the environment. In time, in the course of the interaction, they become able to anticipate the other's perceptive activity. I investigate a new perspective on forming and framing the artefact's intelligence in a more action- and quality-centred way, rather than a function-centred way.

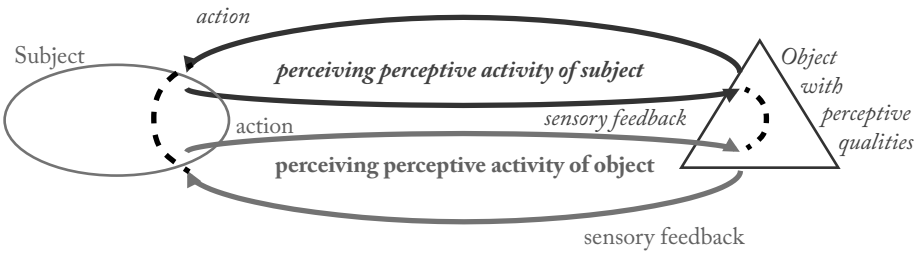


Figure 12. Desriptive theoretical model on perceptual crossing between person and designed artefact.

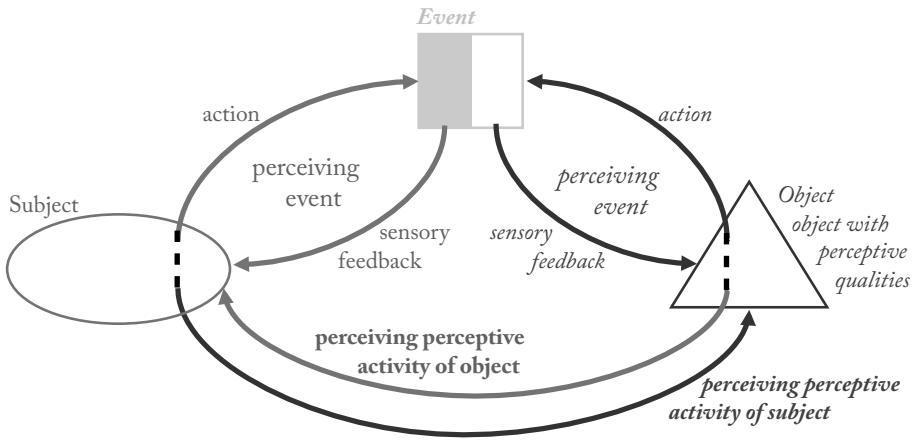


Figure 13. Descriptive theoretical model on perceptual crossing between person and designed artefact in their common space.

Figures 12 and 13 show the proposed design-relevant theoretical models on perceptual crossing between person and artefact. In these models, one of the two subjects in Figures 3 and 4 is the artefact with perceptive qualities. This artefact is able to perceive and show perceptive activity to the person. The addition of the external event sketches their common environment. Throughout this dissertation I will use subjective qualities to describe the activity and behaviour of the artefact. Although I make use of this terminology, by no means can I claim that the perceptive activity of an artefact is identical to the perceptive activity of a human being.

To summarise, by designing perceptive qualities in the artefact, person and artefact hypothetically are able to engage in a rich reciprocal interplay of perceiving and being perceived. Perceptive qualities refer to the qualities of activity and sensing that allow for a reciprocal interplay and engagement with others and with the world. Perceptual crossing happens between them, and they share their perception of their common space. They can build a common history which positively influences the person's feeling of involvement. In the course of their interaction, they come to appreciate each other's viewpoint; they appreciate that they affect each other. The intelligence of the artefact is built in the course of this interaction.

Phenomenology has been introduced as a valuable framework in different related fields, such as Human Computer Interaction (Winograd & Flores, 1986; Svanæs, 2000; Fällman, 2003), Embodied Interaction (Dourish, 2001), Movement and Interaction (Moen, 2005; Robertsen, 2002; Schiphorst 2009), Aesthetics and Interaction (Dalsgaard, 2008; Hallnäs and Redström, 2002), Tangible Interaction (Hornecker et al., 2006), and Social Robotics (Disalvo et al., 2008). In the fields of Mediated Social Interaction (Lenay et al., 2007; Deckers et al., 2009) and Social Robotics (Di Paolo, 2008; Froese et al., 2009; Marti, 2010), the phenomenon of perceptual crossing has been introduced. In these works, phenomenology is often used to provide knowledge of, and a better understanding of how users are acting in the world. I aim to use phenomenology as a means of inspiration and as input for the synthesis of new designs.

In other works, the social position of artefacts is considered. For example, in the work of Ju and Takayama (2009), the approachability of automatic doors is investigated. The authors explore and evaluate the factors that influence people's emotional interpretation of the door's gestures. They conclude that designers can trigger emotional appraisal with very simple actuation. In an earlier work (Ju

and Leifer, 2008), the social position of an artefact is also discussed. The authors make an argument for implicit interactions that occur without the explicit request or awareness of the user. They give various examples of implicit interaction in human-human interaction, e.g. modulating our speaking volume based on ambient noise level, and holding the door open for others when we see that their hands are full. The researchers discuss several cases in which artefacts pose very explicit interaction on us, and propose how to improve these situations. Their work springs from observations in daily life. Their exploration is rather rich but could benefit from iteration on *how to design for* implicit interaction or for the actuation of an artefact.

Researchers in the field of Embodied Cognition and more specifically, Enaction (Stewart et al. 2010) also bring forward the limitations of a cognitive approach to designing (Van Dijk, 2009; Froese et al., 2012). This cognitive approach to designing mainly focuses on the computational properties of abstract information processing and rational interference. The aim is to maximise information content and information flow. Such an interface is characterised by rule-based procedures and representations. Rather than being implicitly facilitated in directly perceiving what to do, the user has to reason the meaning of the abstract output. An enactive perspective proposes that a technological interface can mediate our relationship with the world such that it enhances our perceptual interactions (Froese et al., 2012, p. 366). Similar to the idea that perception is active, here also sensory input and activity are considered as two facets of the same process of generating meaning. Froese et al. (2012) built the so-called Enactive Torch to investigate their enactive approach towards the design of interfaces. Their findings support the claim that enactive interfaces are able to generate qualitatively new forms of perceptual interaction with the environment. The work, which closely connects to the work of Lenay et al. (2007) presented earlier, makes a strong argument for the consideration of lived experience in designing interactive and intelligent artefacts. Different from the previous discussed work of Ju and colleagues, this research springs from, and is strongly positioned in, a theoretical context. This work could also benefit from iteration on *how to design for* such enactive interactions and experiences.

The work of Ross (2008) provides handles for designing the dynamic qualities of the behaviour of an artefact. The work focuses on intelligent products and systems that are characterised by their behavioural qualities. Ross follows a Research through Design approach to design, build and evaluate an intelligent light armature that portrays several social behaviours, e.g. helpfulness, social

power and creativity. He extensively discusses the idea that products socially transform people. He positions himself in Verbeek's (2005) philosophical work on Technological Mediation. Taking Technological Mediation into account in designing means that the social influence of the product or system is considered (Ross, 2005, p. 36). In his work, this is strongly linked to the ethical aspect of designing, as a designer should take a stance on what a desired transformation is. In Bruns et al. (2013) and Stienstra et al. (2012), the transformation of behaviour and how to design for this is also discussed. In these two examples, the behaviour of the artefacts, and hence the interaction, is more implicit compared to the work of Ross and the work presented in this dissertation. The design-research presented in this dissertation builds on the investigations of Ross. An important further step is that the work presented here focuses not only on how the behaviour of an artefact can be meaningful to the person, but also on how the behaviour of the person becomes meaningful to the artefact.

The social role of an artefact is clearly explored and investigated in the field of Social Robotics. There are numerous examples of research in this field. There are also examples that relate to the theoretical background presented here (Stienstra & Marti, 2012, 2013). Based on the work of sociologist Goffman (1959), Mutlu et al. (2009) describe how, during conversations, speakers establish their own and others' participant role using gaze cues. The researchers designed a set of gaze behaviours for their robot. They investigated the influence of the activity of the robot, -i.e. where it focuses its gaze-, on the participant roles. They found significant differences in the experience of the subjects that participated in their study. This is an interesting study as it proposes that the robot shows meaningful perceptive activity to the person. It focuses its attention. Nonetheless, the study was scenario-based and the experimenter controlled the robot. The question arises how to design the robot such that it actually could direct its focus itself? Moreover, like in many studies, here a human-like robot is used. The work in this dissertation focuses on the behaviour of artefacts that do not have anthropomorphic attributions.

In this second sub-chapter of 'Leitmotiv: Introduction', I show that the Research through Design approach allows me experientially to explore the design space, and to generate knowledge through the act of designing. I position my design-research in a recent discussion on the apparent need for the Research through Design approach to mature and formalise. The work is structured in three chapters that are clearly positioned in theory. The role of the artefact is paramount in design-research, and therefore I elaborate the different roles and contributions of different artefacts in these three chapters. It is this structure that allows me to build a body of knowledge that is credible academically, relevant to practising designers and of societal relevance.

process

the act of designing

My doctoral work follows a Research through Design approach. The approach is characterised or even broadly defined by acquiring knowledge through designing, building and evaluating in context highly experiential prototypes (Wakkary, 2005; Frens, 2006; Zimmerman et al., 2007; Hengeveld, 2011). The approach differs from traditional research approaches. In basic sciences, such as physics or psychology, knowledge is generated by fundamental research, and is general and disjointed (Horváth, 2007). In other words, the knowledge is not contextualised or integrated. Based on Cartesian heritage, fundamental research builds on characteristics such as rationalism, truth, objectivity and reduction. This generally held view of science does not always provide us with the handles to approach phenomena that are not easily reduced or decontextualised. From the introduction into the theoretical background of this project, one might understand that from a phenomenological perspective it is even impossible to look at the world in an objective manner, as if it is a mechanism of which we can observe and understand pieces separate from each other. I deliberately choose the term 'designing' over 'design' as I will show that knowledge is not only in the outcome, but also and especially in the actual act of designing and in the interaction that people have with the outcome of this act. The Research through Design approach offers the opportunity experientially to explore the design space and allows for 'doing' as a mechanism to generate knowledge. Phenomenology offers us a way to look at the world as it appears to us in our direct experience, to look at the world in a holistic and contextualised manner.

research through design

Investigating the methods of the Research through Design approach is not the main focus of the project; however, it does aim to be a showcase in this field. Over the last few years, different researchers have made an effort to show and discuss the relevance and methods of the Research through Design approach (Stolterman, 2008; Forlizzi et al., 2008, 2009; Zimmerman et al., 2010; Dalsgaard, 2010; Gaver, 2012; Bowers, 2012; Bardzell and Bardzell, 2011). In their works these researchers extensively discuss the nature of Research through Design, as well as its need to mature and formalise. In this latter discussion, Gaver (2012) is concerned that the standards might lead to a form of what he calls self-policing which would be too restrictive. He argues that the strength of this research approach is in its ability continually and creatively to challenge status quo thinking. Fällman and Stolterman (2010) address this assumed need for rigour and relevance. Although they acknowledge that terms such as validity and reliability do not necessarily correspond with creativity and innovation, they do try to get closer to an answer

as to how to build a body of knowledge that is credible academically, as well as relevant to practising interaction designers and society at large. Although this is an active and ongoing discussion, it has been a live topic since the 1970s, as Buchanan (1992) sets out. Firstly, it is important to get examples where there is an intentional choice for the approach as a methodology, and where the process is both described and critically examined. Secondly, the main contribution of my work is that it has the declared intention of creating and building theory (Zimmerman et al., 2010).

In the discussion about formalisation and rigour, the role of the actual Research through Design artefact and the process leading to it is somewhat underexposed. The role of the artefact is paramount, as the thinking, or maybe even knowledge, is embodied in this artefact. One can question whether the artefact is actually the end product and whether this artefact indeed inherently conveys knowledge that extends verbal expressions. Actually, if the answer to the latter question is yes, it seems not so hard to figure out why the community struggles to formalise the Research through Design methodology so far, as the attempts are merely verbal. These questions are at the core of the Research through Design approach, but are not widely considered in the known literature. Pedgley and Wormalt (2007) make an argument for the place of design in research projects, but their focus is very much on the traditional roles of design, and could benefit from a discussion on the relation to theory. Zimmerman and Forlizzi (2008) discuss the role of the design artefact in design theory construction. Although they give several examples of this kind of artefact and what kind of theory is produced, the link between them -how to get from the artefact to theory, or from theory to the artefact- is not made explicit. How to synthesise from theory and feeding back to it is a central topic in this doctoral work.

Research through Design is often associated (Frens, 2006; Hengeveld 2011), with Archer's 'research through practice', which is a form of action research defined as 'a systematic investigation through practical action calculated to devise or test new information, ideas, forms or procedures to produce communicable knowledge' (Archer, 1995, p. 6). In research through practice, the emphasis is on the actual act: through practical action. This type of research is situation-specific, and so it is difficult and dangerous to generalise from the findings (Archer, 1995, p. 12). Likewise, the findings of Research through Design are situation-specific. As the approach relies on iterative cycles of designing experienceable prototypes that are evaluated in context, the resulting scientific outcome is also contextual. The results 'lead to conditional laws instead of general laws' (Hummels, 2000,

p. 1.27). The artefact can be considered the physical, experiential manifestation of this knowledge. The prototype is a carrier of integrated and contextualised knowledge (Hengeveld, 2011, p. 57). Indeed this knowledge is conditional, but can be generalised in the form of design specifications for future products and in new theory and frameworks (Frens, 2006, p. 210). Building on Archer's warning and discussion on how to generalise from this type of research, a condition for this research is that it has to be clearly positioned (in theory) so that there is a context for the resulting knowledge (Frens, 2006). The design notions that are presented as a result in this work are relevant for designing perceptive product behaviour, and for designing an artefact's intelligence from a phenomenological perspective.

I structure the Research through Design process in three intertwined chapters. In each of these chapters designing plays an essential role. The process is iterative and several artefacts are designed, built and tested. Nonetheless, the role of the artefacts and the process of designing them differ in each chapter. In the first chapter, the designed artefacts flesh out theory and evaluate the outcome. In the second chapter, the artefacts investigate the relevance of generated design knowledge to design practice. In the third chapter, the artefacts are designed by other designers, namely design students. Their third-person perspective corroborates my findings. It is crucial that these three chapters feed into each other to strengthen the argument of the relevance and extensibility (Forlizzi et al., 2008) of the generated design-relevant knowledge.

Figure 14. Example artefact chapter 3, Manoeuvre by Jorg de Bont.

In the tradition of Designing Quality in Interaction group, the environment in which this design-research is conducted, I follow the so-called 'Lab' approach in the first chapter. Design knowledge is generated through empirical research into theoretically inspired designed artefacts (Koskinen et al., 2011). As Frens (2006) proposed, the designed artefact functions as a physical hypothesis in such an experiment. At that time, Frens focused on the interaction with an electronic consumer product, and stated that this physical hypothesis should have ***sufficient product qualities*** in order to draw relevant conclusions (Frens, 2006, p. 185). Hengeveld (2011) reflected upon this idea of physical hypothesis. Considering the fact that designers will be challenged to design increasingly complex products and systems, he stated that we will move from physical hypotheses to what he calls embodied hypotheses, which have ***sufficient system qualities*** in order to draw valid and relevant conclusions (Hengeveld 2011, p. 200).

In my project, the artefacts adopt perceptive behaviour. The artefacts are physical objects, but the physical properties particularly support the dynamic qualities. The body of the artefacts as such is not the physical shape (*body-as-an-image*), but the body that behaves (*lived-body*). It can be an actual moving object, but also, for example, a light or sound with behavioural qualities. Nevertheless, as is apparent from the theoretical introduction, the physicality of the artefact, the fact of having a body, is essential to behave. The artefacts are physical hypotheses, and not yet embodied hypotheses as proposed by Hengeveld (2011). Nonetheless, where Frens (2006) proposed that this physical hypothesis should have sufficient product qualities, in this case they need ***sufficient behavioural qualities*** in order to draw valid and relevant conclusions.

In the first chapter, a minimalist approach applies in terms of implementation and contextualisation. 'Sufficient' in these terms reverses the idea of good enough to very minimal but acceptable. The artefacts are essentially research-artefacts, and are designed to flesh out theory and evaluate this in an experiment. One could even argue that in this chapter I primarily investigate a proposed hypothesis, based on existing theory: namely, that an artefact can adopt perceptive qualities and engage in perceptual crossing. This touches upon the field of experimental phenomenology in which Lenay (2007, 2010) is operating. By designing and evaluating the prototypes, the goal is to provide knowledge relevant for a broader design context; namely, knowledge about designing intelligent systems and product behaviour. The aim of the designed artefacts in this chapter is thus to make theory tangible, and to inform the other two chapters.

The designed artefact in the first chapter is referred to as *PeP*, short for 'perception pillar'. Although the several iterations of *PeP* do not resemble recognisable consumer products and their implementation is minimalist, they do have sufficient behavioural qualities to bring forward *design-relevant knowledge*. The prototypes of Lenay and his colleagues (cf. Theory, p. 8) are made to investigate a phenomenon between two people. The researchers take advantage of the specific minimalist, experimental and technical situation in order to initiate a fundamental study. Their experiments are conducted in the field of experimental phenomenology, and, although their findings inform designing, they are *philosophically relevant knowledge*. There are two main differences with the inventions and evaluations of Lenay and his peers, and my work. (1) The prototypes in this project give freedom to the person in the interaction: the participants are, as far as the context invites them, not restricted in their exploration. In Lenay's experiment, the actions of the participants are restricted as they move a mouse in a one-dimensional plane and receive only tactile stimuli. (2) The evaluations in this project are contextualised. The environment, although reduced to an empty room with the artefact in it, influences the interaction (for example, by its spatial outline or lighting conditions). The context of interaction in Lenay's experiment is a virtual space, unrestricted by boundaries. Only events designed in the space by the experimenter influence the participants' experience.

By going through several iterations of designing, building and evaluating *PeP*, a set of design notions is formulated, applied and validated. These design notions are applied and reflected upon in both the second and third chapter.

A broad range of high-level prototypes, often treated as physical hypotheses, characterise not only my work, but also that within (or related to) the Designing Quality in Interaction group more generally. Against a background of ecology and phenomenology, these cases have in common that they are contextualised in a specific user or product group, e.g. desktop VR (Djajadiningrat, 1998), gestural design tools (Hummels, 2000), alarm clocks (Wensveen, 2005), digital cameras (Frens, 2006), intelligent lighting (Ross, 2008; Magielse, 2011), stress reduction (Bruns, 2010), non- or hardly speaking toddlers (Hengeveld, 2011) and design tools for reflection (Mendels, 2013). As explained earlier, a minimalist approach applies to the first and leading chapter in the process. Nonetheless, in the second chapter, investigating how they are applied in our daily environment contextualises the findings further. Intelligent interior textiles are chosen as the application domain.

In the second chapter, knowledge and insights gained in the first chapter are applied in several iterations of *PeR*, short for 'perception rug'. And, in turn, insights gained in the process of designing *PeR* feed back to the process of designing and evaluating *PeP*. *PeR* functions as an example of how the theory could be applied to our daily environment. The first and second chapters are strongly intertwined.

The reason to choose intelligent interior textiles is many-sided. I have a personal interest in working with textiles. I developed this skill over many years and several projects in this area make me an expert in this field. We allow textiles very close to our body; we wear them against our skin and use them to make our homes comfortable and warm. Their qualities complement the interaction between artefact and person that I investigate in this project. The development of intelligent textiles is paramount in the field of design. Over the last few decades, the traditional textile industry has shifted its focus (Hiemstra, 2004; Dorst, 2004). The union for Dutch textile industry describes Dutch textile companies as niche-players that focus on specialist and innovative textile products and applications: a development the project seizes on and, at the same time, sets out to enhance. Furthermore, choosing interior textiles introduces a spatial characteristic that ties into the development of systems of interactive products.

The first prototype is completely handmade; the second prototype is made in collaboration with the international flooring company DESSO. The collaboration with an external partner explores the feasibility and market value of the design-relevant knowledge generated in the project. Although the theoretical background of this project may not be the main driver of this collaboration, it is the starting point for putting forward high-quality and innovative design opportunities. Besides the core research topic of the project, a considerable amount of knowledge is also generated in the field of textile materials and how to combine them with electronics.

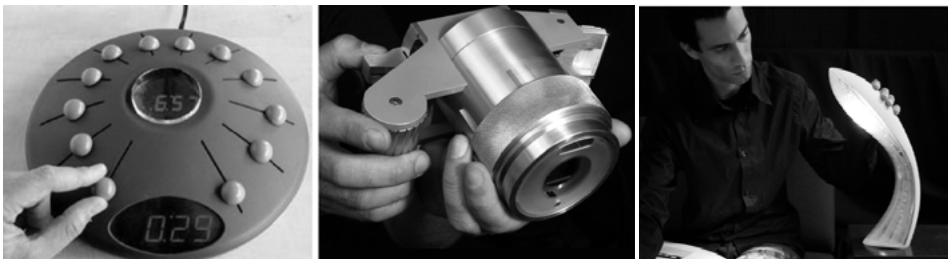


Figure 15. DQI tradition of physical hypothesis in context e.g. alarm clock (Wensveen, 2005), digital camera (Frens, 2006), intelligent lighting (Ross, 2008).

In the third chapter, student projects and shorter assignments are initiated. In this chapter I validate and add to my first-person perspective through a third-person perspective: namely from the perspective of the students. The projects start from the same theoretical background (which is open for questioning), build from the same sources, and are inspired by the design-relevant knowledge generated in the first and second chapters (which students are allowed to reject as well as extend). They bring forward artefacts that can be experienced, analysed and compared. Design-relevant knowledge is especially found in the experience of these artefacts. By designing these artefacts, the students explore in greater depth different aspects of the overall design-research project such as context, functionality, aesthetics and technology. I claim that these projects are valuable iterations and valid argumentation for the relevance and extensibility of the generated knowledge. Design-research and design-education are thus strongly connected.

Considering the first- and third-person perspectives brings into question the role of the designer-researcher in the Research through Design process. Both Hengeveld (2011, p. 203) and Bruns (2010, p. 111) argue that the designer and researcher are the same person in the Research through Design process. According to Bruns, this position is not always easy: a designer and a researcher do not necessarily value the same results. For example, interesting designerly observations may not contribute to statistical analysis. Hengeveld brings forward the advantage of being both the designer and the researcher, as this makes it possible to relate findings to aspects of the actual design, or to factors in the design rationale. He values the subjective intention of the designer.

As I believe that a great deal of knowledge is actually generated in the actual act of designing, especially knowledge of *how to design for* a given situation, I think that the design-researcher has a great advantage when she is also the designer. This does not mean she has to be the only designer; the observation and analysis of this act by other designers can bring valuable new insights. Nonetheless, I do think that without the experience of actually designing, in the context of the research matter, the design researcher will not be able to grasp all facets of it. It is about getting your head and hands around the matter. Furthermore, the skill of the designer is a huge influence on the outcome of the design-research (Hoven et al., 2007). By testing my first-person perspective by a third-person perspective, I corroborate my findings.

Bowers (2012) proposes annotated portfolios as a means 'for explicating design thinking in Research through Design that retains an intimate indexical connection with artefacts themselves while 'connoting' broader concerns in the research community'. The designed artefacts in the third chapter are considered in a similar fashion to the artefacts in Bowers's annotated portfolios. It is paramount to mention that the projects I discuss are all initiated within the context of the broader design-research project. They build from the same theoretical background and are inspired by the generated design-relevant knowledge. They are annotated in the language of this particular work. The goal of annotating is less to show familiarities than to show different aspects of the broader design research, such as context, functionality and aesthetics. The portfolio as a whole validates, and adds to, the generated design-relevant knowledge in the project. A condition for this, like the physical hypotheses in the first chapter, is that the artefacts in the portfolio are all clearly positioned in the light of the broader design-research project, as this is the context of the generated knowledge. This does not exclude other examples. Nonetheless these examples cannot be considered a third-person perspective on my findings.

To recapitulate, the entwining of the three design-research chapters means that I can build a body of knowledge that is, as discussed by Fällman and Stolterman (2010), academically credible (building theory), relevant to practising designers (investigating added value and exploring feasibility) and of societal relevance (exploring context and function).

Figure 16. Example artefact chapter 3, Kinetic Folds by Kevin Andersen

This is the first of three chapters that is structured around the leitmotiv. The chapter deals with the in-depth investigation into how to design for perceptual crossing. I show that I designed an artefact with perceptive qualities that engages with the person in this strong reciprocal interplay of perceiving and being perceived. The minimalist approach in implementation and context allows for generating fundamental design knowledge. By going through three iterations of designing, implementing and evaluating the design-research artefact, a set of design notions (leitmotiv) were developed. Each iteration is discussed in a separate sub-chapter, which allows the reader to get detailed insights into the development of the design notions. The design notions are presented on dark-coloured pages.

first chapter: generating fundamental design knowledge

an investigation into how to design for perceptual crossing

This sub-chapter is divided into four sections and a leitmotiv part. In the four sections, the artefact, the practical implementations, the evaluation of the designed artefact, and the insights gained are all discussed. In this chapter, I show how I operationalise theory in an artefact. Furthermore, the discussion of the practical implementations provides handles to start designing for perceptive qualities. An experiment shows clearly how a person's experience and the interaction are affected by the behaviour of the artefact with perceptive qualities. Going through the first iteration leads to the formulation of the design notions that are discussed at the end of this sub-chapter.

Publication of this sub-chapter:
Deckers, E.J.L., Wensveen, S.A.G., Ahn, R.M.C., Overbeeke, C.J. (2011). Designing for Perceptual Crossing to Improve User Involvement. Proceedings CHI2011, 1929-1937. ACM Press.

first iteration

designing, implementing and evaluating PeP

criteria

PeP, short for 'perception pillar', is a vehicle to explore and define the theoretical design space. *PeP* and its successors are research artefacts that are deliberately designed to investigate whether and how to design for perceptual crossing between person and artefact. As explained earlier (cf. Process, p. 28), this physical hypothesis has sufficient behavioural qualities to draw relevant and valid conclusions about designing for perceptive qualities and the phenomenon of perceptual crossing. A minimalist approach applies in terms of implementation and contextualization to attribute the person's experience and interaction with the artefact to the design variables that are implemented.

Earlier I described three components of perceptive activity in an attempt to make the phenomenon more tangible to start the design process. These three components, namely *perception of presence*, *perception of perceptive actions* and *perception of expressivity* in combination with the proposed theoretical model (Figures 12 and 13), bring forward four criteria that apply to the artefact. (1) The artefact should be able to detect perceptive activity, i.e. the presence, perceptive actions and expressivity of the person. (2) The artefact should be able to show perceptive activity to allow for reciprocity, where the person is able to perceive the presence, perceptive actions and expressivity of the designed artefact. (3) The artefact should be able to detect the presence of an external event. (4) The artefact should be able to show perceptive activity relating to the event, i.e. the perceptive actions and expressivity towards the event should be perceptible for the person.

the body

The physical body of *PeP* (body-as-an-image) is a purple square pillar (200mm x 200mm x 1020mm). The square shape is a deliberate choice, as it gives the person interacting a clear position towards the artefact. Accordingly, one light sensor (Light-Dependent Resistor) is placed on each side. In the top surface, thirteen LEDs (Light-Emitting Diodes) are evenly placed in a five-to-five grid. The perceptive body of *PeP* is reflected in the LED grid, and the dynamic qualities overtake the physical shape. This light body is *PeP's* perceptive body, and the purple pillar functions as a container for this dynamic light design.

The design of the perceptive behaviour of the light body relies to a great extent on the algorithm that translates the input of the four light sensors into the dynamics of the light body, reflected in the LEDs. The dynamic characteristics of the light body were explored and formulated in an acting-out session between two human subjects through an active exploration in movement (Hummels et al. 2007). In this

session, one participant acts as the artefact with perceptive qualities, like *PeP*. The other participant is the person interacting with *PeP*. This design tool allows for an exploration from *PeP's* point of view (Loke & Robertson, 2010). The dynamics that can be exploited are the ***location*** of the light body within the grid, the surface ***size*** and ***brightness*** of the light body, and the ***direction*** and ***speed*** of the movement of the light body. This light body is the perceptive body (lived-body) of *PeP*.

PeP sets out to follow the person. The light body reacts to the person's movement by focusing in the person's direction, and follows the person when she walks around. If the person is no longer present or is standing still, *PeP* is not able to recognise her lived-body and the person will become an object in space. *PeP* now starts to explore the space. When the person is too active, *PeP* will return its focus inwards; the light body moves to the middle of the grid. The behaviour of the light body is continuous. It does not jump from position to position but adjusts gradually. When the light body focuses on the person it will first actively explore by moving along the side where the person is present. Besides perceiving the person, the light body perceives an external event. For this event I chose two pieces of modern music. *PeP* undertakes perceptive actions towards the music. It focuses the light body in the direction of the music and bounces to the beat when it likes the music.

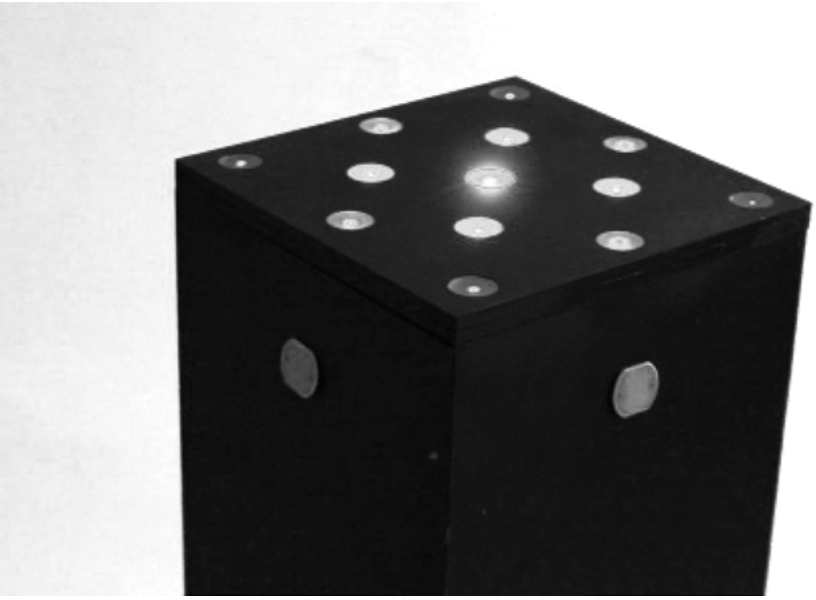


Figure 17. Impression of *PeP*.

The model in Figure 17 presents in detail the perceptive activity and the perception thereof by *PeP* and the person. *PeP* explores the environment when no person is detected. This behaviour shows its presence when not yet engaged in an active interplay. *PeP* undertakes perceptive actions such as moving in the direction of the person and the event. Expressivity in relation to person and event is found in actions such as turning its focus inwards when the person is too active, and bouncing to the beat of the music. *PeP* perceives the presence of the person by the change of input on the four sensors. It is able to perceive perceptive actions of the person, as it is sensitive to the person's position and movement. To some extent, *PeP* is sensitive to the person's expressivity as it differentiates the amount of movement by the person.

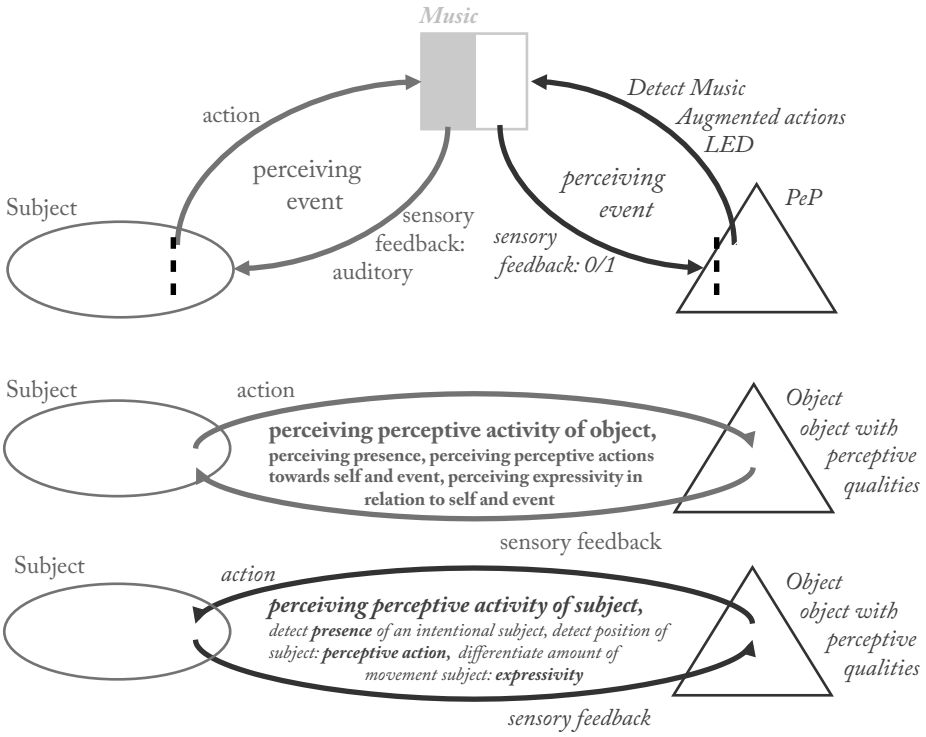


Figure18. Theoretical descriptive model of *PeP*. The perceptive activity and the perception thereof by person and artefact are presented in detail.

Figure 19. Impression of interaction with *PeP*.

I present the algorithm on three levels of abstraction. The ongoing text is a descriptive discussion; here I present the more theoretical and meta-level considerations that are at the core of developing the algorithm. Several schematic overviews concretise these descriptions. These and a data flow diagram (Yourdon, 1989) are the interface between the descriptive discussion and the pseudo-code that is presented at the end of this section. In the data flow diagram, the algorithm is abstracted to processes, variables and the data flow between them (Feijs et al., 1994). The algorithm developed over time: trying several ideas and experiencing the result. The main reason to describe the algorithm extensively is to show how the theoretical outline and examples are implemented. Moreover, in the description of the approach and the implementation, it becomes clear that the structure of the algorithm calls for an open form. By this I mean that the algorithm does not rely on prescribed scenarios. The behaviour I set out to design evolves in time and adapts to multiple people and events; a qualitative and dynamic approach is crucial. The success appears to be in the details. A small change in the constants can change the behaviour significantly. I think that next to the generated design-relevant knowledge the practical implementations should also be clear to allow for extensibility.

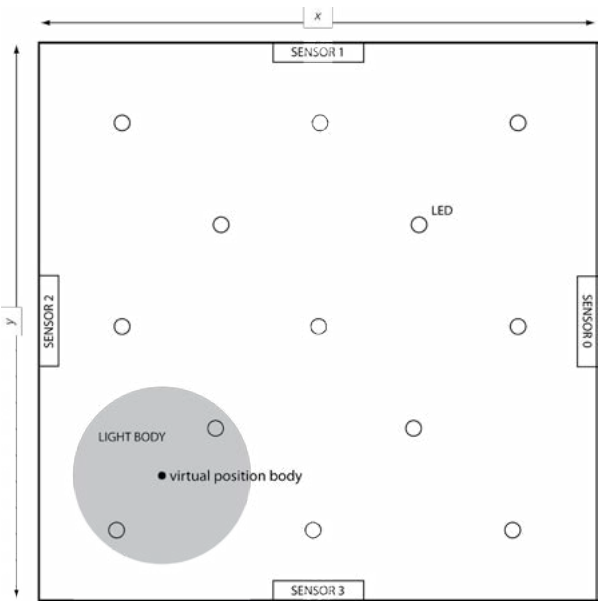


Figure 20a. Schematic overview of *PeP*.

As is evident from the description of *PeP*, the light body should come across to the person as the actual perceptive body. The light body that is reflected in the grid of LEDs is a virtual point of which the movement characteristics and appearance are determined in the algorithm. These characteristics, i.e. ***location***, ***size***, ***speed***, ***brightness*** and ***direction***, are dynamic variables that can be altered to create behaviour. Living organisms concentrate their senses in the direction of stimuli, such as turning your head when you catch a glimpse of something or moving your fingers over a surface. The overall shape of *PeP* is static, as are the positions of the LEDs and sensors. By coupling the sensor input to the behaviour of the light body, it is possible for *PeP* to focus on the person and the music without literally moving.

Figure 20a shows a schematic overview of *PeP*. In the algorithm, the four sensors and the thirteen LEDs are placed in a two-dimensional grid. An x,y notation indicates the location of the components. In this first iteration of *PeP*, the point 0,0 is positioned in the upper left corner of the virtual grid. This appeared to be very unpractical. To make it possible easily to scale or transfer the algorithm to other artefacts, a placement of the point 0,0 in the middle of the virtual grid is advisable.

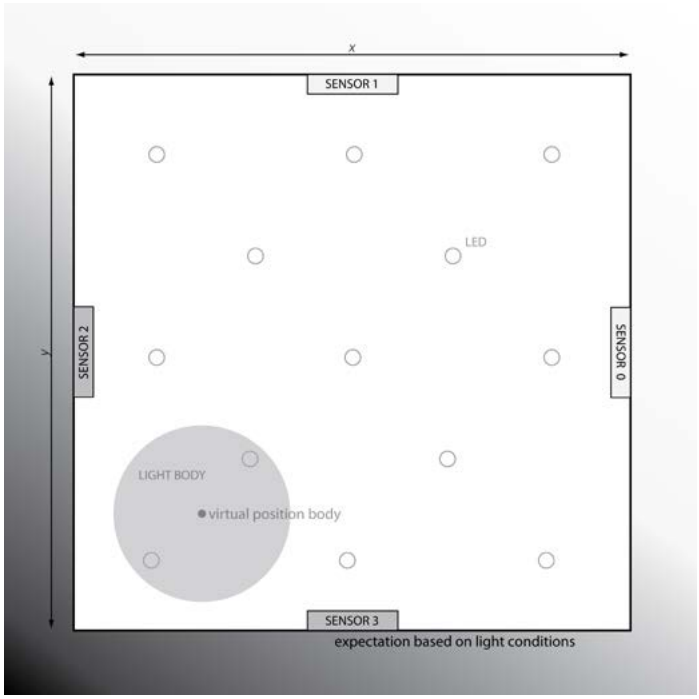


Figure 20b. *PeP* builds an expectation of the light conditions over time.

PeP detects its environment by means of the four light sensors. When it detects a change in the light input, this indicates the presence of a person as she causes a shadow to fall on the sensors. *PeP* is designed for a context in which the light conditions change slowly. For *PeP* to be sensitive to the activity of the person, instead of detecting an image in space, the change detected in sensor input determines the position of the light body. The use of this change in sensor input over isolated sensor values means that *PeP* is able to detect movement. This change is the difference between an expectation and the current input. This expectation is a weighted average over the course of sensor input; the last value is the most important. Figure 20b gives a simplified representation of this expectation of the sensor input based on light conditions. A variable, which determines the influence of the latest input, sets the speed at which the expectation value will increase or decrease. This implementation also filters out unaccounted peaks in the measurements.

The change on the sensor is the difference between the expectation value and the current input (Figure 20c). Again, a variable determines the speed at which the change value increases or decreases. The activity of the person will influence the expectation on this sensor's side, and so the person has to remain active to

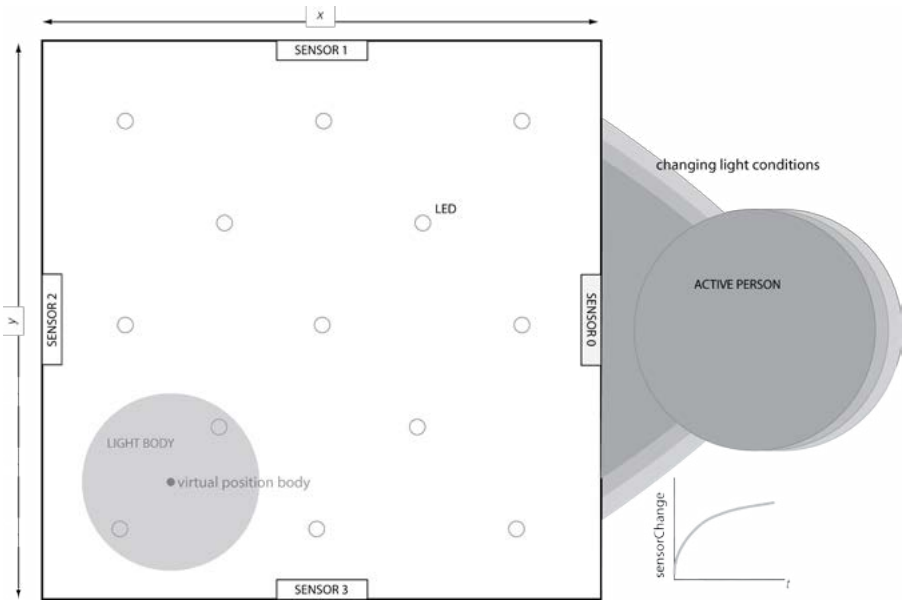


Figure 20c. The change in sensor input increases when a person is present.

be detected. It depends on the type of sensors and the condition in which the artefact operates whether or not there is a need for the weights, and how much influence they should be.

The creation of animations was a first attempt to let the light body move. The behaviour very quickly becomes too predictable and delays occur between the actiond of the person and the light body. The creation of the body as a virtual point in a grid that moves on the basis of change in sensor input provides an open form that is free to move through the grid. Angle and radius determine the position of the body (Figure 20d). In this way the light body uses the resolution of the top surface most optimally. The movement around the pillar ensures that the dynamics are subtle and that the light body can clearly focus.

The body will move from its current position to a target position. This target position is determined by an angle and radius. The angle of the sensor where the highest change in input is detected is the target angle. So when the person is active on the side of sensor 0, the target angle is 0π (Figure 20e). The angle of the light body adjusts gradually towards the target angle to provide for subtlety. The radius depends on the sum of the change value of all sensors (Figure 18e). When

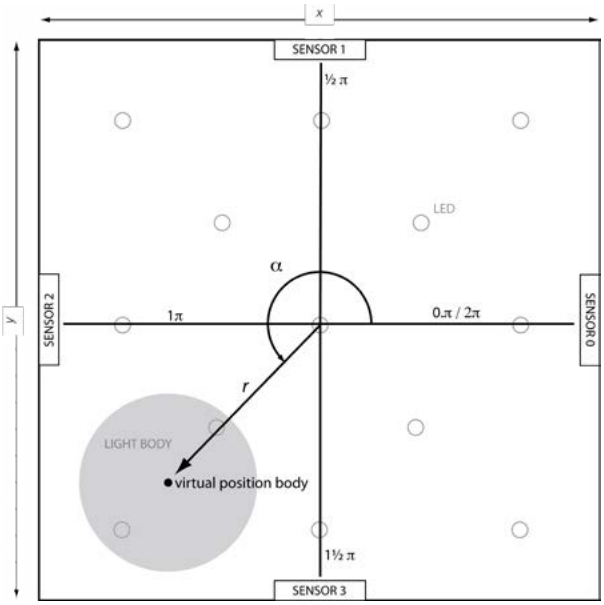


Figure 20d. The position of the light body is determined by an angle and a radius.

this sum is very low, the body will move closely around the middle of the grid. When it increases, the body will move towards the side of the pillar, towards the person. The use of an exponential function amplifies the effect of the sum of the change in sensor input on the radius.

The last step to make the body move is to update the x and y position based on the angle and radius. The body will now move towards the person (Figure 20f). This happens continuously as the angle adjusts gradually to the target angle. In each loop of the programme the new position of the body will get closer to the target: the side where the person is detected. The crux is that the target angle and radius are dynamic. If the person attracts the body to the side of sensor 0, but the body did not yet reach this position when the person moves along to sensor 2, it will change its direction immediately.

So far, the discussion has focused on the virtual position of the body that is reflected in the LEDs. A circle with sharp edges represents this light body in the Figures 20a to 20f. The actual appearance of the light body is subtler. The brightness of the LEDs gradually decreases when the LED is further away from the virtual position of the body. Again, an exponential function amplifies the effect. Figure

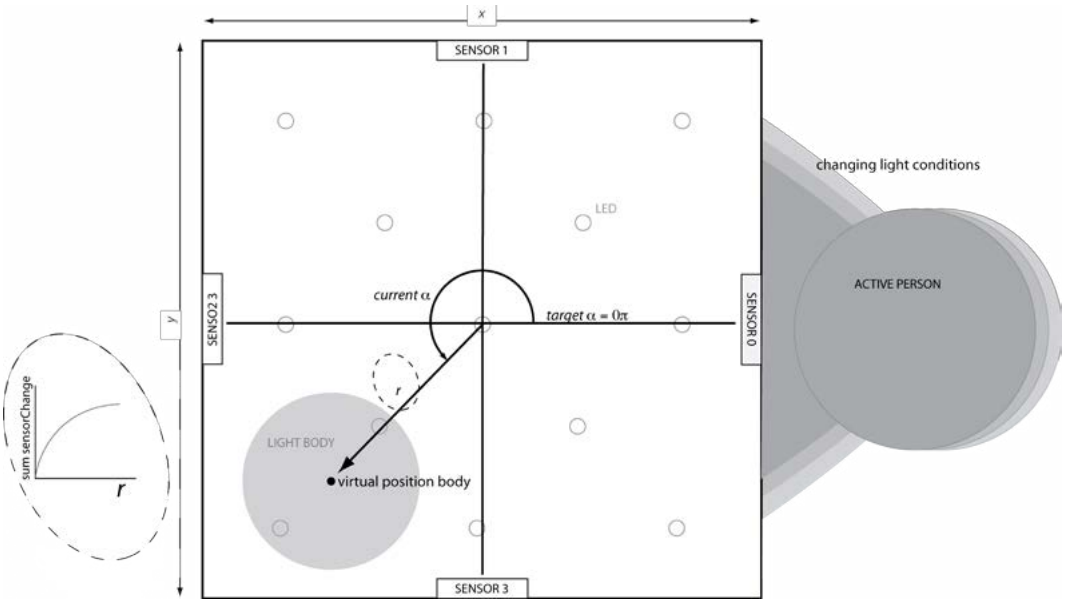


Figure 20e. The side on which the person is active determines the target angle, the sum of the change in sensor input over all sensors determines the radius.

20g presents the result. In a first iteration, LEDs within a certain distance of the virtual body would be on and others off. This results in a very harsh outline of the light body that does not fit the continuous behaviour. As the virtual body and all LEDs have an x,y position in the grid, the distance between them is easily calculated. By using different formulas to determine the brightness of the LEDs in relation to the distance to the virtual body, the appearance is easily altered.

Besides following the person, the light body shows two kinds of animated active behaviour. Living organisms act to explore: e.g. you turn your body and head to look around the room to see whether someone is there. The light body moves around, as if it explores different sides for intentional subjects. It will do this when there is no person present or active. When it detects the activity of the person, the light body will first move past the person in exploratory fashion; this is also an animation. As in this phase of the design-research process, these implementations are just an impression; created by artificially changing the variables, they are not further discussed or noted in the pseudo-code. By moving in this manner, the light body does not really explore. This active behaviour is a point of focus in the second iteration of *PeP*.

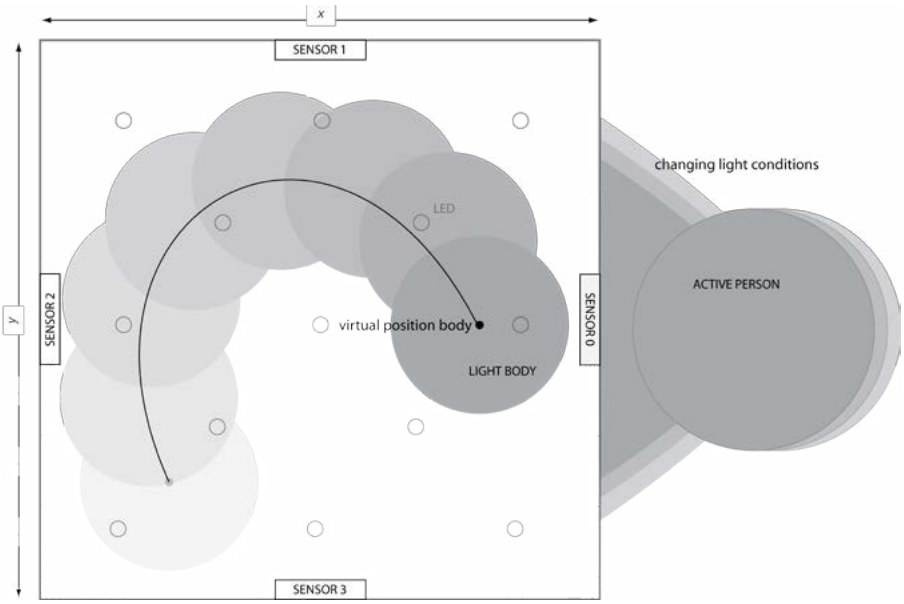


Figure 20f. The position of the light body adjusts gradually.

Next to focusing on the person, the light body focuses in the direction (Figure 20h) of the music and bounces to the music when it likes it. *PeP* will switch its focus depending on how active the person is. So when the light body moves in the direction of the music, the person can lure it back by actively engaging its attention. *PeP* does not really hear by means of a microphone. By adjusting an electronic switch, two functions can be called, both relating to the two pieces of music. In both cases, the change in sensor input, on the side of the auditory event, for example, on sensor 2 (Figure 20h), is artificially increased. This causes the light body to move in the direction of the music. In one case the light body also bounces to the music. This is done by the implementation of a periodic signal that mirrors the beat of the music in the function that sets the brightness of the LEDs. This is a very limited execution as *PeP* is not truly sensitive to the beat of the music. Nonetheless, it is sufficient for demonstrating and evaluating the design-relevant model.

Furthermore, a limitation of this implementation is that the light body will not react to sounds the person produces, whereas *PeP* seems clearly able to perceive

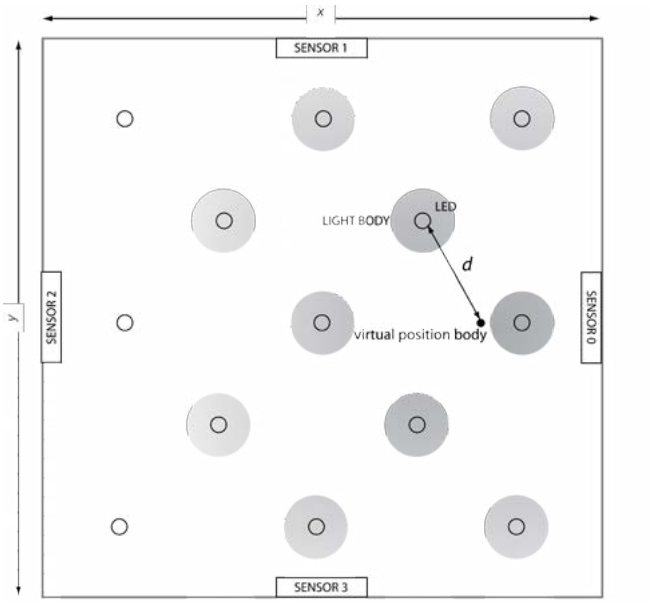


Figure 20g. The closer the LED is to the vitual body, the higher is its brightness.

the auditory event. Whether it is necessary to match the sensorial modalities is an interesting discussion. The experiment, described later, that I conducted with *PeP* showed that participants did try to lure *PeP* by making sounds. This also goes for touching *PeP*. Making the sounds and touching *PeP* were often coupled to bodily movements that are picked up by the sensors. When designing an artefact with perceptive qualities, one should consider the nature of the events, and if and how sensorial modalities have to match. There is a fine line between evoking exploration from the person and confusing her.

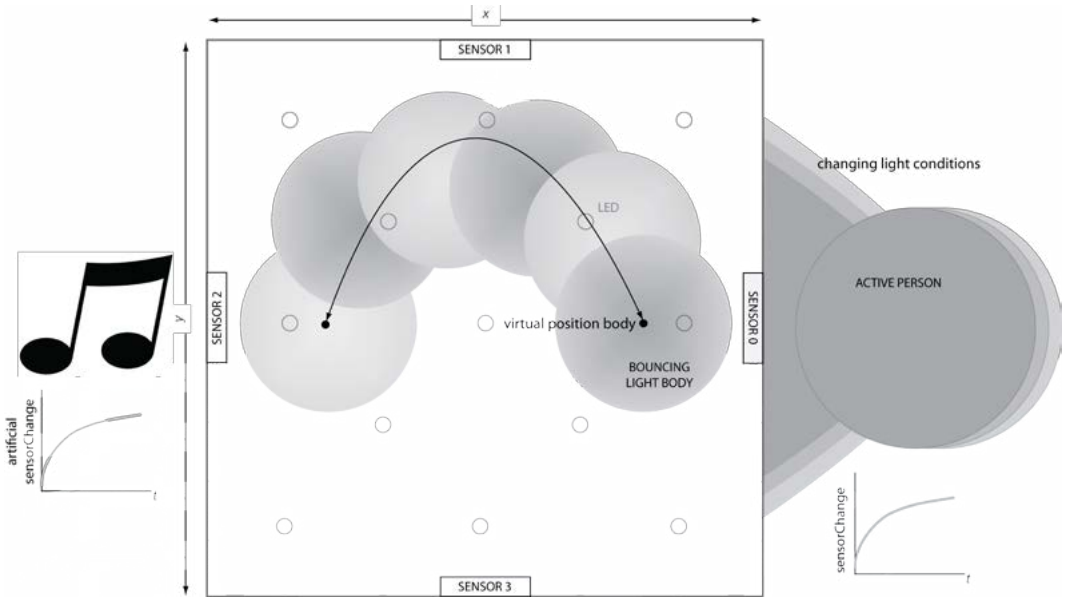
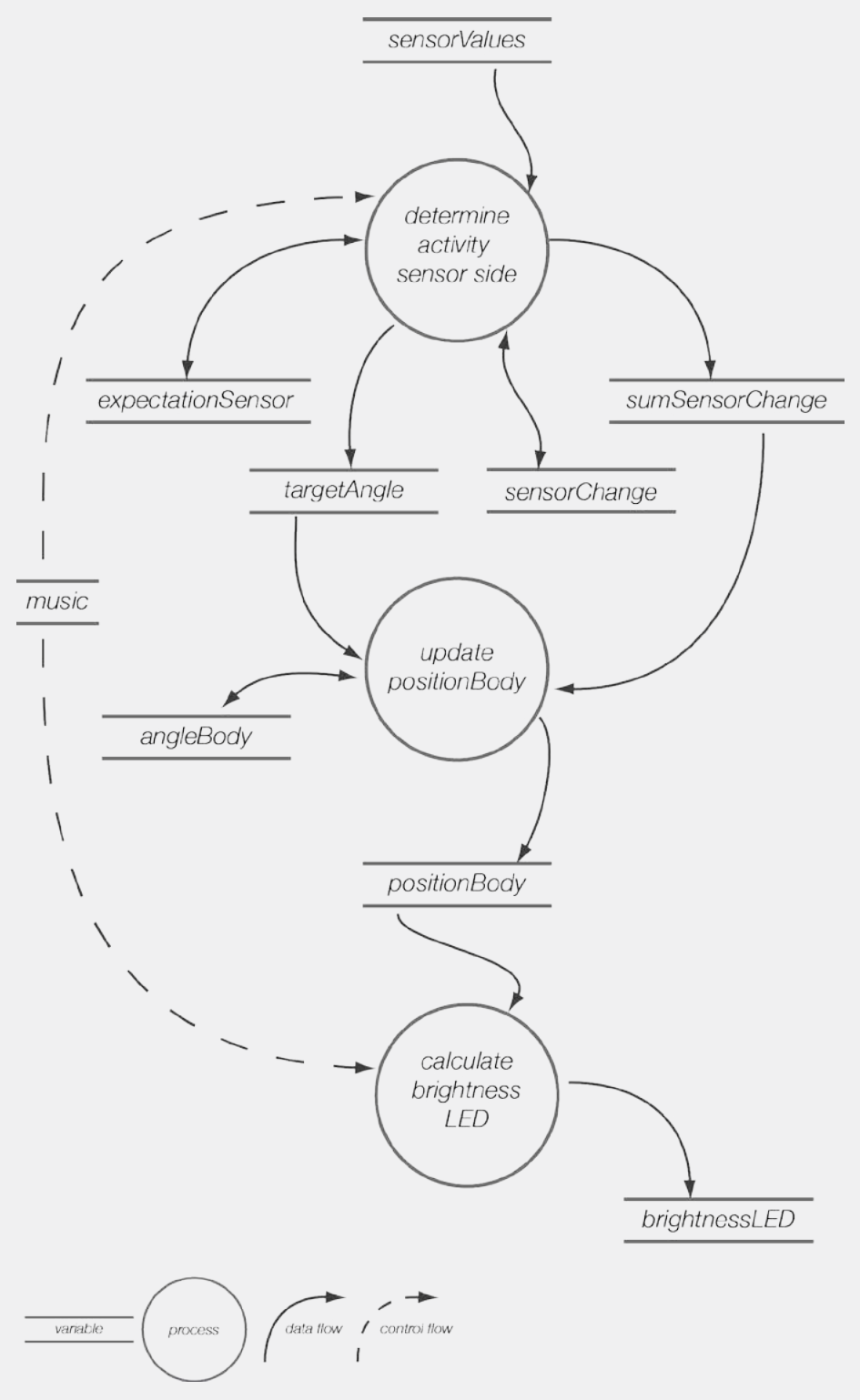


Figure 20h. The light body switches its focus between the music and the active person, the light body fades in and out, to bounce to the music.


sensorValues
determine activity sensor side
expectationSensor
sumSensorChange
targetAngle
sensorChange
music
update positionBody
angleBody
positionBody
calculate brightness LED
brightnessLED
variable
process
data flow
control flow

programme *PeP*

```
//for this programme I used the arduino environment (Arduino, 2012)

input valueLightSensors[4]; //min 0 – max 1023
output valueBrightnessLED[5][5]; //min 0 – max 4000

gridSize = 5; // The size of the grid, determined in the two dimensional plane

newInputSensor[4]; //the last measurement
expectationSensor[4]; //expectation light condition over time
sensorChange[4]; //difference between expectation and newInput
sumSensorChange; //the sum of sensorChange over all sensors


s; //variable between 0 and 1 to determine the influence of a value
z; //variable to determine the size of an effect


angleBody; //the direction of the body
targetAngleBody; //the target direction of the body
radiusBody; //the distance from the middle of the grid of the body


xPositionBody; //the x position of the body in the grid
yPositionBody; //the y position of the body in the grid

musicSwitch1 ; //when this switch is on PeP artificially hears music
musicSwitch2; // when this switch is on PeP hears and bounces to the music

//determine sensor with highest sensorChange, the angle of this sensor is the targetAngle
targetAngleBody() {
  highestSensorChange = 0;
  for all sensors i {
    if (sensorChange[i] > highestSensorChange) {
          targetAngle = i * 0.5π;
          highestSensorChange = sensorChange[i];
    }
  return targetAngle;
}
```

```
//determine the distance between the light body and each LED
distanceBodyLED(int x, int y) {
    return  sqrt ( sq(xPositionBody – x) + sq(yPositionBody – y));
}

loop {

for all sensors i {
  newInputSensor[i] = valueLightSensors [i];

  sensorChange[i] = sensorChange[i] * s + abs(expectationSensor[i] –
                                                    newInputSensor[i] * (1-s));

  expectationSensor[i] = expectationSensor[i] * s + newInputSensor[i] * (1-s);
 }

sumSensorChange = sumSensorChange * s + (sensorChange[0]+
                    sensorChange[1]+ sensorChange[2]+ sensorChange[3]) * (1-s);

angleBody = angleBody * s + targetAngleBody() * (1-s);

//I chose z=4, sumSensorChange ≠ 0
radiusBody = halfGridSize – exp( z0 / sumSensorChange);


xPositionBody = halfGridSize + radiusBody * cos(angleBody);
yPositionBody = halfGridSize + radiusBody * sin(angleBody);

//To update the brightness of the LED the two-dimensional array positionLED is
  mapped to the two-dimensonal array valueBrightnessLED. I used the TLC5940 and
  the libary, available from the arduino website, to control this leddriver. I chose z=2.2.

for all LEDs x,y {
  valueBrightnessLED[x][y] = maxValue / exp(z1 * distanceBodyLED(x,y));
 }
```

```
//The music source is positioned in the direction of sensor 2. When the music piece 1 is
  turned on the sensorChange on sensor 2 is artificially increased. I chose z = 10

if musicSwitch1 is on {
  sensorChange[2] += z2;
}

// When music piece 2 is turned on the light body bounces to the beat using a
   periodic signal.

if musicSwitch2 is on {
  time += timestep;
    for all LEDs x,y {
          valueBrightnessLED[x][y] = (cos(time) + z3) *          //I chose z=1.1
          (maxValue /exp(z4*distanceBodyLED(x,y)));              //I chose z=2.2
     }
  }
}
```

general hypothesis

The underlying thesis for designing *PeP* is that designing for perceptive qualities in objects makes it possible for person and artefact to engage in a rich reciprocal interplay of perceiving and being perceived. Perceptual crossing can happen between them, positively influencing the person's feeling of involvement. Sharing their perception of an external event will amend the interaction and experience of the person.

In an experiment I evaluate the influence of the designed perceptive qualities on the interaction and the person's experience. These qualities were further defined in components of perceptive activity. *The general hypothesis is that when person and artefact are able to engage in a rich reciprocal perceptive interplay and share their perception of the event, the feeling of involvement of the person increases.*

Before discussing the experiment further, I would like to elaborate on the use of the term 'perceptual crossing'. Over the course of the project, naturally my level of understanding of how to design for perceptual crossing developed. At the time of designing and conducting the experiment with *PeP*, I considered the interaction and experience in terms of perceptual crossing. In the discussion and following iterations it will become clear that, in this phase, *PeP* and person are not truly able to engage in perceptual crossing, and the experience might be better described as 'rich perceptive reciprocal interplay'. Nonetheless, I will use the term in the description of the experiment, as this was the line of thinking at the time.

set-up

In this experiment twelve participants, all design students, go through five situations in which *PeP*'s perceptive activity and the presence of the external event vary. The possible perceptive connections presented in the proposed theoretical model vary (Figure 17). There is a deliberate order effect as all participants go through the five situations in the same order. This allows for the participant to get familiar with *PeP*'s activity; moreover, the perceptive activity of *PeP* is built up over the five situations. Only subsequent situations are compared.

The theoretical model shows four perceptive connections. (1) The participant (subject) perceives the perceptive activity of *PeP*; (2) *PeP* perceives the perceptive activity of the person; (3) *PeP* perceives the music (event); and (4) the person perceives the music. In the experiment, these connections are treated as variables. The first is a constant, as the participant is always able to perceive *PeP*, either when *PeP* performs perceptive activity in relation to the participant, or not. The

other three connections can vary: *PeP* perceives the participant or it does not; *PeP* perceives the music or it does not; and the participant perceives the music or she does not. Table 1 gives an overview of all possible situations. The participant goes through the grey-marked situations in the given order. These five situations are most relevant for the evaluation. The order and choice for these situations means that the perceptive activity build up. Furthermore, the position of the subject changes in each situation. The overview in the results and discussion section (page 58) presents a more detailed description of each situation and the situation-specific theoretical model in relation to the results.

Thirteen seven-point differential semantic scales are used to measure the participants' feeling of involvement. A semantic exploration of the term involvement is the basis for the list of differentials (Osgood et al., 1957). The differentials are: intense/shallow, contact/no contact, close/distant, intimate/not intimate, connected/detached, warm/cold, understanding/ignorant, familiar/unfamiliar, sharing/isolated, influential/not influential, united/individual, associated/dissociated, and involved/alone. In relation to the semantic scale, the participants answered a few open questions. All participants were filmed. Their answers and the observations complement the results and discussion.

Table 1. Overview on different conditions

order	*Subject Perceives PeP*	*PeP Perceives Subject*	*Subject Perceives Music*	*PeP Perceives Music*
4	**x**	**x**	**x**	**x**
5	**x**	**x**	**x**	**-**
3	**x**	**x**	**-**	**x**
	x	**-**	**x**	**x**
2	**x**	**x**	**-**	**-**
1	**x**	**-**	**-**	**x**
	x	**-**	**x**	**-**
	x	**-**	**-**	**-**

sub-hypotheses

The main hypothesis is that the feeling of involvement of the participant increases if perceptual crossing between participant and *PeP* (can) happen. Furthermore, hypothetically sharing the perception of an external event increases the participant's feeling of involvement. The comparisons between subsequent situations are the sub-hypotheses, namely:

(1) the feeling of involvement of the participants is in situation 2 greater than in situation 1; **(2)** the feeling of involvement in situation 3 is greater than in situation 2; **(3)** the feeling of involvement in situation 4 is greater than in situation 3; and **(4)** the feeling of involvement in situation 4 is greater than in situation 5.

The chi-square test for non-parametric statistics between two successive situations shows whether the observed sample significantly differs from the expected sample (Siegel, 1956). The test does not show the direction of the effect. The direction is presented by comparing bar diagrams of all cumulated ratings of all differentials (n=13) over all participants (n=12) for each of the seven scales from high to low involvement. An overview of the data is presented on page 58. In the comparisons, the expected values are the values measured in the first of the two compared situations. The observed values are the values measured in the second of the two compared situations.

results and discussion

The participants' feeling of involvement is significantly ($p<0.001$) higher in situation 2 than in situation 1. Participants indicate that they feel perceived in situation 2, matching sub-hypothesis 1.

In situation 3, the feeling of involvement significantly differs from the feeling of involvement in situation 2, but participants feel less involved in situation 3, contradictory to sub-hypothesis 2. The participant can experience perceptual crossing in situation 3, but does not perceive the external event that *PeP* perceives. The feeling of involvement decreases significantly ($p<0.001$). From the participants' answers and observations, it appears that the participants do not relate *PeP*'s activity to perceiving music or any other specific event. In case the participant would be able to relate *PeP*'s perceptive activity to the music, she would be able to perceive, as it were, 'through' the designed artefact. When you see someone dancing to music, you do not hear yourself, you indirectly perceive the acoustic event. So if the person is able to perceive 'through' the designed artefact, the person becomes aware of events that she cannot perceive or is not capable of

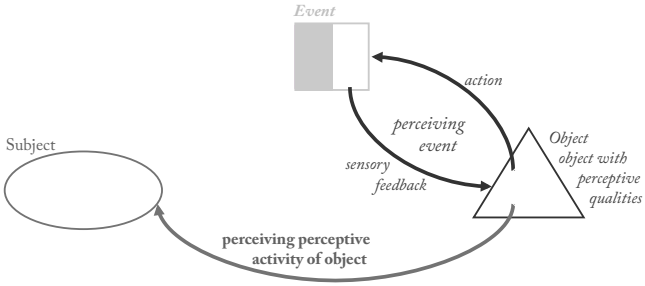
perceiving directly herself. This observation refers back to the work of Bach-y-Rita on sensory substitution systems. In these systems, direct sensory mediation gives a person the ability to perceive objects and events that her perceptive capabilities do not allow her to. In the experimental situation (situation 3), this mediation could indirectly happen through the perceptive activity of the artefact. This brings forward various opportunities in designing for systems. Evidently this did not happen in the experiment. Participants are confused about *PeP*'s behaviour, as its activity is, in their experience, not directed to anything. They have never seen *PeP* reacting to music before, nor are they aware of the effect that an event could be present.

The feeling of involvement of the person in situation 4 is significantly ($p<0.001$) higher than in situation 3. Corresponding with sub-hypothesis 3, as in situation 4 both *PeP* and the person perceive the event and each other. Several participants indicate this situation to be the richest in terms of interactive qualities.

Participants also feel significantly ($p<0.001$) more involved in situation 4 than in situation 5 (sub-hypothesis 4). Although there is a significant difference, it is clearly visible in the bar diagrams that the size of the effect is smaller than in preceding comparisons. When you perceive an event and the other does not, this is of less influence on your experience than when you do not perceive the event and the other does. It is especially the position of the self that affects a person's feeling of involvement in a situation (Deckers et al., 2009).

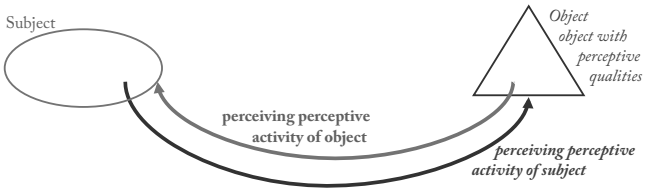
Situation 1

The participant encounters PeP. PeP does not perceive the participant, but is able to perceive music. The participant cannot hear this music. PeP and the participant cannot engage in perceptual crossing and cannot share the perception of the music.



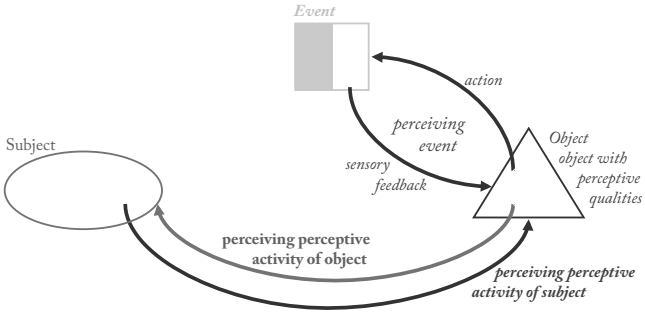
Situation 2

The participant encounters PeP. PeP is able to perceives the person. There is no music in this situation. Participant and artefact can engage in perceptual crossing.



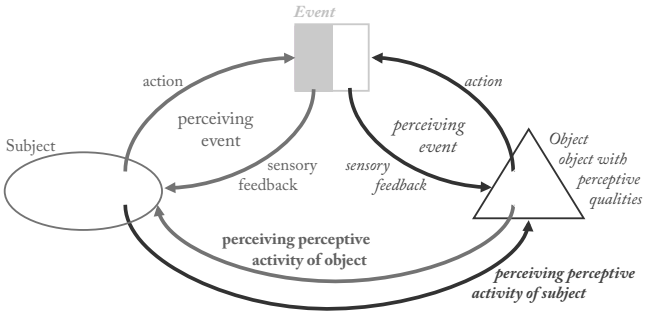
Situation 3

In this situation PeP perceives both the participant and the music. The participant does not hear the music. Perceptual crossing can happen between person and artefact, but the participant is not able to directly share PeP's perception of the music.



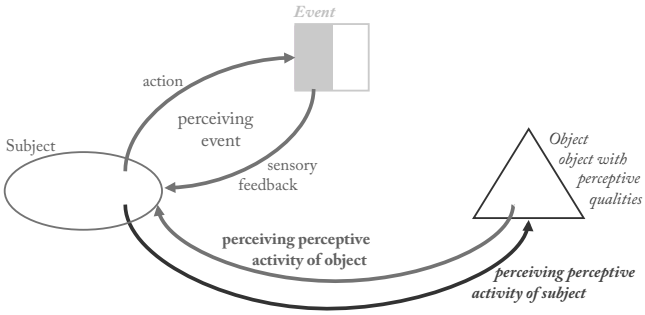
Situation 4

In this situation PeP and participant can engage in perceptual crossing and can share their perception of the music. All perceptive connections are evident.

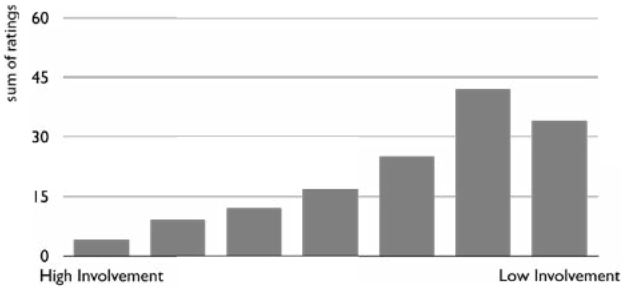


Situation 5

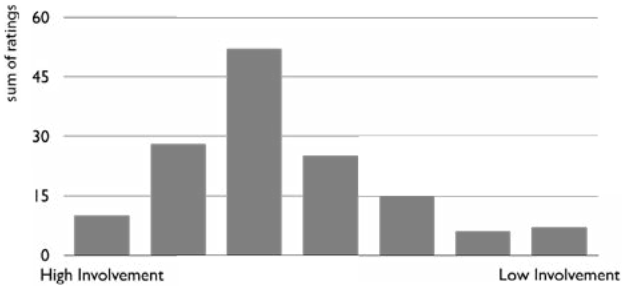
The participant encounters PeP. PeP is able to perceive the participant and they can engage in perceptual crossing. Only the participants is able to hear the music, and so she cannot directly share her perception with PeP.



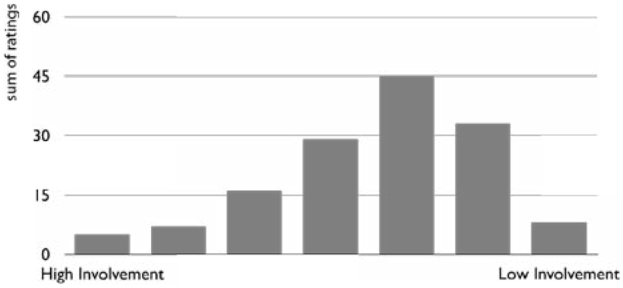
Situation 1



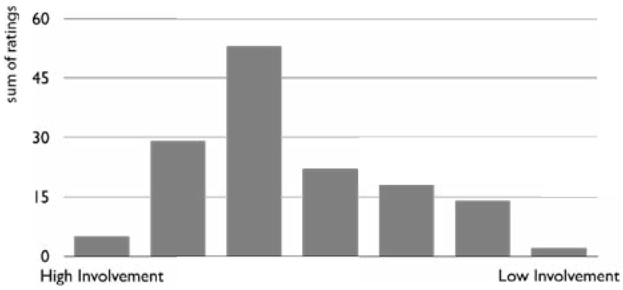
Situation 2



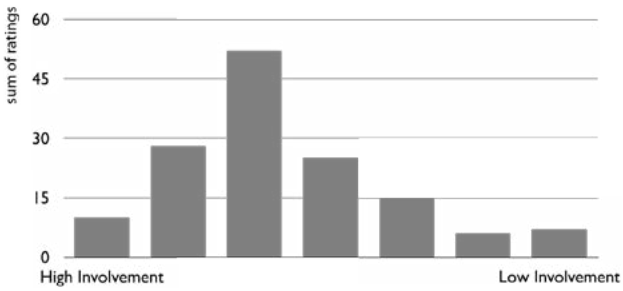
Situation 3



Situation 4



Situation 5



This first iteration clearly shows how a person's experience is affected by the behaviour of the artefact with perceptive qualities. When the artefact does not perceive the person, or when it acts independently of the person or an event the person feels that she does not affect the artefact. She feels not involved or less involved. Although the participants feel to be perceived by *PeP* and experience a rich reciprocal interplay, it is questionable if perceptual crossing truly happens. The game of attraction and escape does not really take place, as all actions of the light body to explore are really just animations. Sensor input is gathered at all sensor sides all the time, so there is no need to explore. The light body just follows the person. The addition of the external event amends the interaction and experience of the person. Nonetheless, the interplay between artefact and person is not sufficiently refined for the person to perceive through the artefact. The reciprocal interplay needs to be stronger for the person to trust and follow the activity of the artefact.

The theoretical background and designing and evaluating *PeP* bring forward several designerly, theoretical and practical insights that I formulate in a set of design notions, namely: Focus the Senses, Show Explorative Behaviour, Subtleness of Movement, React to External Event, Recognise Explorative Behaviour Subject, Reflect Contextual Noise, Remember and Anticipate Perception over Time. The design notions develop throughout the process. Note that the labelling of these design notions also developed throughout the project. Consequently, the labelling of the notions in several publications differs from the labelling in this dissertation. These design notions are part of the leitmotiv through the work and reappear several times in the text. Some of the design notions (Focus the Senses, Show Explorative Behaviour, Recognise Explorative Behaviour Subject) were formulated early in the process, as a result of the movement session. Other design notions (Subtleness of Movement, Reflect Contextual Noise) came forward while interacting with the first iterations of designing the behaviour of *PeP*. Some of the notions (React to External Event, Remember and Anticipate Perception over Time) are directly in line with the theory and the theoretical model: the notions develop throughout the project. Next I will introduce each notion. Some of the notions are already implemented in *PeP* and developed further by analysing the experiment and process. When applicable, the implementation in *PeP* and the implications for the next iteration are discussed. For other notions, it is not yet clear how to develop them further.

Figure 21. Impression of interaction with *PeP*.

focus the senses

Living organisms typically focus their senses, e.g. you close your eyes and turn your ear in the direction of the sound. In similar fashion, *PeP*'s light body moves in the direction of the person and focuses on the person by following her. Naturally, actions and sensory feedback are directly coupled. Perception is interactive and participatory; it is the coupling of actions we undertake and the sensory feedback this results in, and the other way around. This is not the case for *PeP*: it is sensitive at all sides all the time. The challenge in the next iteration is to couple the sensory and active characteristics more directly in the algorithm to improve the embodiment of the sensing and acting.

show explorative behaviour

Living organisms act to gain sensory input on the environment, e.g. you turn your body and head to look around the room to see whether someone is around. *PeP*'s light body also moves around to explore the four sensor sides for intentional subjects. In addition, when *PeP* detects the presence of the person, it will give the impression that it actively explores the person. The light body focuses in the direction of the person and makes little movements from left to right to explore the interaction space. Both these explorative actions of *PeP* are just an impression: by these actions the light body does not really explore. This activity has to be enhanced to become more than an animated, pre-programmed movement of the light body. The artefact has to obtain intrinsic motivations to explore, depending on the situation; it has to obtain perceptually motivated perceptive activity.

subtleness of movement

The actions we undertake to perceive are smooth, e.g. you turn your head in a continuous movement to look at what is behind you. The light body does not appear, but moves gradually from one position to the other. It moves in a continuous and sustained manner. The appearance of the light body enhances the dynamic quality. The centre of the body is brighter than the edges; the lapse is exponential, instead of linear, to create a more gradual and natural effect. An analogue output appeared to be crucial. The balance between, and the integration of, the aesthetics of the behaviour, electronics and physical appearance are a major point of interest in the next iteration, as the subtlety provided in the algorithm does not work through in the dynamic appearance of the light body.

react to external event

In inter-subjective interaction, people build a common space in the environment. This environment influences and shapes the interaction. Are you sitting at the table or standing in an open space? Can anyone enter the space or can the telephone ring? The surrounding and the events in it influence the interaction. In this design phase, the addition of an external event shapes the common space. *PeP* can perceive music. *PeP* focuses in the direction of the music and can expressively bounce to the beat. Sharing the perception of an external event amends the interaction and the experience of the person. It becomes possible for the person to perceive events that she normally cannot, or not directly, perceive, as it were, through the artefact. For this to happen, the perceptive reciprocal interplay between person and artefact should be strong. The person has to trust and follow the artefact's activity.

recognise explorative behaviour subject

The designed artefact not only shows but also perceives perceptive activity. It should be sensitive to the exploratory actions the person undertakes to perceive it and their common space. *PeP* is sensitive not to isolated sensor values, but to a change in sensor input. It has an expectation based on the foregoing measurements, and compares this to the current input. *PeP* is sensitive to movement and when the person is still her lived-body is no longer detected, and she becomes an object in space. The light body loses its focus and shows explorative action in relation to the environment. This notion is at the core of building the intelligence of the artefact in the course of the interaction, as the person's actions become meaningful to the artefact. Detecting and differentiating the activity of the person are essential yet complex.

reflect contextual noise

When you are in dialogue with someone, you are focused on the person you are talking to. This, however, means neither that there is no contextual sensory input, nor that you do not undertake actions to get other sensory input. Particularly when the sensory input reaches a certain level you will perceive and act upon this event. For example, when something makes a lot of noise or moves suddenly and quickly. As *PeP* makes use of light sensors, it is sensitive not only to the presence of the person but also to other changes in the light conditions. Moreover, the influence of the person on each sensor can differ, as the four sides do not have to be equally exposed. It appears that this influence of the contextual conditions gives a natural feel to the behaviour, as it causes activity of the light body that is not anticipated. However, for *PeP* to function, a conditioned setting is preferable. There is a fine line between being too predictable and confusing.

remember and anticipate percption over time

In our perception of the world we are aware of bygone perception and we anticipate future perception. *PeP* is not aware of its own perception and does not rely on history or anticipate what could happen next. The integration of the expectation is a very limited but initial hint of the implementation of this design notion. The challenge in the next iterations is to build an experience.

Figure 22. Person interacting with *PeP*.

Like the preceding sub-chapter, this sub-chapter is also divided into four sections and a leitmotiv part. In the four sections, the artefact, the practical implementations, the evaluation of the designed artefact, and the insights gained are respectively discussed. In this chapter, I show how I further operationalise theory in the artefact and develop the design notions. To investigate more closely the phenomenon of perceptual crossing, I focus solely on the reciprocal interplay between person and artefact. I get a better understanding of how and to what extent perceptual crossing is achieved. It not only becomes clear which design notions to develop, but also how to further develop the design notions.

Publication of this sub-chapter:
Deckers, E.J.L., Lévy, P.D., Wensveen, S.A.G., Ahn, R.M.C., Overbeeke, C.J. (2012). Designing for perceptual crossing: applying and evaluating design notions. International Journal of Design, 6(3), 41-55.

second iteration

designing, implementing and evaluating PeP+

a new iteration

The insights gained by designing and evaluating *PeP*, as well as those gained by designing *PeR* in chapter 2, are input for an iteration of *PeP*, named *PeP*+. *PeP*+ is short for 'perception pillar plus'. After designing and evaluating *PeP*, I formulated a set of design notions that I apply and evaluate in this iteration. The experiment with *PeP* showed that the addition of an external event amends the interaction. Nonetheless, it appeared that perceptual crossing between person and artefact did not truly happen. The goal for designing and evaluating *PeP*+ is to investigate more closely the reciprocal interplay between person and artefact, not taking into account an external event. The design notions further develop through the process of applying and evaluating them. In this iteration I set out to get a better understanding of how and to what extent perceptual crossing is achieved.

the body

PeP+, is in line with *PeP*, a square pillar (190mm x 190mm x 1160mm). Looking at it straight from above gives the person a very dominant position, which is not desirable as the interaction happens *between* person and artefact. *PeP*+ is higher than *PeP* to change the person's perspective on the top surface. Each of the four sides and each of the four corners hold an ultrasonic sensor (Devantech Ranger, SRF04). This sensor measures the distance to the person. *PeP*+ uses eight sensors instead of four to gain more detailed information on the position of the person. Moreover, it allows to follow more closely the movements by the person. The algorithm links the sensor input to the brightness of seventeen LEDs that all have a position in a static matrix. The light body is reflected in the seventeen LEDs.

When designing *PeP*+ the focus is also on the dynamic qualities of the light body. The light body is the perceiving body. The sensors of *PeP* are visually detached from the light body and, thus the sensing and acting bodies are visually disembodied. The eight sensors of *PeP*+ are placed out of sight of the person. Furthermore, the physical body of *PeP* does not provide a high-resolution presentation of the light body, whereas the algorithm does provide for subtle, continuous movement. The top surface of *PeP* houses a grid of thirtheen LEDs covered by separate sandblasted pieces of Plexiglas. Designing and the experience of *PeR* made it very evident that a subtle integration of material and electronics is crucial. Therefore I conducted several material explorations to create a top surface for *PeP*+ in which the aesthetics of the digital is better balanced and integrated with the aesthetics of the materials and the appearance of the light. The top surface of *PeP*+ consists of a combination of nylon threads and cast silicon. The light body appears to move in the surface instead of being projected onto the surface. The light has more body.

Figure 23. Impression of *PeP+*.

The light body of *PeP* follows the person around the space. As discussed earlier the exploratory movements that it portrays are animated, and the light body does not actually explore. There is no need to explore, as all sensors are active all the time. By implementing the design notions Focus the Senses and Show Explorative Behaviour more thoroughly, sensing and acting become more strongly coupled in the algorithm. In relation to this, the light body gets intrinsic motivations to explore. This behaviour is referred to as the *active* behaviour.

Based on Bayesian surprise (Itti & Baldi, 2009) theory, I defined several more meta-level concepts to achieve this *active* behaviour of the light body. *PeP*+ will be sensitive to **surprise**. Surprise can only be defined in a relative and subjective manner. There are two essential elements of surprise, namely **uncertainty** and **expectation**. *PeP*+ will be surprised when something happens it did not expect; moreover, it becomes uncertain when the expectation is not based on its recent experience. To build the expectation, *PeP*+ needs to be aware of bygone activity: it needs a memory. *PeP*+ can only get uncertain when it cannot perceive in all directions all the time. Not only should the sensory input determine its actions, as is the case in *PeP*, but also its actions should determine the sensory input. Its activity has to be perceptually motivated. You can only get curious when you do not yet know everything. On the other hand, we are sensitive to events that happen outside our focus. When something makes a lot of sound or moves quickly and suddenly you will epecially perceive this. What is behind me is not visually absent (Merleau-Ponty, 1958, p. 6).

When the person is active she will attract the light body. The light body will focus in the person's direction and actively explore the side she is on. The person has to remain active to keep the light body's attention. The light body will follow the person around the pillar, but in time the light body gets curious about what is happening on other sides and moves towards other sides to explore them. The light body has to move there to gain sensory input. The person might follow the light body, but if she does not, the light body will quickly return to her as it remembers her presence. When the person is still or is no longer present, the light body explores the space.

Figure 24. Impression of interaction with *PeP+*.

The algorithm of the *active* behaviour builds on the algorithm of *PeP*. The light body of *PeP* merely follows. The concepts of detecting the change in sensor input, the virtual arrangement and the position of the body, sensors and LEDs in it, and the reflection of the light body in the brightness of the LEDs still all apply (Figure 25a). The placement of the 0,0 point other than in the middle of the grid appeared to be unpractical, so this is adjusted. Different from the first iteration of the algorithm, the position of the light body is not determined by an angle and a radius. The use of the angle and radius means that the light body optimally uses the resolution provided in the top surface of *PeP* by moving along the sides of the pillar. This is no longer needed for *PeP+*, as the resolution of the top surface provides for sufficient subtlety and focus, which is also the case if the light body moves through the middle of the surface. The body has an x and y position in the grid.

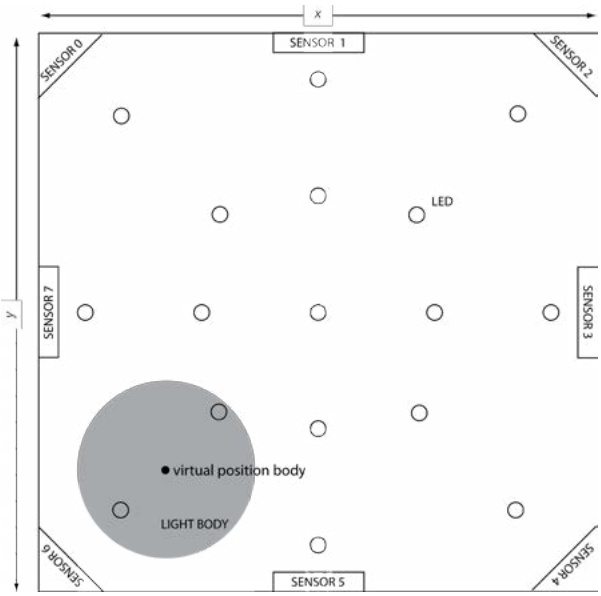


Figure 25a. Schematic overview of *PeP+*.

As explained earlier, the position of the body in this algorithm not only depends on the sensor input, but also the sensor input depends on the position of the body. The eight sensors all have an x,y position in the grid. The distance between the light body and each sensor is easily calculated. When the body is within a certain range of the sensor, the sensor becomes active (Figure 25b); at this moment, the sensor is most sensitive. By increasing or decreasing this range, the artefact has blind spots or a sensor field of two or more sensors.

When a sensor is active, the surprise is determined based on its expectation. The expectation value relies on a short memory. *PeP+* stores a number of input values. The input is the distance from *PeP+* to an object or person in the environment. The latest input has the greatest weight. *PeP+* expects a certain input on this sensor. The surprise is the difference between the expectation value and the latest input. The more the latest input value deviates from the expectation, the higher

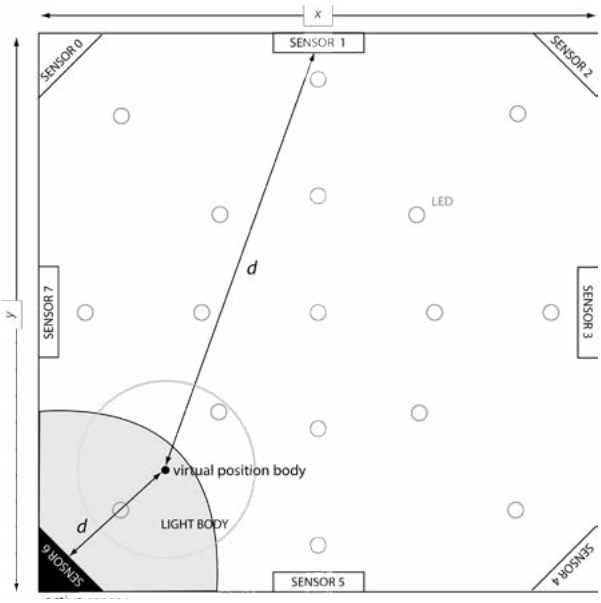


Figure 25b. When the light body is in a certain range of the sensor, the sensor is active.

the surprise. Although this is similar to the approach in the first iteration of the algorithm, the memory is now more refined. Moreover, the time lapse of the memory is easily adjusted. The surprise gradually adjusts to filter out peaks in the input. The surprise only directly adjusts when the sensor is active. *PeP*+ remembers the latest surprise value. When the sensor is not active, it is less sensitive to input. On the inactive sensors, the change in sensor input is determined in the same manner as the behaviour of *PeP*. The expectation value is a weighted average over the course of sensory input that is compared to the latest input value. The difference between them is the change value. Only if this change value exceeds a threshold does the surprise on this sensor increase.

Besides a surprise value, each sensor side has an uncertainty value. The time passed since the body was in range of the sensor, and the sensor was thus active, influences *PeP*+'s uncertainty or curiosity. The longer ago the light body was at a

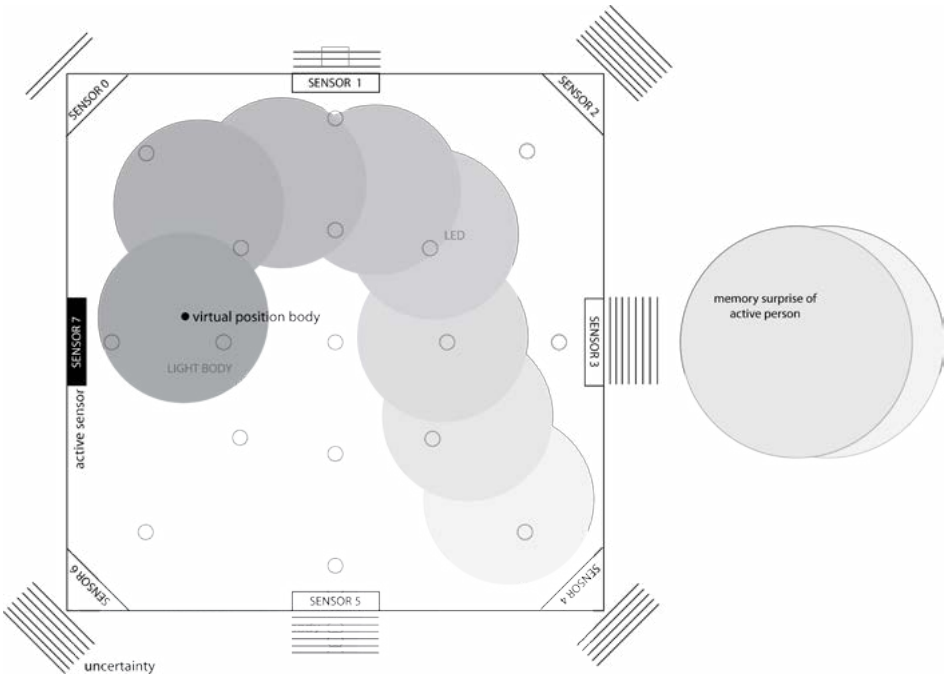


Figure 25c. The time past since a sensor was last active, and the memory of surprise determine the uncertainty.

sensor side, the more anxious the body will be to move towards this side (figure 25c). This experience of time is subjective, as it takes into account the stored surprise value. The higher the surprise *PeP*+ experienced on this sensor side, the quicker it will become curious about this side. When the sensor is active, *PeP*+ does not experience any uncertainty on this side.

Both the surprise and the uncertainty define the attraction the sensor side exerts on the body. For the light body actively to explore the sensor side the person is on, all sensors influence the attractiveness of their neighbouring sensor. When the attraction that sensor 3 exerts on the light body raises, the attraction that sensor 2 and sensor 4 exert on the light body also increases. The light body actively focuses on a side, instead of staring in a direction. The x,y position of the sensor with the highest attraction on the body is the target position of the body.

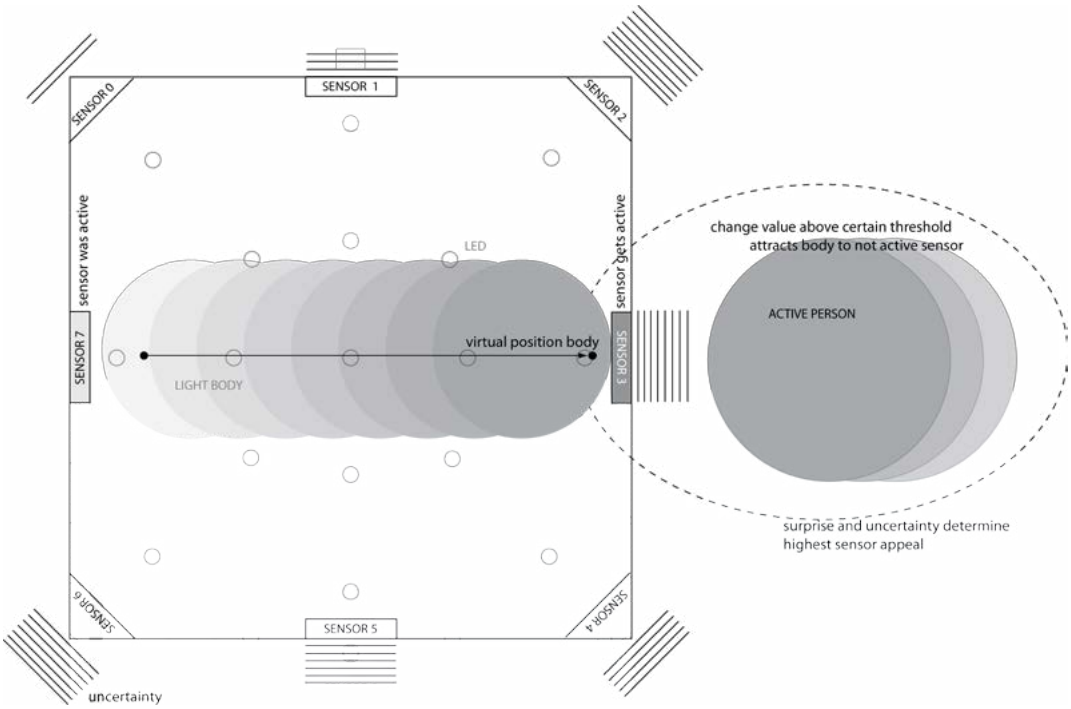


Figure 25d. The body adjusts its position towards the target position. The target is the position of the sensor that exerts the highest attraction.

The body moves as it gradually adjusts its position towards the target position. The difference between the current and target position sets the direction in which the body moves. It moves in this direction with a certain speed. This speed depends on the direction, and thus on the distance, between the current and target position. To make sure that the velocity does not get too high, a norm, based on the radius between x and y position, restricts it. The updated position of the body is the current position plus the velocity that holds a certain direction. The body moves towards the sensor side that exerts the highest attraction (Figure 25d).

The approach for setting the brightness of the LEDs did not change compared to the algorithm of *PeP*. All LEDs have an x,y position in the grid. The distance between the body and each LED is easily calculated. The closer the LED is positioned to the body, the higher the brightness. The addition of a few LEDs and the improvement of the top surface mean that the effect in *PeP*+ has a different physical appearance as in *PeP* (Figure 25e).

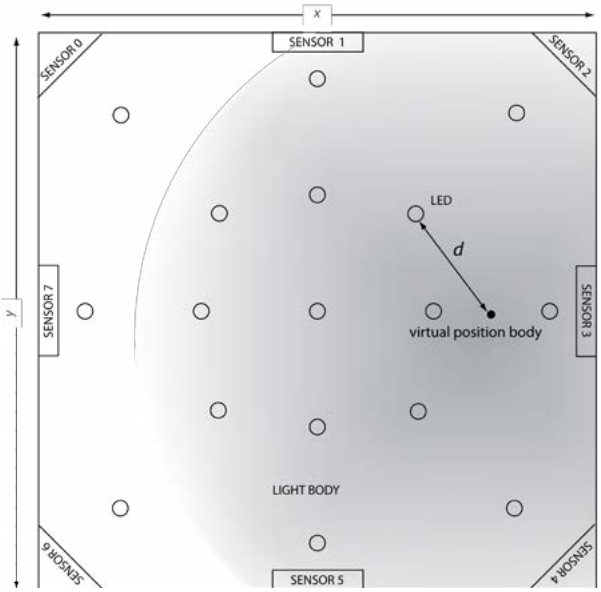
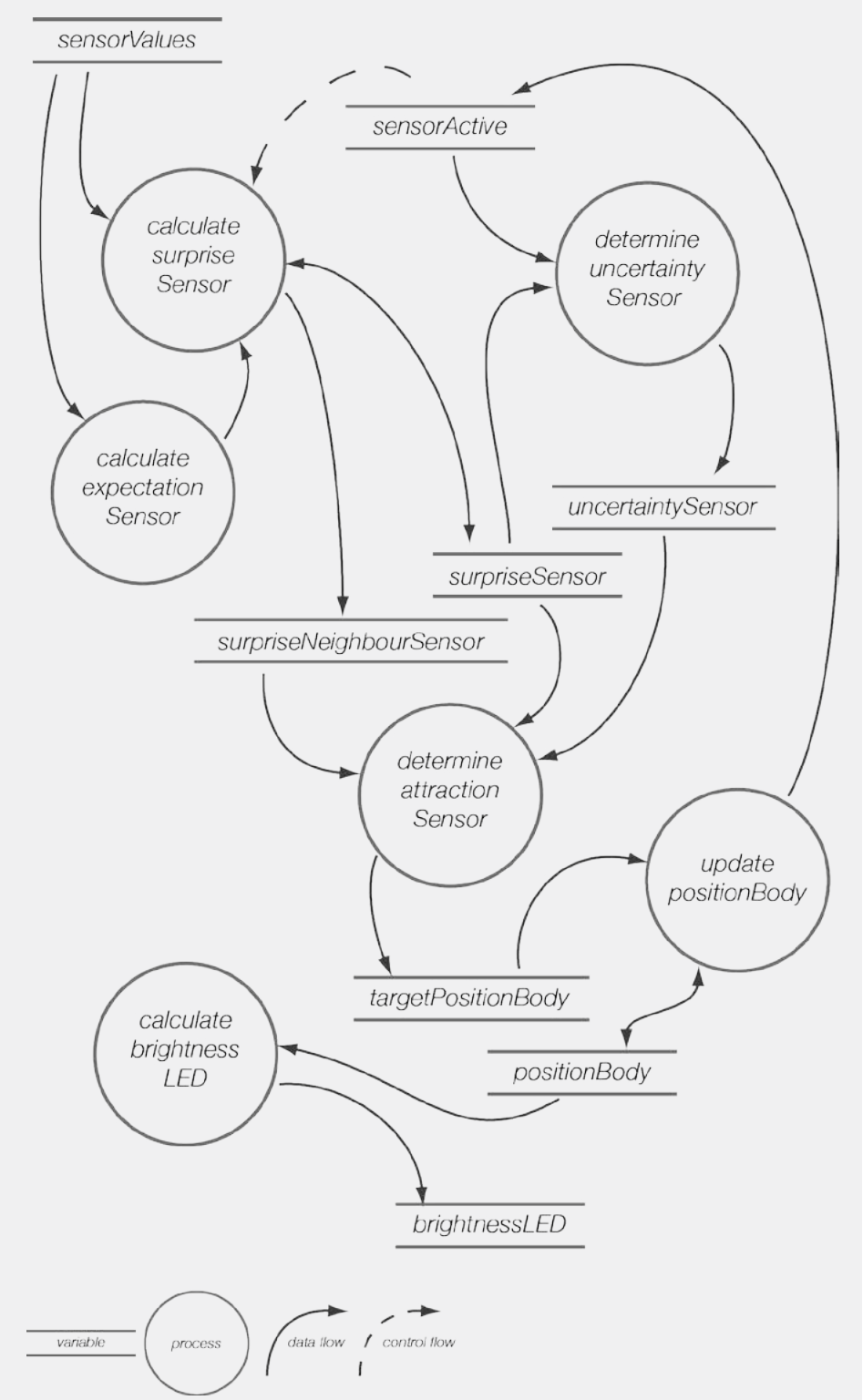


Figure 25e. The closer the LED is to the vitual body, the higher its brightness is.

Figure 26. Impression of interaction with *PeP+*


sensorValues
sensorActive
calculate surprise Sensor
determine uncertainty Sensor
calculate expectation Sensor
uncertaintySensor
surpriseSensor
surpriseNeighbourSensor
determine attraction Sensor
update positionBody
targetPositionBody
calculate brightness LED
positionBody
brightnessLED
variable
process
data flow
control flow

Programme Active Behaviour *PeP+*

```
//for this programme I used the arduino environment (Arduino, 2012)

input Sensor[8] // values normally between 5 and 600
output valueBrightnessLED[17] //min 0 – max 4000, TLC5940 leddriver

//Body, sensors and LEDs have a position between -0.5 ≤ x ≤ 0.5 and -0.5 ≤ y ≤ 0.5

xPositionSensor[8] = { -0.47 , 0 , 0.47 , 0.47 , 0.47 , 0 , -0.47 , -0.47 };
yPositionSensor[8] = { -0.47 , -0.47 , -0.47 , 0 , 0.47 , 0.47 , 0.47 , 0 };

xPositionLED[17] = {-0.40 , 0 , 0.40 , -0.2 , 0 , 0.2 , -0.42 , -0.25 , 0 , 0.25 , 0.42 ,
                    -0.2 , 0 , 0.2 , -0.40 , 0 , 0.40};
yPositionLED[17] = {-0.40 , -0.42 , -0.40 , -0.2 , -0.25 , -0.2 , 0 , 0 , 0 , 0 , 0, 0.2 ,
                    0.25 , 0.2 , 0.40 , 0.42 , 0.40};

xPositionBody;
yPositionBody;

xTargetPosition; //the body moves towards a target position
yTargetPosition;

maxHistory; //determines the length of the history I chose maxHistory=10

s; //variable between 0 and 1 to determine the influence of a value
z; //variable to determine the size of an effect

inputSensor[8]; //the latest input

sensorActive[8]; //boolean sensor active is true or false

timeSensorActive[8]; //the time when sensor was last active

sensorMemory[maxHistory][8]; // sensor input over the length of maxHistory

surpriseSensor[8];  // difference between expectation and latest input

uncertaintySensor[8]; // uncertainty based on time passed and memory

expectationInactiveSensor[8]; //expectation weighted average

sensorChange[8]; //difference  expectationInactiveSensor and latest input

attractionSensor[8]; //attraction sensor position exerts on body
```

```
distanceBodySensor(i) {
    return  sqrt ( sq(xPositionBody – xPositionSensor[i]) +
                   sq(yPositionBody – yPositionSensor[i]));   }

distanceBodyLED(i) {
    return  sqrt ( sq(xPositionBody – xPositionLED[i]) +
                   sq(yPositionBody – yPositionLED[i])); }

//Calculate the expectation for each sensor based on the stored values in sensorMemory.
  The newest input is always placed at the last position of sensorMemory. The other values
  move one position lower (cf. surpriseSensor()). The newest input has the heighest weight.

expectationValueSensor(i) {
   for all positions in memory j {
     sum += sensorMemory[j][i] * (j+1);
     divider += (j+1);
    }
      return (sum/divider);
}


loop {

  time += timestep;

  setSensorActive();        //all functions are described after the main loop
  surpriseSensor();
  uncertaintySensor();
  attractionSensor();
  setTargetPosition();

//The position of the body is updated based on the velocity that takes into account the
   direction and distance to the target position. The velocity is normalized to make sure it
   does not get too high

  dX = xTargetPosition – xPositionBody;
  dY = yTargetPosition – yPositionBody;

  velocityX = velocityX + dX;
  velocityY = velocityY + dY;

  vector = sq(xPositionBody) + sq(yPositionBody);
```

```
 norm = (1 + vector) * z0 * sqrt(sq(velocityX)+sq(velocityY));        //I chose z= 3

 velocityX = velocityX / (z1 * norm);       //I chose z=2
 velocityY = velocityY / (z1 * norm);

 xPositionBody = xPositionBody + velocityX;
 yPositionBody = yPositionBody + velocityY;

 brightnessLED();
}

setSensorActive() {
 for all sensors i {
   if (distanceBodySensor(i) < z2){          //I chose  z=0.25
       sensorActive[i] = true;
    }
   else {
        sensorActive[i] = false;
    }
  }

surpriseSensor(){
 for all sensors i {
   if (sensorActive[i] == true) {
    for all positions in memory j {
       sensorMemory[j][i] = sensorMemory[j+1][i];
       }
   timeSensorActive[i] = time;
   sensorMemory[maxHistory-1][i] = sensorInput[i];
     }

  else {             //sensorActive ==false
     expectationInactiveSensor[i] = expectationInactiveSensor[i] * s +
                                    inputSensor[i] * (1-s);
     sensorChange[i] = sensorChange[i] * s + abs((expectationInactiveSensor[i] –
                          inputSensor[i]) * (1-s));
    }

 surpriseSensor[i] = surpriseSensor[i] * s + abs((sensorMemory[i][maxHistory-1]
                       – expectationValue[i]/ abs(expectationValue[i] +1) * (1-s));
```

```
  expectationValue[i] = expectationValueSensor(i);       //refers to return function

   if (sensorChange[i] > threshold){                    //I chose threshold=30
      surpriseSensor = surpriseSensor[i] + z4;          //I chose z=3
    }
  }
}

uncertaintySensor(){
 for all sensors i {
   uncertaintySensor[i] = (time – timeSensorActive[i]) * (1+surprise[i]);
  }
}

attractionSensor() {
  for all sensors i {
     attractionSensor[i] = uncertaintySensor[i] * w1 + surpriseSensor[i] * w2 +
                           (surpriseSensor[rightNeighbour] * 0.5 +
                           surpriseSensor[leftNeighbour] * 0.5) * w3;
   }
}

setTargetPosition() {
  highestAttraction = 0;
    for all sensors {
      if (attractionSensor[i] >highestAttraction) {
          xTargetPosition = xPositionSensor [i];
          yTargetPosition = yPositionSensor[i];
          highestAttraction = attractionSensor[i];
    }
  }
}

brightnessLED(){
  for all LEDs i {
   valueBrighnessLED[i] =  maxValue – (distanceBodyLED(i) * z5);
   //I chose z=12000. Make sure to constrain the brighness to the min and max output
  }
}
```

Figure 27. Student interacting with *PeP+*, photo Chris Gruijters.

three behaviours

The light body of *PeP* just follows the person. To compare this behaviour to the *active* behaviour, a *following* behaviour is also implemented in *PeP+* and adjusted to fit the body of *PeP+*. The dynamic characteristics, the way of moving, match the algorithm of the *active* behaviour. Moreover, in this implementation of the *following* behaviour, the position of the light body is still completely determined by the sensor input at that moment; the light body just follows. In the *active* behaviour, the direct coupling between sensing and acting applies. Curiosity and expectation motivate the light body to explore the person and the environment. The light body is more active than in the *following* behaviour. In the *following* behaviour, the light body is sensitive at all sides all the time and follows the person one-to-one. Exploratory movements are animated, and by these actions the light body does not actually explore. The design notions are more thoroughly implemented in the *active* behaviour, and it connects more strongly to the theoretical outline and examples than the *following* behaviour.

Besides the *following* and *active* behaviour, *PeP+* can show a third behaviour, namely *random* behaviour. The *random* behaviour functions as control condition in the experiment. The *random* behaviour completely relies on the algorithm of the *active* behaviour, but the sensor input is generated randomly. The activity of the light body is random, and thus *PeP+* does not sense the person in this behaviour.

general hypothesis

The experiment evaluates the effect of the three different behaviours on the person's experience and the interaction. *As the implementation of the design notions is further developed and closer connected to the theoretical outline and accompanying examples in the active condition, the general hypothesis is that reciprocal perceptive interplay between person and PeP+ is stronger than in the following condition. For the same reason, the hypothesis is that, in both the active and following conditions the experienced reciprocal perceptive interplay is stronger than in the random condition.*

As explained earlier by designing and evaluating *PeP+* and the *active* behaviour, I want more closely to investigate the phenomena of perceptual crossing. I focus solely on the reciprocal interplay. In this iteration I set out to get a better understanding of the influence of the design notions, and to what extent perceptual crossing is achieved. Hypothetically, the experience of the person and the interaction in the *active* condition are the closest to perceptual crossing.

considerations

Before conducting the experiment, several experts were invited to experience the interaction with *PeP+* and compare the three behaviours. Discussions on the dynamic qualities of the three behaviours led, for example, to some adjustments in the algorithm of the *following* behaviour to level the dynamic qualities with the *active* and *random* behaviour. The considerations I would like to discuss here regard the set-up of the experiment.

An extensive point of discussion was whether or not to give the participants a task in the experiment. The experts agreed that preferably the participant enters the lab situation with no explanation or task. The participant can explore the interaction with *PeP+* freely and the experience is purest. However, the risk is that participants feel themselves to be the topic of the test themselves. Furthermore, without any introduction they might feel alienated in the lab with *PeP+*. Therefore, the experimenter will tell the participant about the artefact she will encounter, that it has two behaviours, and that she is asked to compare these two behaviours.

Several experts addressed the method of measurement. The initial idea was to follow the same approach as in the experiment with *PeP* and use semantic differential scales to measure the participants' involvement in the situation. Nonetheless, it appeared that this, although in combination with a few open questions, does not evoke expressive descriptions of the interaction and of the participants' experience, and therefore deviates from the phenomenological approach. On the other hand, a true phenomenological description asks for trained participants who are well able to articulate what they perceive. As a result, the experimenter will conduct an open interview with a set of guiding questions. Moreover, the participants' movements will be analysed to derive the dynamic qualities of their exploration.

set-up

In the experiment 25, participants compare two of the three behaviours. The participants are architecture students. These students are trained in giving design critiques, but are not aware of the ongoing research project, and are unlikely to know about the theoretical departure. As I am particularly interested in comparing the *following* and *active* condition, the participants are divided over the different comparisons accordingly. This means that more participants compare the *active* to the *following* condition (*active/following* n=6, *following/active* n=7) than participants who compare the *random* to the *active* or *following* condition (*active/random*, *random/active*, *following/random* and *random/following* n=3).

Before entering the lab, the participants get a short introduction to the experiment. It is explained to them that they will encounter *PeP+* when entering the lab. The door to the lab is shortly opened to give the participant an impression of *PeP+*. From this distance the participant only gets an impression of *PeP+*'s physicality; they are not able to interact with *PeP+*. They are told that *PeP+* has two different behaviours, and their task is to compare them. The experimenter emphasises that the participant can freely explore while in the room with *PeP+*.

After the introduction, the participant enters the lab alone and starts the free exploration. When the participant feels she has finished exploring, she leaves the room. On average the participants (n=25) spend approximately 2'30" exploring the first condition. The experimenter tells the participant to wait a few moments and prepares the next condition. The participant enters the lab again to freely explore the second behaviour of *PeP+*. At this time the participant leaves the lab whenever she feels ready. On average, the participants (n=25) spend approximately 2'00" exploring the second condition. All participants are filmed during the experiment.

The experiment ends with an interview about the two behaviours the participant experienced. The interview takes place in the lab to give the participants the opportunity to refer to *PeP+* directly. The interview is also filmed.

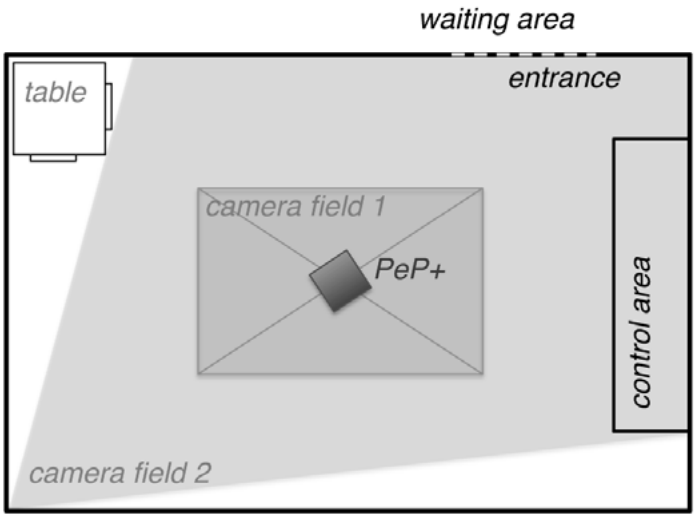


Figure 28. Overview of the lab setting.

Participants are asked to describe both behaviours they experienced, to compare them and elaborate on the aspects: clarity, preference, pleasantness and involvement. To get a deeper understanding of the participants' experience, the questioning is based on the laddering technique (Rugg & McGeorge, 1995). The use of a list of open, guiding questions ensures that all relevant topics are discussed and drive the participants' descriptions. Although I am most interested in the qualitative description and the movement of the participant, I do find it important to compare the transcribed descriptions of the participants with the intended design variable to frame the findings. If participants, for example, have a hard time describing the difference between the behaviours, this changes the view of the qualitative data. The questions in the interview address different topics listed below. An answer from one of the participants exemplifies each topic and gives an impression of the data. Note that the conditions, between brackets and in italic type, are added for ease of reading.

global description of the experience
e.g. "The first one (*following*) was a bit calmer and smoother and the second (*active*) was a bit faster and reacted faster. It looks for you, it is quite funny that it reacts to where you are in the room." (participant 19, *following-active*)

the feeling of being perceived
e.g. "The first time (*following*) I felt strongly that he saw me and wanted to guide me somewhere, wanted to move me. And second time (*random*) it seemed the light was busy with other things." (participant 2, *following-random*)

preference for one of the two conditions
e.g. "On one side the first one (*random*) is nice as you don't know what it is but the second one (*active*) is more interesting, I have a feeling of interaction." (participant 3, *random-active*)

the clarity of the behaviour
e.g. "The first one (*random*) is not clear, the second (*following*) is. In the first one I wondered if it mattered I was there, if it would react to anything. In the second this was clear." (participant 13, *random-following*)

the experienced pleasantness
e.g. "The second one (*following*) is more pleasant as it is calmer, but maybe also because it was a bit more familiar the second time. He was more continuous the second time but could not perceive better." (participant 11, *active-following*)

the experienced feeling of involvement
e.g. "The first (*active*) seems to move because of you. I had more a feeling of ignorance that the second (*random*) acted so different. (participant 4, *active-random*)

the participants' strategy
e.g. "I wanted to see what it is and try to find logic, and try to mislead." (participant 16 *active-random*).

A method for investigating 3-D form perception (Locher et al., 1999) is used to analyse the participants' movements while interacting with *PeP*+. Several markers (figure 29) indicate the different types of movement. This analysis allows for an immediate overview of the exploration of the participants. It is possible to see strategies and parametres of exploration. Possible shifts and correlations in the plots between the different conditions are annotated. In these plots, a black line, for example, shows 'walking around'. Coloured lines indicate variations like running, arm movements while walking or making a feint. A circle presents that participant stood at one spot for a second or longer. The diameter of this circle corresponds with the seconds the participant was standing at that spot. A black outline shows that the person standing still and observed *PeP*+. Different fill colours present actions that the participants undertake while standing at one spot, e.g. arm movements, touching or making sound. The opacity indicates the intensity of these actions. A higher opacity means there was more activity in

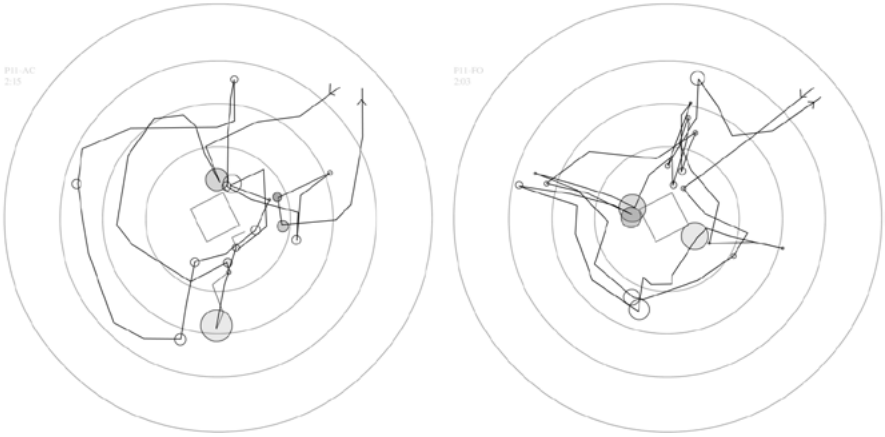


Figure 29. Movement plots of participat 11, left *active*, right *following* condition. The participant for example observed, touched, moved his arms, and made a feint.

relation to the time, e.g. moving the arms twice is rated with a lower opacity than moving the arms continuously. Furthermore, the time the participants spent per condition is measured.

From the interviews I abstracted qualitative descriptors that the participants used in their discussion of the two conditions they encountered, using the affinity diagramming method. All the descriptions were clustered according to their affinity. Nine main categories came forward, namely: explorative behaviour, character, contact, movement qualities, asking/steering, testing, relation, value judgement, and understanding.

Three types of data are gathered: (1) quantitative data on the feeling of being perceived, clarity, preference, pleasantness and involvement. (2) Qualitative data in the form of the participants' description and (3) qualitative data in the form of movement plots of the interaction. The results section is divided into three parts. Firstly, I discuss whether the descriptions of the participants match the intended design variables; secondly, I discuss the clarity of the behaviour; and finally I discuss the preference, pleasantness and feeling of involvement.

To see whether a significant number of participants describe the different conditions comparable to the intended design variables, the participants' descriptions are scored on their correspondence to the design variables. The example given on 'global description' (measurements sub-section), for example, corresponds to the intended design variables. The results are analysed using the chi-square test for non-parametric statistics between two successive situations to see whether the observed sample significantly differs from the expected values (Siegel, 1956). The expected values are based on a random distribution. For both the *active* and *following* condition the random distribution is rejected ($p<0,05$). Participants seem to see meaningful behaviour in the *random* condition and relatively often ($p<0,1$) do not describe the behaviour as random. This phenomenon has been referred to as Apophenia (Conrad 1958, cited in Brugger, 2001).

Table 3. Correspondence of descriptions, observed values (expected values)

	Active	*Following*	*Random*	*Total*
Corresponds	9 (6)	14 (9,5)	14 (9,5)	37 (25)
Conflicts	3 (6)	5 (9,5)	5 (9,5)	13 (25)

Table 4 gives an overview of the data gathered about the topic 'clarity'. The numbers indicate how many of the participants found the condition clearest of both the conditions. The numbers suggest that the *active* condition is clearer than the *random* and slightly clearer than the *following* condition. As experience of and expectation based on earlier interaction with the artefact might influence the result, the first experienced condition is also considered (Table 5). Also when comparing the first experienced conditions the numbers suggest that the *active* condition is clearer than both the *following* and *random* condition.

The scores correspond with the movement plots and the descriptors. Participants figured out the *active* condition faster. The time spent and the activity of the participants in the *active* condition (ū=1'36", n=9) are less than in both the *following* (ū=2'48", n=10) and *random* (ū=3'12", n=6) condition. This can be clearly seen when plotting all the plots of the first experienced *active* and *following* conditions respectively together (Figure 30). The movement qualities of the exploration are as rich. Positive descriptors in relation to the clarity are mostly used for the *active* and *following* condition, although slightly more for the *active* condition: e.g. "The first time (*following*) there was a light that moves and seems to follow me but I am not completely sure. … The second (*active*) was faster and clearly followed where you are standing." (participant 15, *following* / *active*)

Table 4. Clarity of conditions (e.g. to 8 participants the active condition is clearest)

	Active	*Following*	*Random*
Clearest	8	5	0
No distinction	8	9	7
Unclearest	3	5	5

Table 5. Clarity of the conditions, first experienced condition

	Active 1	*Following 1*	*Random 1*
Clearest	3	0	0
No distinction	3	6	3
Unclearest	3	4	3

As the results on preference, pleasantness and feeling of involvement are similar, they are discussed together. Table 7 shows that participants prefer, find more pleasant and slightly feel more involved in the *active* and *following* condition compared to the *random* condition. Table 6 shows that there is no clear difference in preference between the *following* and *active* condition. This also goes for pleasantness and feeling of involvement. The preference, pleasantness and feeling of involvement correspond with the feeling of being perceived or not. The interview shows that when participants feel not to be perceived, this condition is not preferred and least pleasant, and the person feels least involved. Note that the data shows all the gathered data on these three topics. When only considering the participants who indeed feel to be perceived in the *following* and *active* condition and feel not to be perceived in the *random* condition the effect increases.

Looking more closely at the data shows that the order by which the *active* and *following* conditions are experienced is of influence on the outcomes. Participants especially prefer the second behaviour and find this behaviour also more pleasant. There seems to be an order effect. A reason for this can be that participants are more familiar with the artefact in the second condition: e.g. "Situation 2 (*following*) is more pleasant, maybe a little because of habituation but also because he did not react too fast." (participant 12, *active-following*)

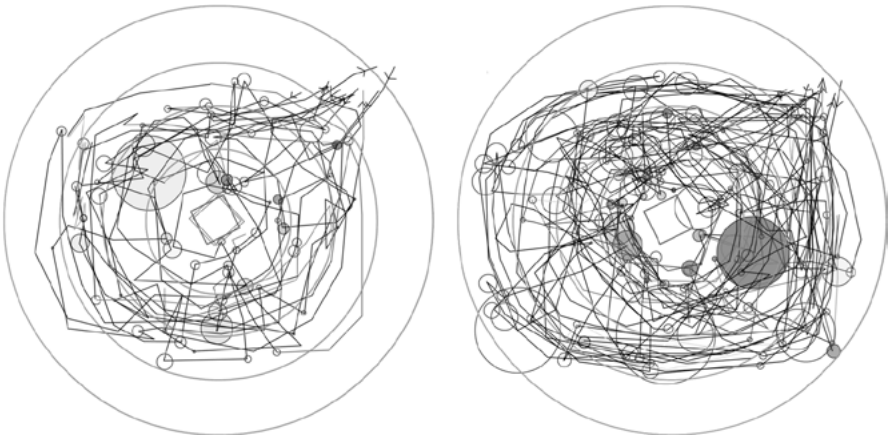


Figure 30. Only participants of which the description corresponded are considered. Left: all plots *active 1* (n=6). Right: all plots *following 1* (n=6).

Descriptors in relation to explorative behaviour are used more to describe the *active* and *following* condition compared to the *random* condition. This also goes for the descriptors of contact (feeling in contact with) and relation (feel there is a relation). The *following* and *active* do not differ. The movement qualities in the *active* condition are described as quick, dynamic, active and agile. Descriptors (bold) in the category asking/steering are, on several occasions, used to describe the *active* condition, e.g.:

"Situation 2 (*active*) is a lot more interactive. In situation 1 (*following*) you can stand somewhere and nothing happens. In the second *PeP+* **undertakes action itself** that **triggers you to do something**. … The second is **impatient**, like a puppy." (participant 25, *following-active*)

"I had the idea that the first one (*following*) followed me more, and in the second (*active*) I was more **asked to go in a certain direction**. He did follow in the second but **tried to get me in a direction** and I was so stupid to do it." (participant 22, *following-active*)

Table 6. Comparing *active* to *following* considering order

	Active 1	*Following 2*	*Following 1*	*Active 2*
Preference				
Preferred	1	5	1	6
No Preference	0	0	6	1
Pleasantness				
Pleasantest	0	3	0	5
No Distintion	3	3	2	2
Involvement				
Most Involved	2	4	3	3
No Distinction	0	0	1	1

The experiment shows that the intended difference between the conditions is recognised and described accordingly by the participants. Participants attribute movement qualities as active, agile and dynamic to the *active* behaviour. Moreover, they attribute provocations to the *active* behaviour like 'trying to get me in a direction' and 'actives me'. The *active* condition is described as clearer than both the *following* and *random* condition. The *following* and *active* condition is preferred over the *random* condition. They are also experienced as more pleasant and the feeling of involvement is higher. Between the *following* and *active* condition no differences in preference, pleasantness or feeling of involvement are measured. There is a strong order effect where the second experienced condition is preferred and more pleasant.

Table 7. Comparing *active* and *following* to *random*

	Active	*Random*	*Following*	*Random*
Preference				
Preferred	4	2	3	0
No Preference	0	0	3	3
Pleasantness				
Pleasantest	2	1	3	0
No Distintion	2	2	1	1
Involvement				
Most Involved	2	2	3	1
No Distinction	1	1	1	1

Although the person perceives and describes the difference between the *active* and *following* behaviour the person does not feel necessarily more involved in the *active* situation. Where some people appreciate *PeP+*'s initiative, and even follow it to see what happens, others feel more comfortable when *PeP+* more calmly follows. The *active* behaviour, on the other hand, does seem to be clearer. I came to realise that in the *active* behaviour *PeP+* is maybe even better capable of following active people, as it anticipates on what could happen next, because the attraction of a side increases over time. In the *following* behaviour the light body is always behind, as the fact that the person moves away from the sensor also causes a significant change in sensor input. From a technical point of view, the *active* behaviour is more advanced, as by adjusting the variables of the *active* behaviour one can create the *following* behaviour. The fact that people attribute meaning to the *active* behaviour in terms of 'it wants something', 'it tries to get me in a direction' and 'I am trying to trick it' are promising in terms of experiencing perceptual crossing, and a strong argument to develop the design notions further.

Although some people had the feeling that the light body points out a direction the game of attraction and escape does not visually happen. The person tries mostly to attract the light body, and, although people try to trick it, actually escaping from its perception is not easy. I considered this observation in relation to the design-relevant theoretical model, the three components of perceptive activity, and the criteria that apply to the artefact. The artefact should be able to perceive the perceptive activity of the person, and be able to show perceptive activity to allow for reciprocity. By going through this iterative cycle and reflecting upon it I came to understand that indeed (1) the person can perceive the artefact; (2) the artefact can perceive the person; (3) the person can perceive the artefact perceiving her; but (4) *the artefact* ***cannot*** *perceive that the person perceives it*. The initiative *PeP+* shows, and to which people attribute the meaning of 'it wants something', is actually not an initiative that directly relates to *PeP+*'s perception of the person. It is an intrinsic motivation to explore the (common) space, which is subjective to the activity of the person. This is different from recognizing the presence of the person and exploring the person rather than the common space. *PeP+* does not appreciate yet that it is being perceived and logically does not act upon this. Although the descriptions show that the person feels engaged in a rich reciprocal interplay, the perception of the person and *PeP+* cannot cross. Perceptual crossing does not truly happen.

The movement plots provide insights on the person's strategies. They show parametres for exploration, such as alternating between moving and standing still, and varying position around and her distance from *PeP*+. It appears that people who do not behave actively and explore little more often feel not to be perceived by *PeP*+. In other words, the person has to be active to engage in the reciprocal interplay, supporting the theoretical stance on active perception. Figure 31 illustrates this observation. Participant 5 (left) mainly observes the behaviour and describes the *active* behaviour as random. Participant 22 actively explores, and feels that the light body in the *active* behaviour tried to get him in a direction. People also refer to this in their description of the *active* behaviour: e.g. "The second (*active*) is more clear. At the beginning it was not as I stood still to see what happened. When I moved it was a lot clearer." (participant 6, *following – active*).

Next, the design notions are considered again. Their development is a reflection on the process of designing *PeP*+, implementing the *active* behaviour and the evaluation. Through this process their connection to the theory is also strengthened. For each design notion, its definition and relevance is discussed based on theory and examples (both in italic). To clarify the development, sometimes the design of *PeP* and the implementation of the *following* behaviour are used as a reference.

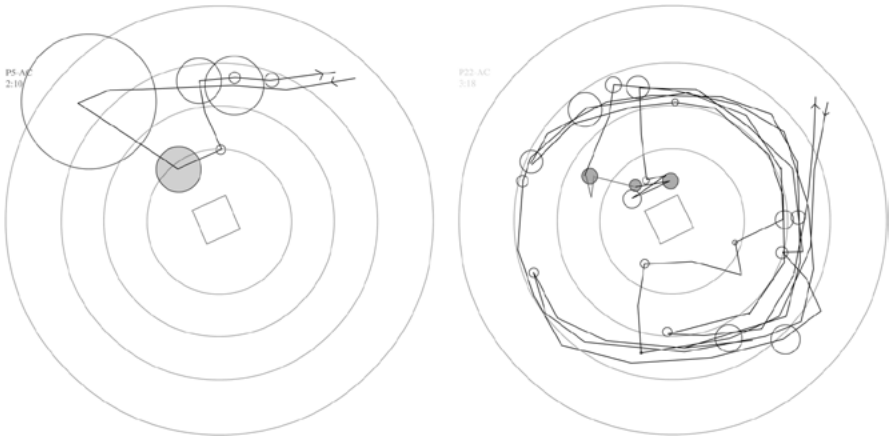


Figure 31. Example of relation between explorative behaviour of the person, and the person's experience of the *active* behaviour.

Sensing and acting have to be embodied in order for the artefact naturally to focus its senses and to become more than just a following entity.

For living organisms it seems natural to concentrate their senses in the direction of the stimuli: e.g. you close your eyes and turn your ear in the direction of the sound so as better to perceive the acoustic event. Sensing and acting are embodied. In other words, perception is active, as it is a result of actions we undertake and the sensory feedback these result in, and the other way around.

The use of a static matrix of sensors means that, without manipulation within the algorithm, the artefact is sensitive at all sides all the time. In *PeP+* not all sensors are active all the time, and there is a strong relation between the sensor sensitivity and the action of the light body. The position of the light body not just depends on the sensor input, as was the case in *PeP*, but the sensor activity also depends on the position of the light body. At the moment that the light body is in a certain range of the sensor, the sensor becomes more sensitive than the others. Sensing and acting are much more integrated, in line with the theoretical idea of active perception.

Also stimuli that we experienced before steer our focus. Time is considered a subjective experience (Merleau-Ponty, 1958, pp. 494-495). It is the experience of the continuous nature of our activity. The experience of time is more a sentence of activity that is our own or that we can anticipate than the perception of concepts such as minutes or hours. A notion of time, and thus memory, means that there is not just a direct relation between the person's activity and the light body. Foregoing activity or the lack of foregoing activity in the environment steers the light body (cf. Show Explorative Behaviour).

Although it seems natural to concentrate our senses in the direction of the stimuli this does not mean that we purely perceive in the direction in which our senses are focused. What is behind me is not visually absent (Merleau-Ponty, 1958, p. 6). When something behind you is loud or moves quickly or suddenly, you will react to this. In the artefact, though only the sensor in range of the light body is active, large or sudden changes elsewhere will be detected. All sensors are sensing in the background and influence the behaviour when they detect a movement in the environment that exceeds a certain threshold.

All our sensors are moving sensors. We move our hand in exploratory fashion over a surface to perceive the surface, and we turn our head in such way that eyes or ears are in the direction of the event. One could argue that the use of a moving sensor naturally embodies this focus of the senses, like the eyes in your head. Using a static grid of sensors means that the algorithm becomes very significant when designing for perceptive behaviour. However, the use of a matrix of static sensors covers a wider range of design applications, e.g. carpets (Deckers et al., 2010, 2011). Moreover, the artefact is set apart from anthropomorphic shapes. The emphasis is really on the dynamic properties, the behaviour, of the light design.

show explorative behaviour

The artefact should be motivated to explore: this way the person is able to perceive its presence and able to engage in an active interplay of attraction and escape.

Perceptual crossing heavily depends on explorative movements such as the ability to escape from and attract each other's perception (Lenay, 2010). By the implementation of this design notion the artefact is capable of "perceptually motivated perceptive activity". If the artefact is just a following entity, this might indicate that indeed the body is sensing and acting but it is questionable if this is a perceiving body. Two kinds of active, explorative behaviour are considered. (1) The light body should adopt active and explorative behaviour to scan the environment. This is like living organisms that scan the environment for events: e.g. you turn your body and head to look around the room to see whether someone is there. It is these kind of movements that, when we are not yet in an active interplay with each other, make me recognise the other's ability to perceive: her presence. (2) The artefact should also adopt this explorative behaviour when focusing on something. For example, to experience the surface of the table top one will not just touch it, but also move one's fingers over it in an exploratory fashion. In a similar way, our eyes are always in action to perceive. Perception is active (Gibson, 1986).

The light body is therefore attracted not only by the person's movement, but also by uncertainty (or curiosity) and expectation based on the past. Uncertainty and expectation are implemented in the algorithm inspired by principles known from Bayesian surprise theory (Itti & Baldi, 2009). The light body of *PeP+* actively explores the subject. This active behaviour strongly depends on implementations described in the foregoing notion Focus the Senses. If not all sensors are active all the time, the light body has to move in order to find out more about the person and the environment. The light body of *PeP* was merely a following entity. In *PeP+*, a notion of time is added. The time past since the last exploration (uncertainty or

curiosity) of a specific side influences the explorative movements of the light body. The activity detected in the previous exploration (expectation) of this specific side also influences the probability to explore this side again. This means that time is a subjective experience; the more interesting the perception on a side was, the more quickly the light body will get curious. Moreover, the activity measured on a sensor also influences the appeal of the neighbouring sensors, which will allow for the light body actively to explore the side where activity is detected. In other words, time and previous input is used as a subjective motivation for *PeP+* to explore different sides.

subtleness of movement

When designing for perceptive activity, the subtleness of the physical appearance, the actual movements and their integration should be considered.

The actions we undertake to perceive are smooth: we turn our head in a continuous and sustained movement to look at what is behind us. Both in the physical appearance and in the algorithm subtleness should be created by taking into account this sustained continuous nature of perceptive actions. In the algorithm, the position of the light body adjusts gradually to allow for this sustained and continuous movement: this way the light body, as it were, slides towards the new position instead of popping up there.

The physical characteristics of *PeP* did not allow for the subtleness that is reached within the algorithm. The resolution of the surface, in which the body of light acts, is increased in *PeP+*. The material of the top surface allows for a better spreading of the light. Furthermore, the light seems to act within the surface instead of under it. The aesthetics of the behaviour and physical appearance are better balanced in *PeP+*. The behaviour might ask for a certain jumpiness in the movement of the light body; however, this jumpiness should be designed in the algorithm, instead of being the limitation of the physical aspects and electronic components.

react to external event

Sharing perception of the common space, by the addition of an external event, amends the reciprocal interplay.

The addition of an external event will enrich the common history the person can build with the artefact in the course of their interaction. When you interact with someone, events in the environment shape and influence the interplay: e.g., music, noise, light or objects. The artefact is able to perceive an event and show perceptive activity in relation to this. The experiment with PeP showed that the addition of an external event amends the course of interaction between the artefact and the person sharing a common space.

The person can perceive, as it were, 'through' the artefact. This is like when we see someone dancing to music that we don't hear ourselves: we perceive the music 'through' the dance, the activity of the person. If, indeed, the person can perceive 'through' the designed artefact, the person is able to become aware of events that she cannot perceive directly.

In the experiment with *PeP,* the perceptive connections between subject, object and external event varied and were explored by the participants. For now the external event is excluded in the design of *PeP+* in order to investigate closer the phenomena of perceptual crossing between the person and *PeP+* and the influence of the other proposed design notions. This notion of React to External Event becomes especially meaningful when person and artefact are actually able to engage in a strong reciprocal interplay.

recognise explorative behaviour subject

The perceptive activity of the person should become meaningful to the artefact in the course of the interaction.

We are living organisms showing active and explorative movements in order to perceive. In the course of the interaction, the artefact should be enabled to detect this perceptive activity of the person. In the context of their interactive interplay, these actions become meaningful to the artefact. Therefore, the light body is sensitive to changes in sensor input. Staying still for too long will result in no longer being detected as an intentional subject (perceiving the lived-body), but as an object in the environment (perceiving the body-as-an-image). Perceptual crossing can no longer occur and the light body loses its focus.

We attract and, try to escape from, each other's perception to engage in perceptual crossing. The dynamics of disappearing, being there and being absent, create a tension between us. So although, at a certain moment, you do not see me anymore, there is still an active relation between us. Or when I sneak up to you, I already experience an active relation between you and me. As explained earlier, a sensor is only active; or, in other words, *PeP+* has only detailed perception on the side the light body focuses on, and is only sensitive to movement. This means that the person could sneak up to the artefact or try to escape from its perception.

reflect contextual noise

Contextual noise can be reflected in the perceptive activity of the artefact to create behaviour that is not anticipated, but is a natural result of the context.

When one is in dialogue with someone else, one's perception is focused on the other. However, this means neither that there is no contextual sensory input, nor that one does not undertake any action to get other sensory input. This is especially the case when the sensory input reaches a certain level: for example, when something makes a lot of noise, or a movement is sudden and quick, one reacts to this event. These are actually events in the common space, but not per se anticipated like the events under React to External Event.

The light sensors integrated in *PeP* are very sensitive to the environmental light conditions. The amount of environmental light is changed by the presence of a person as she causes a shadow to fall on the sensor. Not every side of the artefact might be equally exposed, and so the effect the person causes might vary for different sensors. Moreover, events besides the presence of the person might cause the environmental light conditions to change. For the design of *PeP+*, ultrasonic sensors are chosen that make the design, and especially the experiment, more controllable. These sensors are not that sensitive to contextual noise. However, the characteristics of these ultrasonic sensors make it very hard for the person to repeat the input exactly. This increases the quality of the behaviour, as it does not become too predictable.

The artefact gets, as it were, an experience; it is aware of bygone perception and anticipates future perception.

The notion of Remember and Anticipate Perception over Time refers to experience. As explained earlier time is considered here to be a subjective experience, a continuum of activity (cf. Focus the Senses). In line with this, experience here is considered the continuum of perceptions and thus the awareness of bygone perception and the anticipation of future perception (Schutz, 1967). It is in this design notion that the artefact, as it were, builds an 'experience' based upon other design notions.

PeP has no awareness of its own perception. In other words, it does not rely on history or anticipate what could happen next. A notion of memory is already considered and implemented in the design notions Focus the Senses and Show Explorative Behaviour. Foregoing activity, or the lack thereof, motivates the light body to move. We have also seen that the detection of perceptive activity becomes meaningful to the artefact in the course of the interaction with the person (Recognise Explorative Behaviour Subject). The advanced level of integration which this design notion entails leaves room for development but adds complexity. To make this step it was useful to evaluate the development of the design notions at this stage.

Like the two preceding sub-chapters, this sub-chapter is divided into four sections and a leitmotiv part. In the four sections, the behaviour of the artefact, the practical implementations, the evaluation of the designed artefact, and the conclusions are all discussed. Different from the previous iteration, I do not improve the physical appearance of the design-research artefact, but focus on the development of its behaviour. The intelligence of the artefact is further refined. The activity of the person becomes meaningful to the artefact. Moreover, it is able to anticipate the activity of the person and to influence her behaviour at the same time. In this last iteration, I show that the interplay of attraction and escape that characterises perceptual crossing happens between person and artefact. The perception of person and artefact crosses.

Publication of this sub-chapter:
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third iteration

designing, implementing and evaluating explorative behaviour

Based on the findings of designing, implementing and evaluating the *active* behaviour of *PeP+* in this iterative cycle, I will further develop the design notions and their implementations in the behaviour. The aim is for *PeP+* to come to appreciate that a person perceives it, and to let *PeP+* explicitly explore the interaction with the person. Perceptual crossing happens as we attract and escape from each other's perception. When you are in a dialogue you will look the other in the eye and then escape from this again. In this iteration I will focus on this play of attraction and escape as it is characterised by very distinct dynamic qualities that inform the design process.

People feel engaged in a rich reciprocal interplay with *PeP+* when it behaves *actively*. *PeP+* influences the interaction and thus the person's behaviour. The difference between the *active* and the new behaviour is that *PeP+* in the latter has the directed intention to influence the person's behaviour. I especially develop the design notions Recognise Explorative Behaviour Subject and Remember and Anticipate Perception over Time. Before evaluating the effect of the *active* behaviour on the person's experience and the interaction, it was already clear that some design notions were more strongly developed than others. Nevertheless, it is the observations and insights gained from going through the whole cycle of designing, implementing and evaluating that made me understand not only which design notions but especially how to develop these notions further. Table 8 gives an overview of the development and implementation of the design notions in the three behaviours as applied in *PeP+*. The darker the shading, the stronger the design notion connects to theory, and the stronger its implementation. Note that Reflect Contextual Noise depends on the integration of electronics, which is identical in this case, as the three behaviours are all the behaviour of *PeP+*. As the focus is solely on the reciprocal interplay between person and artefact, React to External Event is not considered.

The new behaviour is referred to as the *explorative* behaviour. The form and dimensions of *PeP+* are unchanged. The challenge is to design the algorithm in such a way that *PeP+* comes to appreciate it is being perceived. Besides, the appearance and dynamics of the light body have to lure the person in a game of attraction and escape. What dynamics motivate the person not only to attract (lead), but also to follow the light body? The dynamics and appearance of the light body in the *explorative* behaviour show to the person that *PeP+* is aware of the fact that they perceive each other. In other words, the moment of appreciation –*we see each other*– reflects in the perceptive activity of the light body.

The person sees *PeP+'s* perceptive activity: the behaviour of the light body. *PeP+* obviously does not see. Nonetheless, in the experiment and expert evaluation it appeared common to refer to the visual modality when interacting with *PeP+*. In line with this, it would be reasonable to argue that *PeP+* should be enabled to 'see' that the person sees it. An implementation of 'seeing' is complex and I want to keep the minimal physical and technical implementation of *PeP+*. The addition of visual detection, like the implementation of a camera, is not a possibility from this perspective. The movement plots that resulted from the previous experiment inspire a different approach. Apparent from all these movement plots is that (1) participants have a certain strategy that is recognisable in both conditions; and (2) there are different parametres that characterise the exploration. Examples are alternating between walking and standing still, and moving around and varying the distance from *PeP+*. Participants explored and observed, i.e. they move and then see what happens. Participants who actively explored the interaction felt more often to be perceived by *PeP+* than participants who tended to act more observingly. The question arises: can *PeP+* perceive the exploratory movements of the person perceiving it? Can it detect it is being explored?

The algorithm of the *explorative* behaviour directly builds on the algorithm of the *active* behaviour. The latter algorithm entails several variables that motivate the light body to move, such as surprise, expectation and uncertainty (cf. Designing *PeP+*, p. 70). Uncertainty rises in time and in relation to previous experience. The person causes surprise by actively exploring, *PeP+*, and based on this activity and the environmental conditions, it builds an expectation. Several experiments

Table 8. Overview of implementation of design notions in the three behaviours

	Focus the Senses	*Show Exploratives Behaviour*	*Subtleness of Movement*	*Recognise Explorative Behaviour Subject*	*Remember and Antic-ipate Perception over Time*	*Reflect Contextual Noise*	*React to External Event*
Following							
Active							
Explorative							

brought in samples of the course of these variables for two situations: namely (1) the person actively explores; and (2) the person just wanders around, ignoring *PeP+*. It shows that for both the variables of uncertainty and surprise the course is significantly different when the person actively explores *PeP+*, compared to just wandering around. The chance that uncertainty rises above a certain value is significantly higher when the person actively explores, as well as the chance that the surprise rises on multiple sensors. In the course of the interaction *PeP+*, will get more confident it is being explored or not.

Again the development of the algorithm was an iterative process of implementing and trying out. In a first attempt, tracking the person based on the input of the eight sensors was implemented. *PeP+* is well able to follow the path of the person and to draw information from this. Nonetheless, using all sensors all the time, not taking into account the position of the light body disregards the embodiment of sensing and acting. Changes in *PeP+*'s behaviour that are based upon this information are predefined mechanisms, while I aim to build intelligence in the course of the interaction. It is actually the uncertainty of only perceiving a limited space that triggers the dynamics of attraction and escape. The variables that are used to detect whether *PeP+* is being explored are inherent to the *active* behaviour, and thus *PeP+* becomes certain that the person perceives (explores) it in the actual course of the interaction.

When *PeP+* perceives it is being perceived, i.e. it detects it is being explored, it adjusts its behaviour and tries to engage in an active interplay of attraction and escape. In a first attempt of designing this interplay of attraction and escape, I ran into the pitfall of making a mechanism of predetermined actions of the light body. Through an exploration in movement, similar to the creative session at the start of the process of designing *PeP*, I regained the feeling for the dynamic qualities of the play of attraction and escape, or leading and following. The session brought to the fore that it is not always clear who is leading and who is following. When the leader is confident that the other will follow, she dares to move away from her follower. However when the leader has to lure the other into following she will move away carefully, strongly keeping her eyes focused on the other. It is ambiguous if the leader is pulling the follower or if the follower pushes the leader. It is at this moment that the follower can take over the lead. Figure 32 gives an impression of the movement session. The leader (person at the back) tries to lure the follower (person at the front) to move along. The leader turns her body in the direction she wants the follower to go, but keeps her focus on her follower. This causes a twist or tension in her body. The dynamic qualities of her movements and

Figure 32. Screenshot movement session; the leader builds a tension in her body to lure the follower along

appearance are directed towards the other and pulling her along. The moment of appreciation, i.e. you see each other, is crucial for the play of attraction and escape to start. The leader has to be certain that the follower perceives her to be able to lure the other in a direction.

When *PeP+* detects it is being explored, the variables of the *active* behaviour no longer motivate the light body to move. These variables provide for the light body to be sensitive to things it is not focusing on. They motivate the light body to explore the space, rather than actively focusing on the person. In the *explorative* behaviour, the light body only gains sensory input where it focuses. It is absorbed in a play with the person and is no longer interested in what happens around it. The light body has to move to get input on other sides. This ignorance is an advantage, as this motivates the light body to start moving in direct relation to the person's activity.

The tension in the body that arises when one focuses on the other while turning the body to lure the other along inspires the creation of two layers in the light body. These layers are directed separately in the algorithm, but appear as one body to the person. The first layer (layer-focus) focuses on the person. The second layer (layer-explore) moves through layer-focus from left to right to explore the interaction space. By these exploratory movements of the layer, the light body gains sensory input and can anticipate the person's activity. Also layer-explore only gains input where it is and has to keep moving in order to perceive the person and anticipate what the person might do next. When the person likes the light body to follow her, she needs to be in the field of focus of the light body and move at the moment that layer-focus can actually follow: which is not possible when it moves in the other direction. When the person does step away, the light body will not immediately follow, and so the person has to wait or step back. When she quickly moves further, she really escapes from *PeP+*'s perception. Who is following whom can be rather ambiguous. The implementation of the two layers changes the dynamic qualities, but also the appearance of the light body. The dynamic change in both the *lived-body* and *body-image* supports the appreciation of 'I perceive you'. *PeP+* tries to be closely connected to the person in the *explorative* behaviour. It might happen that the light body moves too far away from the person when it does not succeed in luring the person along. It can also happen that the person escapes from its focus. When this happens, *PeP+* sets out to find the person again by exploring the environment: it shows *active* behaviour. The play of attraction and escape can be resumed when the person keeps or starts actively exploring *PeP+* again.

Figure 33. Screenshot participant interacting with *PeP+*.

The algorithm of the *explorative* behaviour directly builds upon the algorithm of the *active* behaviour. The functions of the *active* programme are all used. One function is added for *PeP+* to detect whether the person explores it. This is possible because the course of the variables in the *active* behaviour, such as the uncertainty and surprise, differ when a person actively explores the interaction compared to when a person just wanders around. Figure 34 (top) shows the course of the uncertainty value when a person actively explores the interaction. Figure 34 (bottom) shows the course of the uncertainty value when a person wanders around the room and does not actively interact with *PeP+*; note the scale difference. The chance that the uncertainty value rises above 500 or even above 2000 is significantly higher when the person actively explores the interaction. In the algorithm, the

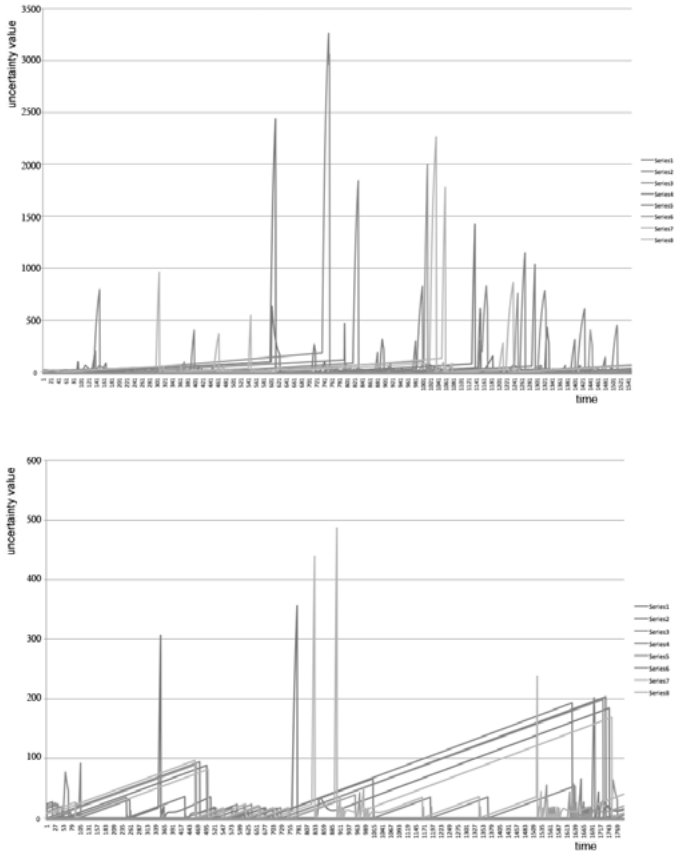


Figure 34. Top: uncertainty values when person actively explores, note max value is 3500. Bottom: uncertainty values when not actively exploring, max value 600.

occurrence of these events influences the probability that the person explores *PeP+*. Furthermore, the probability that the surprise value increases on different sensors is higher when the person actively explores; in addition, this event influences the probability that *PeP+* is being explored. Summarising the algorithm holds a list of possible events. For these events, there is a clear difference in their chance of occurring when the person explores or ignores (not actively exploring) *PeP+*. When these events happen, *PeP+* adjusts both the probability that it is being explored and the probability thay it is being ignored, using Bayesian statistics. When the probability of being explored exceeds a threshold, *PeP+* starts to behave in an *explorative* fashion.

For the purposes of the design-research, it is satisfactory to change the behaviour from *active* to *explorative* based on a static threshold. Nonetheless, to build the intelligence of the artefact further, a more dynamic approach is favourable. A direct coupling between the probability value and the movement of the light body is most suitable.

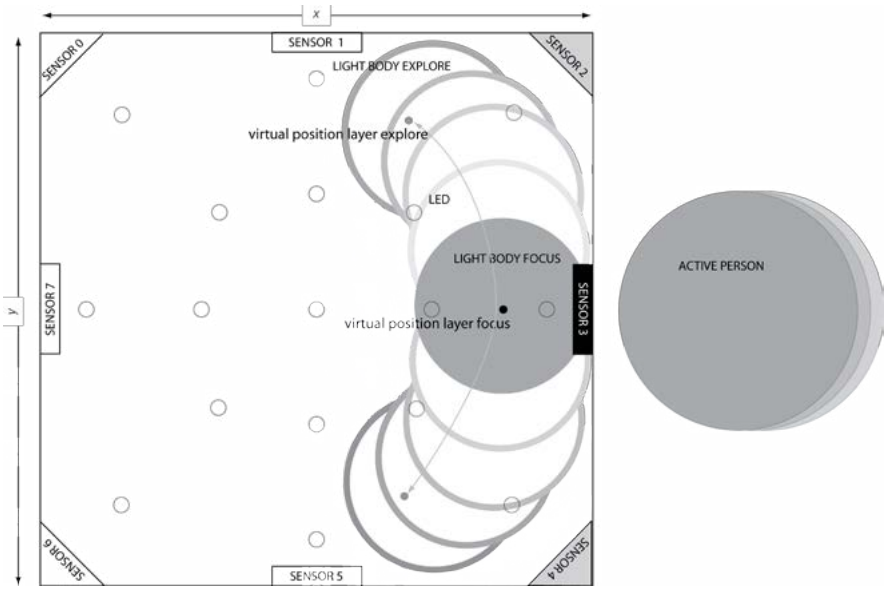


Figure 35a. Layer-focus focuses on the person, layer-explore moves from left to right, through layer- focus, to explore the interaction space.

When the light body exhibits *explorative* behaviour, it consists of two layers: layer-focus and layer-explore. Layer-focus focuses in the direction of the person. The position of the person is the sensor where the highest surprise is found. Layer-explore looks to the left or right: whether the person is or might move there (Figure 35a). Over time, the position of layer-focus adjusts based on the input that layer-explore gathers. The sensor side with the maximum surprise attracts layer-focus. Only the sensors in close range of layer-focus (sensor focus) are active; therefore layer-explore needs to visit the sensor sides left and right (sensor explore) to explore the space. Layer-explore moves to the left, looks and measures the surprise. *PeP+* determines if the surprise detected by layer-explore is higher than that detected by layer-focus. If this is not the case, layer-explore switches direction (Figure 35b). Otherwise layer-focus adjusts to layer-explore (Figure 35c). To make sure that the two layers do not jump around too quickly, layer-explore has to explore for a certain time before layer-focus adjusts its position.

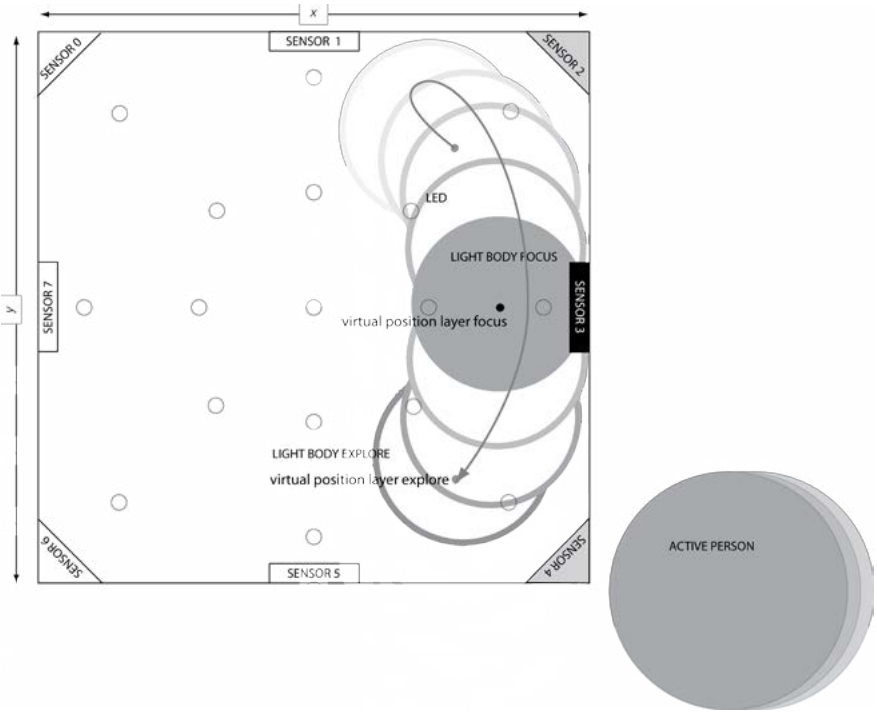


Figure 35b. When the surprise on sensor-explore is lower than on sensor-focus, layer-explore will move in opposite direction.

The position of the two layers corresponds with the placement of the sensors. The target position of layer-focus is determined on a weighted surprise over the focus sensor and its neighbours. This way, layer-focus moves freely and does not suddenly switch from sensor side to sensor side. The surprise on the neighbouring sensor side is gathered by layer-explore. Layer-explore also moves subtly as its position is determined by an angle that adjusts in relation to time.

Layer-focus moves towards the target position in the same manner as the body does in the *active* behaviour: based on a direction and speed. Layer-explore moves towards its target position in a similar fashion, but takes two more qualities into account. Although layer-explore and layer-focus are obviously two separate layers, they have to come across as one body. Layer-explore always has to move through layer-focus. The direction in which layer-explore moves is compared to the position of layer-focus. When the layers are too far apart, layer-explore is pulled towards layer-focus. This tension is also found in the dynamics by which layer-explore moves through layer-focus. There is an elastic force between the two layers.

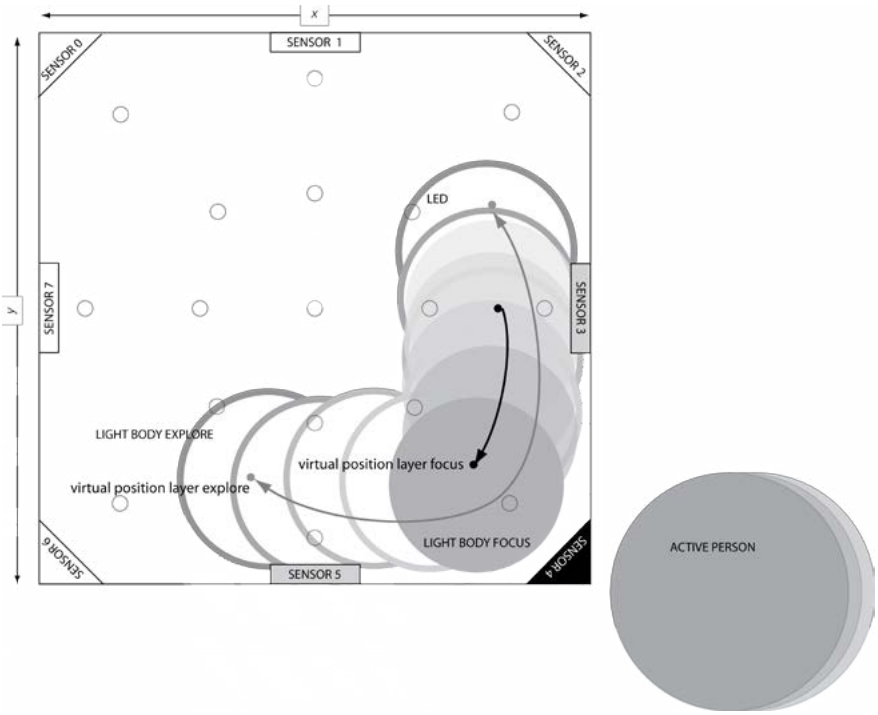
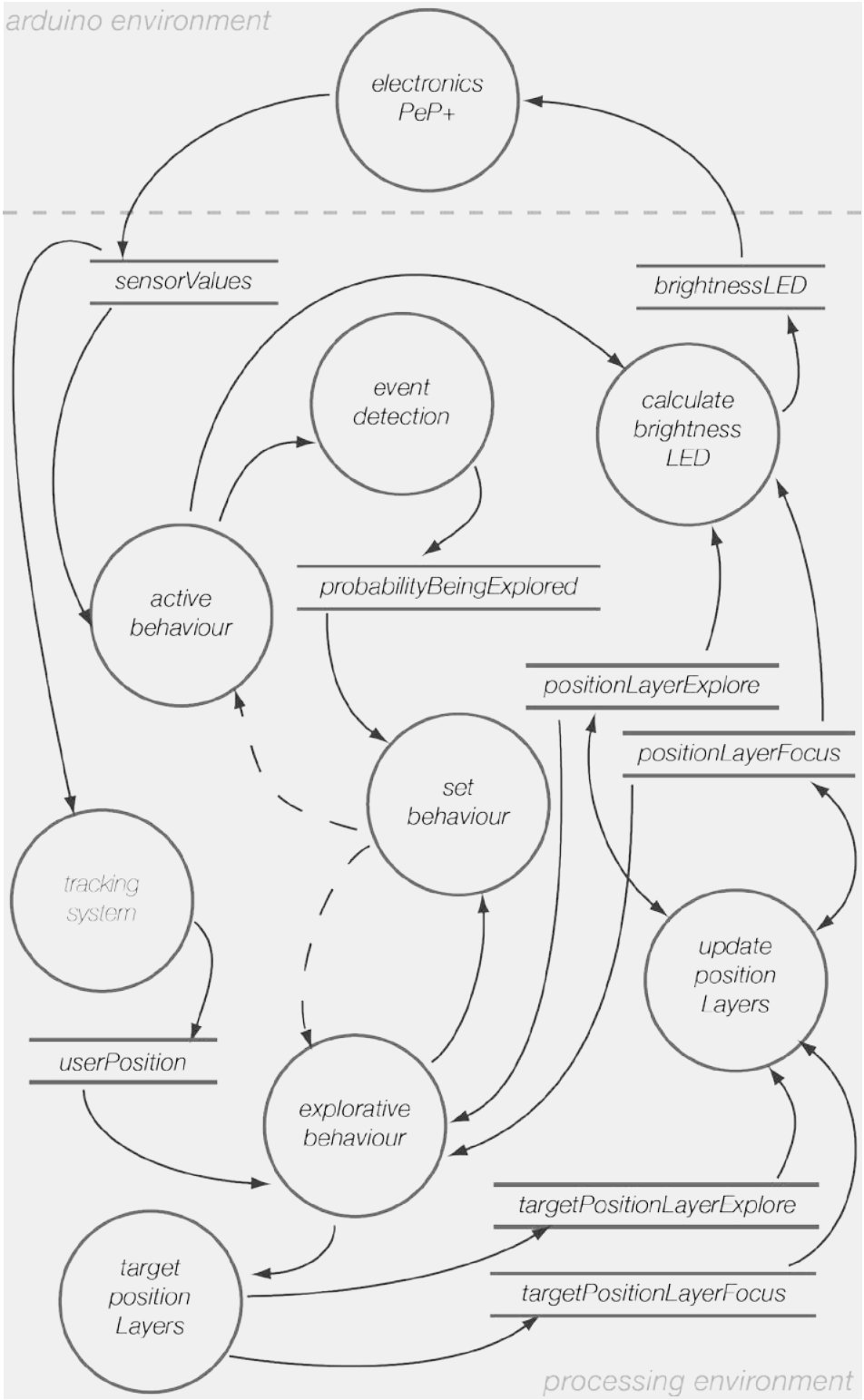


Figure 35c. The position of layer-focus adjusts, in time, on basis of the input gathered by layer-explore.

The person can escape from *PeP+*'s perception, and if the person is not active it can happen that the light body moves away from the person. *PeP+* sets out to stay in close contact with the person. When the link between them breaks, when they are too far apart, *PeP+* needs to switch back to *active* behaviour to explore the space and find the person again. To determine whether the light body and person are in contact, it is not possible solely to rely on the highest surprise, therefore the tracking of the person is used. Based on the information from the tracking, the angle between person and artefact is determined. As long as person and the light body are engaged in the play of attraction and escape, the angle will be relatively small. When the angle is larger for a period of time, *PeP+* will show *active* behaviour again.

In the time-frame and goals for this design-research project, it is reasonable to base the transition from *explorative* to *active* behaviour on the tracking of the person. Nevertheless, it is feasible and worthwhile to create a variable that indicates the probability that *PeP+* and person are engaged in a play of attraction and escape. A continuous transition is much more beautiful and a condition to build the intelligence further. This implementation has a very similar effect as the current implementation in this case, as *PeP+* only has two behaviours. *PeP+* does not provide enough resolution for the light body to behave to show this kind of nuance. I have reached the boundaries of the minimalist set-up of *PeP+*.

The tracking of the person might not be most suitable to build the intelligence of the artefact, but it does provide detailed information that can be used to analyse the interaction. Using a Bayesian approach, the algorithm fills a grid of buckets that are positioned circularly around the pillar, with probabilities that the person is there. The current input is compared to a noise profile; this profile models the empty room. When the person moves, the current input deviates from this image, increasing the estimated probability that someone is there. The algorithm relies on gathering input on all sensors all the time, and is therefore minimally used to create *PeP+*'s behaviour. It is out of my scope here to discuss the tracking of the person in detail.


arduino environment
electronics
PeP+
sensorValues
brightnessLED
event
detection
calculate
brightness
LED
active
behaviour
probabilityBeingExplored
positionLayerExplore
positionLayerFocus
set
behaviour
tracking
system
update
position
Layers
userPosition
explorative
behaviour
targetPositionLayerExplore
target
position
Layers
targetPositionLayerFocus
processing environment

Programme *PeP+ Explorative* Behaviour

```
//The Arduino platform (Arduino, 2012) is used read out the sensors and to set the
  brightness of the LEDs. The main programme is written in the Processing
environment
  (Processing, 2012). Processing and Arduino communicate over a serial port.

input valueUltrasonicSensor[8]; // values normally between 5 and 600
output valueBrightnessLED[17]; //min 0 – max 4000

//Body, sensors and LEDs have a position between -0.5 ≤ x ≤ 0.5 and -0.5 ≤ y ≤ 0.5

xPositionSensor[8] = { -0.47 , 0 , 0.47 , 0.47 , 0.47 , 0 , -0.47 , -0.47 };
yPositionSensor[8] = { -0.47 , -0.47 , -0.47 , 0 , 0.47 , 0.47 , 0.47 , 0 };

xPositionLED[17] = {-0.40 , 0 , 0.40 , -0.2 , 0 , 0.2 , -0.42 , -0.25 , 0 , 0.25 , 0.42 ,
                    -0.2 , 0 , 0.2 , -0.40 , 0 , 0.40};
yPositionLED[17] = {-0.40 , -0.42 , -0.40 , -0.2 , -0.25 , -0.2 , 0 , 0 , 0 , 0 , 0, 0.2 ,
                    0.25 , 0.2 , 0.40 , 0.42 , 0.40};

xPositionBody; //body has position when active, this is also position layer focus
yPositionBody;

xTargetPosition; // the body moves towards the target position when active
yTargetPosition;

xTargetLayerFocus; // layer focus moves towards target when explorative
yTargetLayerFocus;

xPositionLayerExplore; //layer explore has a position when explorative
yPositionLayerExplore;

xTargetLayerExplore; // layer explore moves towards target when explorative
yTargetLayerExplore;

beingExplored; //boolean, if true PeP+ behaves explorative

s; //variable between 0 and 1 to determine the influence of a value
z; //variable to determine the size of an effect

//c.f. PeP+ active programme for initialized arrays and variables
```

```
loop {
//functions that are called are defined outside the loop

if (beingExplored == false){
   activeBehaviour();                  //function for active behaviour
   brightnessLED();   }                //set the brightness of the LEDs when behaving
                                         active cf.  algorithm PeP+ active, p. 78
else {
   explorativeBehaviour();             //function for explorative behaviour
   brightnessLEDLayers(); }            //set the brightness of the LEDs when behaving
                                         explorative

//Updating the position of the body. Layer-explore moves exactly as the body in active
   behaviour, thus: xPositionBody in explorative behaviour refers to layerFocus

   xTargetLayerFocus = xTargetPosition;
   yTargetLayerFocus = yTargetPosition;

   xPositionBody += velocityX;
   yPositionBody += velocityY;

   dX = xTargetPosition- xPositionBody;
   dY = yTargetPosition- yPositionBody ;

   velocityX = velocityX + dX;
   velocityY = velocityY + dY;

   vector = sq(xPositionBody)+sq(yPositionBody );

   norm = (1 + vector) * z0 * sqrt(sq(velocityX) + sq(velocityY));  //I chose z0=3

   velocityX = velocityX/(z1*norm);          //I chose z1=2
   velocityY = velocityY/(z1*norm);

   dXExplore = (xTargetLayerExplore - xPositionLayerExplore);
   dYExplore = (yTargetLayerExplore - yPositionLayerExplore);

//layerExplore moves towards a target position. For layerExplore and layerFocus to appear
as one body layerExplore has to move through layerFocus. Therefore layerExplore is pulled
towards layerFocus

   test_dX = dXExplore + xPositionBody;
   test_dY = dYExplore + yPositionBody;
```

```
  if (sq(test_dX) > sq(test_dY)){
        dXExplore = z2 * dXExplore;        //I chose z2=1.2
        dYExplore = z3 * dYExplore; }      //I chose z3=0.5

else {
        dXExplore= z3 * dXExplore;
        dYExplore= z2 * dYExplore; }

  velocityXExplore += dXExplore;
  velocityYExplore += dYExplore;

  vectorExplore = sq(xPositionLayerExplore) + sq(yPositionLayerExplore);

  normExplore  = (1 + vectorExplore) * z4 * sqrt(sq(velocityXExplore) +
                     sq(velocityYExplore ));            //I chose z4=3

  velocityXExplore = velocityXExplore /(z5*normExplore);          //I chose z5=7
  velocityYExplore = velocityYExplore /(z5*normExplore);

//There is an elastic force beteen layerExplore and layerFocus
  distance = sqrt(sq(xPositionLayerExplore - xPositionBody)+
                    sq(yPositionLayerExplore -yPositionBody));

  tension = z6 * distance + 0.5;  //I chose z6=2

  xPositionLayerExplore = xPositionLayerExplore + (velocityXExplore * tension);
  yPositionLayerExplore = yPositionLayerExplore + (velocityYExplore * tension);
  }  //end loop

activeBehaviour {

  setSensorActive();  //sensor in range of the body is active cf. algorithm PeP+ active

  surpriseSensor(); //by moving the person causes surprise cf. algorithm PeP+ active

  uncertaintySensor(); // motivates to explore sides in time cf. algorithm PeP+ active

  attractionSensor(); //attraction exerted to move to a side cf. algorithm PeP+ active

  setTargetPosition(); //side highest attraction is the target cf. algorithm PeP+ active

  beingExplored(); //determine probability being explored or not
}
```

```
//return functions used in beingExplored();
check_event0() {
  event[0] = false;
     for all sensors i {
       if (uncertaintySensor[i] > 499.9) {
           event[0] = true; }
       }
 return(event[0]);  }

check_event1() {
  event[1] = false;
   for all sensors i {
     if (uncertaintySensor[i] > 999.9) {
        event[1] = true; }
  }
 return(event[1]);  }

check_event2() {
  event[2] = false;
   maxSurprise = surpriseSensor[sensorMaxSurprise] ;
      for all sensors i {
        if (surpriseSensor[i]> maxSurprise) {
          maxSurprise = surpriseSensor[i];
          sensorMaxSurprise = i;
          event[2] = true; }
       }
 return(event[2]); }
```

//The next function, added to the activeBehaviour, determines whether *PeP+* is being explored. Both the probability that *PeP+* is explored and ignored is taken into accounct. Three events have a certain chance of occurance when the person explores or ignores *PeP+* (cf. page 110).

```
beingExplored(){

  probabilityExplore;
  probabilityIgnore;

 //chance of occurrence for event 1, 2 and 3 when exploring and when ignoring are
   determined on basis of experiments
  chanceEventExplore[3] = {cExplore0, cExplore1, cExplore2};
  chanceEventIgnore[3] = {cIgnore0, cIgnore1, cIgnore2};
```

```
  arrayEvent[3];    //event 0 is uncertainty higher than 500, event 2 is uncertainty
                      higher than 2000, event 3 is surprise exceeds maximum surprise

for each event i{
      for each chance explore i and for each chance ignore i {
         if (check_event[i] == true) {
           probabilityExplore = probabilityExplore * chanceEventExplore[i];
           probabilityIgnore = probabilityIgnore * chanceEventIgnore[i]; }
        else {
          probabilityExplore = probabilityExplore * (1-chanceEventExplore[i]);
          probabilityIgnore = probabilityIgnore * (1-chanceEventIgnore[i]); }
      }
  }

  probabilityNorm = probabilityExplore + probabilityIgnore;

  probabilityExplore = probabilityExplore / probabilityNorm;
  probabilityIgnore = probabilityIgnore / probabilityNorm;

  probabilityExplore = probabilityExplore * s + probabilityIgnore * (1-s);
  probabilityIgnore = 1 – probabilityExplore;   //the probability is normalized to 1

  if (probabilityExplore > threshold) {   //I chose threshold = 0.9
   beingExplored = true; }  //PeP+ now behaves explorative
 }

//return functions and variables used in explorativeBehaviour();
maxTimeLoop; //number of  sensor reading loops in which the exploreSensor is
                        constant or before focusSensor is updated

timeLoop = maxTimeLoop; //sensor reading loops to go before update

getHighestSurprise {
  highestSurprise = 0;
  highestSensor = 0;
      for all sensors i {
         if (surpriseSensor[i] > highestSurprise){
            highestSensor = i;
            highestSurprise = surpriseSensor[i]; }
      }
  return(highestSensor);  }
```

```
  sensorFocus = getHighestSurprise();
  sensorExplore;
```

//In this function the explorative behaviour of the light body is determined. When the PeP+ shows explorative behaviour the light body exists out of two layers. One focuses on the person and the second layer explores the interaction (cf. page 112). Functions that are called are defined outside explorativeBehaviour().

```
explorativeBehaviour(){

 timeloops = timeloops -1; //initiate a time lapse to determine when to adjust layerFocus

  if (leftwards == true) {
       sensorExplore =   leftNeighbour(sensorFocus); }
  else {
        sensorExplore = rightNeighbour(sensorFocus); }

  setSensorActive2(); //make the sensor closest to layerExplore and layerFocus
                          active cf. algorithm PeP+ active, p. 78

  surpriseSensor2();  //If sensor is active: read sensor and determine surprise, cf.
                          algorithm PeP+ active, p. 78. Note that nothing happens when
                          sensor is not active different from the PeP+ active algorithm.

  if (timeloops < 1){
       setDirection(); } //determine direction in which layer explore moves

 setTargetPosition2(); //determine target position of layer explore and layer focus
```

//The tracking system that follows the position of the person is used to determine the angle between person and layerFocus. When this angle is small layerFocus is actually focused in the direction of the person, else the person is out of range of layerFocus. As it is out of scope to describe and show the tracking system the next if statement is descriptive.

```
  if (person is out of range of focusLayer for too long){
   beingExplored = false;  }
 }


setDirection(){
 timeloop = maxTimeLoop;
    if ( surpriseSensor[sensorFocus] >= surpriseSensor[sensorExplore]){
        leftwards =! leftwards;  }    //not leftwards is rightwards
```

```
else {
        sensorFocus = sensorExplore; }
}

//return function used in setTargetPosition2();
sensorAngle() {
  return( π * (-0.75 +  sensorExplore * 0.25));
  }
```

//In the active behaviour the function setTargetPosition() determines the target position of the light body. In the function setTargetPosition2() the target position of both layerFocus as layerExplore is determined as part of the explorative behaviour.

```
setTargetPosition2(){

  xTargetLayerFocus = xPositionSensor[sensorFocus];
  yTargetLayerFocus = yPositionSensor[sensorFocus];
```

//The weighted sum that determines the target position for layerFocus makes that layerFocus does not jump between sensors but focuses on the position of the person

```
  x += xPositionSensor[sensorFocus] * surpriseSensor[sensorFocus]);
  x += xPositionSensor [rightNeighbour(sensorFocus)] *
        surpriseSensor[rightNeighbour(sensorFocus)];
  x += xPositionSensor[leftNeigbour(sensorFocus)]*
        surpriseSensor[leftNeighbour(focussensor)];

  weightsum = surpriseSensor[sensorFocus];
  weightsum += surpriseSensor[rightNeighbour(sensorFocus)];
  weightsum += surpriseSensor[leftNeighbour(sensorFocus)];

  y += PositionSensor[sensorFocus] * surpriseSensor[sensorFocus]);
  y += yPositionSensor [rightNeighbour(sensorFocus)] *
        surpriseSensor[rightNeighbour(sensorFocus)];
  y += yPositionSensor[leftNeigbour(sensorFocus)]*
         surpriseSensor[leftNeighbour(focussensor)];

   xTargetLayerFocus= x/weightsum;
   yTargetLayerFocus = y/weightsum;
```

//The target position for layerExplore is determined based on an angle to make its movement from left to right through layerFocus subtle.

```
  if (leftwards == true){
      xTargetLayerExplore = 0.9 * cos(sensorAngle(sensorExplore -
                    1.1*(maxTimeLoop – timeloop) / (1.2*maxTimeLoop)));
      yTargetLayerExplore = 0.9 * sin(sensorAngle(sensorExplore -
                    1.1*(maxTimeLoop – timeloop) / (1.2*maxTimeLoop))); }

else {
      xTargetLayerExplore = 0.9 * cos(sensorAngle(sensorExplore +
                    1.1*(maxTimeLoop – timeloop) / (1.2*maxTimeLoop)));
     yTargetLayerExplore = 0.9 * sin(sensorAngle(sensorExplore +
                    1.1*(maxTimeLoop – timeloop) / (1.2*maxTimeLoop))); }
}

//return functions used in brightnessLEDLayers();
distanceLayerExploreLED(i){
   return sqrt( sq( xPositionLED[i] - xPositionLayerExplore ) +
            sq( yPositionLED[i] - yPositionLayerExplore) );
    }

distanceLayerFocusLED(i){
   return sqrt( sq( xPositionLED[i] - xPositionBody ) +
            sq( yPositionLED[i] - yPositionBody) );
     }

brightnessLEDLayers () {
 for all LEDs {

   LEDValueLayerExplore[i] = maxValue - (distanceLEDLayerExplore(i) * z7);
          //I chose z7=10000, layerExplore is more diffuse than layerFocus

   LEDValueLayerFocus[i] = (maxValue –s) - (distanceLEDLayerFocus(i) * z8);
          //I chose z8=15000, layerFocus is more focused

   valueBrightnessLED = max (LEDValueLayerExplore[i] ,
                                                LEDValueLayerFocus[i]);
 }
}
```

general hypothesis

In an experiment I compare the *explorative* behaviour to both the *active* and the *following* behaviour. It evaluates the effect of the different behaviours on the experience of the person and the interaction between person and artefact. Similar to the foregoing experiments, following the theoretical outline, *the hypothesis is that, if perceptual crossing between person and artefact happens, the person feels more involved. She comes to appreciate that she affects and is affected by the artefact.*

In the *following* behaviour, the light body is very reactive and cannot engage in the rich reciprocal interplay of attraction and escape, as is the case in the *explorative* behaviour: it only follows. *The hypothesis is that people will feel more involved in the explorative condition than in the following condition.* In the *active* behaviour, the light body explores the space rather than the person. As in the *explorative* behaviour, the light body focuses more directly on the person, *the hypothesis is that the person feels more involved in the explorative condition than in the active condition.* When *PeP+* behaves *exploratively,* the play of attraction and escape can happen; perceptual crossing can happen. The experience of this active interplay of perceiving and being perceived shows when participants feel that they can attract the light body, but that the light body also sets out to lure them in following it.

set-up

The set-up of this experiment draws very closely on the set-up of the experiment of evaluating the effect of the *active* behaviour of *PeP+* on the experience of the person and the interaction (cf. Experiment, p. 86). The 24 participants are students at the Department of Architecture, and compare two of the three behaviours. The *explorative* behaviour is compared to the *active* and *following* behaviour. The *following* and *active* behaviour are not compared again, so each participant compares either the *following* (N=12) or *active* (N=12) behaviour to the *explorative* behaviour. For ease of reading, I repeat the procedure briefly. For a more precise description and considerations concerning the set-up please refer to page 85. The participants get a short introduction to the experiment and are familiarised with *PeP+*'s physicality. The participant is asked to compare the two behaviours of *PeP+* which she will encounter. The experimenter emphasises that the person can freely explore and leave the lab whenever she feels ready. The experimenter prepares the second condition and the procedure is repeated. The experiment ends with an open interview following the laddering technique (Rugg & McGeorge, 1995). Both the explorations and the interview are filmed.

Similar to the process of preparing the previous experiment different experts, design-researchers in the Designing Quality in Interaction group experienced the interaction with *PeP+*. It appeared that all experts had a vocabulary readily available to describe both the *following* and *active* behaviour. Nonetheless, they all indicated that describing the *explorative* behaviour is much harder. Especially for the participants in the experiment it will be hard verbally to explain what happens in the *explorative* behaviour. Therefore I am not necessarily that much interested in whether their descriptions correspond with the intended design variables, but more in the experience of feeling to be perceived or not. If participants do not feel to be perceived in one or two of the conditions, this changes the view of the qualitative data. For the same reason, the clarity of the behaviour is not considered in depth in the analysis.

In the *explorative* condition, *PeP+* directly focuses on the person and sets out to attract and lure the person. Therefore the interview also holds guiding questions in relation to *PeP+*'s strategies and preferences. The movement plots part of the analysis of the previous experiment solely focused on the person's movement. To show the reciprocal interplay, the behaviour both of the light body and of the person should be plotted in the same overview.

The measurements in this experiment are also very similar to the collection of data in the previous experiment. I gather three types of data by interviewing and observing the participants: (1) quantitative data on the feeling of being perceived, preference, pleasantness, and involvement; (2) qualitative data in the form of the participants' description; and (3) qualitative data in the form of movement plots of the interaction (Table 9). The participants are asked to describe both behaviours they encountered, compare them and elaborate on the feeling of being perceived, involvement, preference and pleasantness. Other questions address whether they gave themselves a task and if *PeP+* might have had a goal. The last set of questions addresses the possibility of *PeP+* having a preference for one of the two behaviours. Next, a few examples of descriptions on *PeP+*'s goals and preferences are given.

Does PeP+ have a goal?

e.g. "Seeking contact? The first (*following*) is very much claiming me; the second (*explorative*) has more its own will. Like he likes you but also wants something for himself." (participant 13, *following-explorative*)

e.g. "Detecting data? I did not feel this so consciously." (participant 17, *following-explorative*)

***PeP+*'s preference for one of the two situations**

e.g. "Not directly in this situation but in use he could have a preference for the second (*explorative*), because it could lure people in a direction." (participant 1, *following-explorative*)

e.g. "Haha, no, it is an object, so no." (participant 16, *active-explorative*)

The movement plot gives an overview of the movement of the participant and the light body. The movement plots are a direct presentation of data collected while running the experiment. The tracking of the person in the algorithm is used to store the positions of the participant and light body over the course of the interaction. To indicate the time, the line diverges from light to dark. It is only possible to make the movement of the light visible by enlarging it in the visualisation compared to the participant's movement. To create an immediate overview, the movement of the person is distorted over the distance from the pillar (compressed). The plots get too large or the movement of the light body invisible if this is not done. The data is still correctly readable.

An overview of the feeling of being perceived in the different conditions forms the perspective on the qualitative data. If the participants do not feel to be perceived, this changes the view of the other data sets. Table 10 gives an overview of how many participants felt to be perceived, seriously doubted if they were perceived, or did not feel to be perceived by *PeP+* for all conditions. As each participant experiences the *explorative* condition (N=24), and only half either the *active* or *following* condition (N=12), percentages are provided to give an immediate overview. The order in which the participant experiences the two conditions is considered.

It stands out that when participants experience the *explorative* condition first, relatively a lot of them feel not to be perceived. On the other hand, when they experience the *explorative* condition second, almost all participants feel to be perceived. The previous experiment also showed that the order by which participants encounter the condition influences the experience. The descriptions indicate that familiarity with *PeP+* causes this effect. When *PeP+* behaves *explorative,* it first behaves *active* to explore the space, and adjusts its behaviour when it is certain a person is exploring it. As participants feel to be perceived

Table 9. Example of three types of data, participant 24

Participant 24, *explorative - active*
Quantiative Data
Participant feels to be perceived in both conditions Participant prefers the *explorative* condition Participant finds the *explorative* condition most pleasant Participant feels most involved in *explorative* condition
Qualitative Data Descriptions
e.g. "I find they are quite similar. I had the idea that he tried to indicate where you are in the room. In the second he lets go of that quicker and went its own way" e.g. "Second is least pleasant, I did not really have the idea that *PeP+* was really focusing on me, that I was really influential." e.g. "In both I thought that he was trying to go in a direction, that he clearly said go in this direction."
Qualitative Data Movement Plots

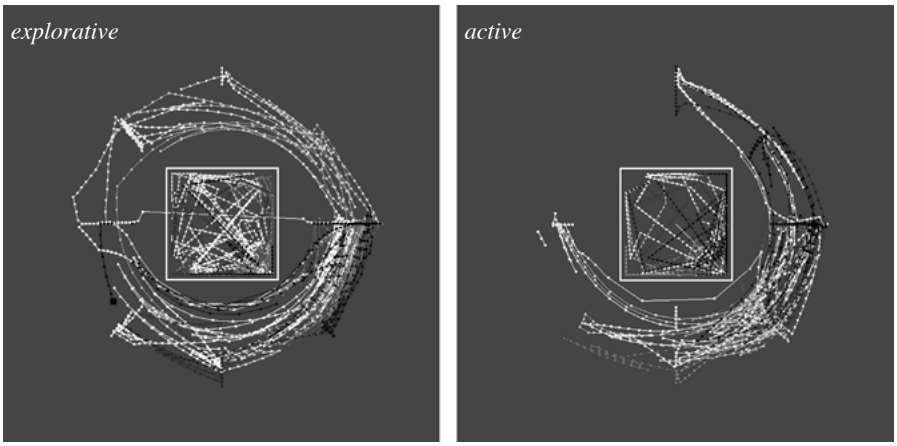


Table 10. Overview participants feeling of being perceived, considering order

	FO1	*FO2*	*AC1*	*AC2*	*EX 1*	*EX 2*
Feels to be perceived	5 (83%)	5 (83%)	4 (67%)	4 (67%)	5 (50%)	11 (92%)
Not sure to be perceived	0	0	0	1 (17%)	2 (17%)	0
Does not feel to be perceived	1 (17%)	1 (17%)	2 (33%)	1 (17%)	4 (33%)	1 (8%)

when the *explorative* condition follows on the *active* condition, it seems that the person did not yet appreciate it was being perceived when *PeP+* started to behave *explorative*. Both person and artefact have to be certain they are being perceived. The person has to appreciate that she is affecting *PeP+*'s behaviour before the play of attraction and escape is appreciated by both. In case the participant experiences the *explorative* behaviour second, the *following* or *active* behaviour assumedly has influenced the expectation of the participant.

14 out of 24 participants feel to be perceived in both conditions. These participants are considered when comparing preference, pleasantness and feeling of involvement. When participants feel not to be perceived in a situation, this influences their experience. Six people felt to be perceived in one of the conditions, and felt not to be perceived in the other. In five of these cases, this also results in the fact that they prefer, feel most involved in, and find more pleasant the condition in which they did feel perceived. The people who do not feel to be perceived in either of the two conditions have a hard time comparing them, or they relate the behaviour of *PeP+* to unrelated phenomena that are not mentioned by any of the other participants. As people feel relatively as often not perceived in the *explorative*, *following* and *active* condition, I here only consider the data from the participants who feel to be perceived in both conditions.

Table 11.Overview data on preference, pleasantness and involvement

	Following (N=7)	*Active (N=7)*	*Explorative (N=14)*
Preference			
Preferred	3 (43%)	2 (29%)	8 (57%)
No Preference	0	1 (14%)	1 (7%)
Pleasantness			
Pleasantest	2 (29%)	2 (29%)	8 (57%)
No Distintion	2 (29%)	1 (14%)	3 (21,5%)
Involvement			
Most Involved	2 (29%)	2 (29%)	8 (57%)
No Distinction	1 (14%)	1 (14%)	2 (14%)

Table 11 gives an overview of how many participants prefer, find most pleasant, and feel most involved in the different conditions. The overview also shows how many participants made no distinction between the different conditions on these three topics. Again the percentages provide a more immediate overview. The chi-square test for non-parametric statistics shows that the *explorative* sample differs significantly ($p<0,001$) from both the *active* and *following* sample. The table shows the direction of the effect. Participants prefer, find more pleasant, and feel most involved in the situation when *PeP+* behaves *explorative*.

The descriptions of the participants bring forward three main categories of qualities on *why* participants prefer, find most pleasant, or feel most involved in a condition. The first category (1) holds descriptions that relate to the feeling of control or understanding of the participant (Table 12). Although it lies in the line of expectation that these qualities that closely relate to the clarity of the behaviour are positively mentioned in relation to the *following* and *active* behaviour, this reason is found multiple times for all three behaviours. (2) The *explorative* behaviour is preferred over the *following* behaviour as a result of its playfulness and own initiative (Table 13). This corresponds strongly to the intended design variable, as in the *explorative* behaviour, *PeP+* actively explores the person and sets out to lure the person in the play of attraction and escape. (3) The *explorative* behaviour is preferred over the *active* behaviour because participants feel ignored in the *active* condition (Table 14). This also strongly corresponds with the intended design variables. In the *active* behaviour the light body is motivated to explore the space, rather than actively to focus on the person and explore the interaction space.

In their description of both the *active* and *explorative* behaviour, participants use terms such as 'steering' or 'trying to get me in a direction'. They use these terms slightly more for the *explorative* behaviour, but there is no significant difference. On several occasions, participants find it hard to describe the difference between the *active* and *explorative* behaviour: e.g. "I did not notice a lot of difference, the second (*active*) was a bit slower but not a lot of difference. The first time (*explorative*) he followed my movement and in the second (*active*) also, but then he stayed longer on one spot" (participant 23, *explorative – active*). Compared to the *following* behaviour, the *explorative* behaviour is more strongly described in terms of 'giving directions. Tables 15 and 16 exemplify these observations that relate to the play of attraction and escape. In addition, the movement plots are presented. These are discussed next.

Table 12. Descriptions control/understanding

Control/Understanding
e.g. I prefer the second (*following*), it is nice to have control." (participant 6, *explorative-following*)
e.g. I prefer the second one (*active*) because it really stops with you. So you really know it is going with you." (participant 20, *explorative – active*)
e.g. I had the idea that the second (*explorative*) reacted faster and I like that better. It is quicker clear which you could say is a nicer feeling." (participant 7, *active – explorative*)

Table 13. Descriptions playfulness/initiative

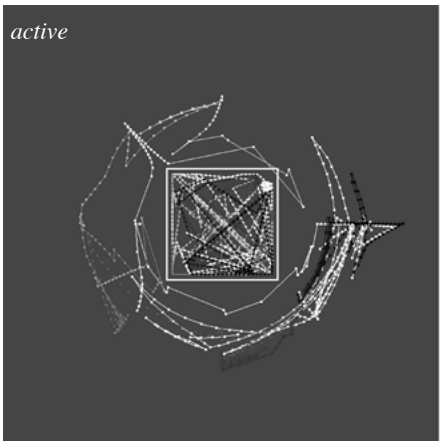
Playfulness/Initiative
The second (*explorative*) was nicer, more surprising. If he comes to you at once (*following*) the game is over, you immediately know how it works. The second time (*explorative*) I had to find it out more. (participant 13, *following-explorative*)
e.g. In the first (*following*) I had the idea that it was a kind of camera, the feeling someone was watching. The second (*explorative*) is more *explorative*, more the feeling of an inter*active* object. The second (*explorative*) is more pleasant because you are not just being looked at but it makes more curious." (participant 17, *following-explorative*)
e.g. I felt more involved in the first (*explorative*), the second (*following*) could do it all by himself". (participant 10, *explorative-following*)

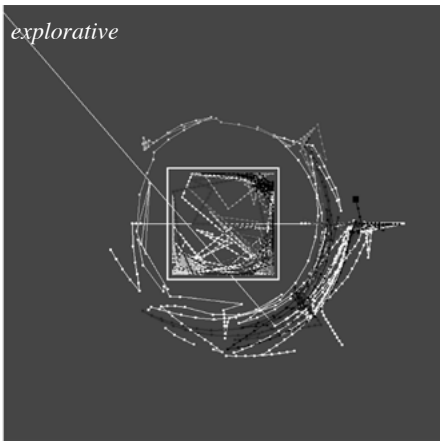
Table 14. Descriptions feel to be ignored

Ignorance
e.g. "I felt more involved in the first (*explorative*), in the second (*active*) it is like he lets go again after he notices you." (participant 8, *explorative –active*)
e.g. "I prefer the first (*explorative*), because in the second (*active*) I got the idea that he did no have that much interest anymore in my presence. In the first (*explorative*) that was more." (participant 24, *explorative-active*).

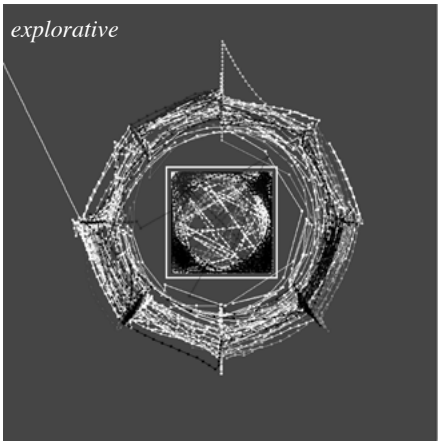
Table 15. Play of attraction and escape in *active* and *explorative* condition

Play of attraction and escape *explorative / active*
"Well somehow in both you think quite quickly that it is trying to give a direction because in the beginning he first focuses on you and than moves away again: that is a kind of follow me instruction. …" (participant 16, *active-explorative*)





"In the first one (*explorative*) it was alternating who kept an eye on who." (participant 12, *explorative-active*)



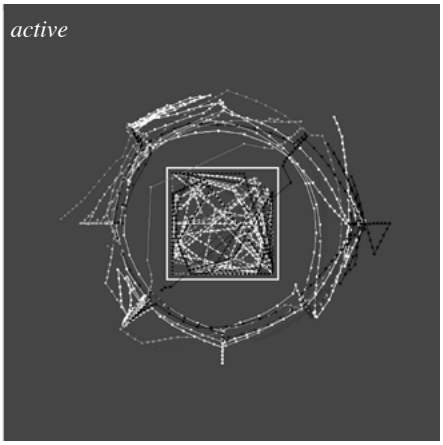
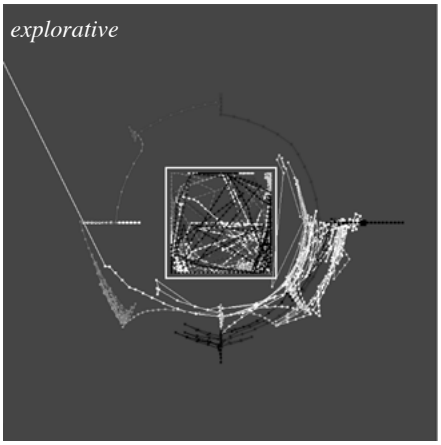
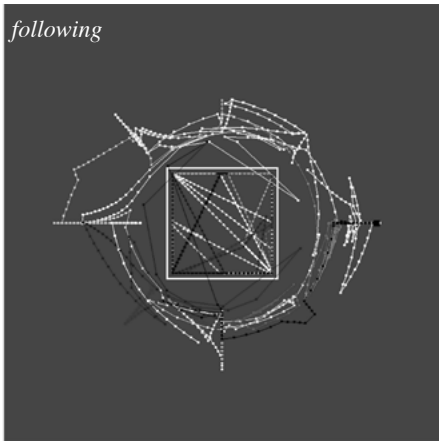


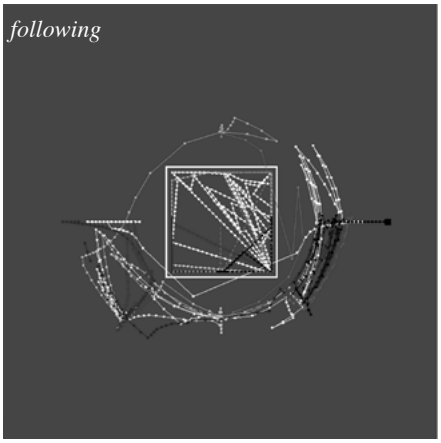
Table 16. Play of attraction and escape in *following* and *explorative* condition

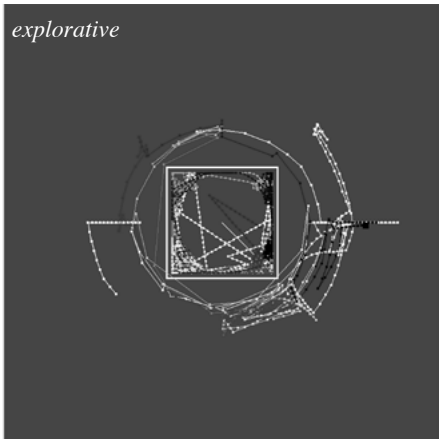
Play of attraction and escape *explorative / following*
"The first time (*explorative*) he tried to steer me more, tried to force one side by moving the light in that direction. Did it work? If I say no I would lie." (participant 6, *explorative-following*)





"Maybe in the second (*explorative*) he tried to get you to another side, now I think about it, because he was more vague and moved away. In the first (*following*) solely the idea it followed me." (participant 5, *following-explorative*)





The movement plots show the spatial relation between the participants and the light body. The difference in behaviour and the effect on the relation between the participant and light body are clearly visible in the movement plots. The activity of the light body is minimal in the *following* behaviour, even if the participant is very active. In the *active* behaviour, the light body is obviously more active, and it shows that the light body moves often through the middle of the grid towards and away from the person. When *PeP+* behaves *explorative* the activity of the light body is high but very clearly focused on the person, and the other way around; the angle between person, and light body is small and the light body moves along the sides. Figure 36 shows the different relations between person and light body in the three conditions. This emergent behaviour clearly shows the active engagement between person and artefact.

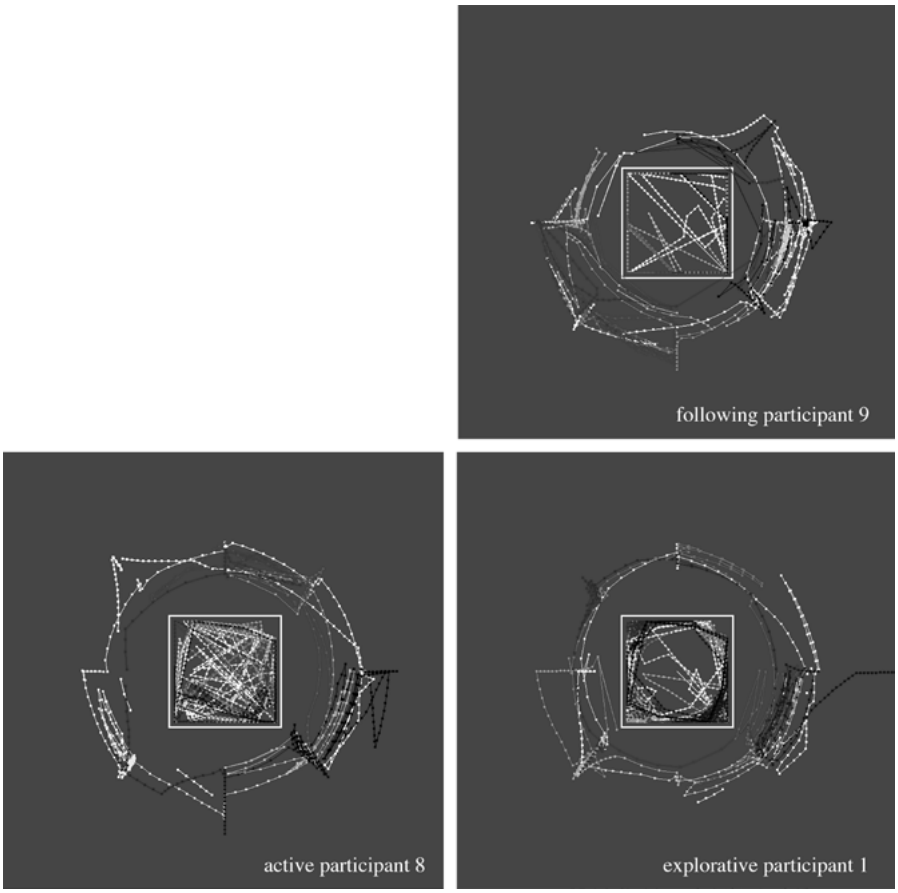


Figure 36. Spatial relation between participant and light body.

The difference between the activity of the light body in the *active* and *explorative* behaviour is very clear. When behaving *explorative,* the light body moves along the sides and not through the middle. Nonetheless, in the *explorative* condition, the light body shows *active* and *explorative* activity. It is clearly visible in the movement plot when *PeP+* alternated between behaving *active* and *explorative*. In this case, the light body frequently moves through the middle. On some occasions the play of attraction and escape visually happens, and at other times the light body sets out to explore the space, rather than the person. *PeP+* is not so sure that the person is exploring it and the connection between person and artefact is less strong. When this is the case, participants tend to be less explicit in describing the *explorative* behaviour. Table 17 exemplifies this observation.

Table 17. *Active* behaviour versus *explorative* behaviour

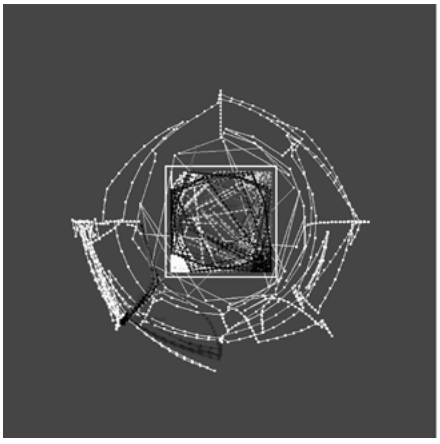
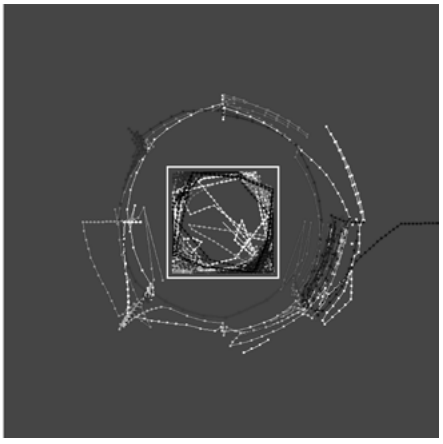
***Active* and *explorative* behaviour**	**Mainly *explorative* behaviour**
„He reacts to movement and where you are standing. I had the feeling he reacted less quick, different, I do not know exactly. That he moved a bit more freely (*explorative*). The first time (*following*) he quite quickly came to me." (participant 13, *following-explorative*)	"The first one (*following*) the light was *following*, the second (*explorative*) I had the idea he was pointing where I should go. In the second (second) it took a while before I figured out does it follow me or does it give a direction?" (participant 1, *following-explorative*)
	

Figure 37. Screenshot participant interacting with *PeP+*

I went through three iterations of designing, building and evaluating *PeP*, an artefact with perceptive qualities. Through these iterations, a set of design notions relevant for designing perceptive qualities, and more specifically for designing for perceptual crossing, developed. The different iterations showed the state of the art of the development of the design notions at that moment in the process. The phenomena of perceptual crossing between person and artefact, and if or to what extent the rich reciprocal interplay happens are closely investigated. The three iterations were needed not only to formulate which design notions are relevant, but also to understand how to develop them further. In the last iteration I show that I designed an artefact with perceptive qualities that engages in a strong reciprocal interplay with the person of perceiving and being perceived.

The person can perceive the artefact: the artefact can perceive the person; the person can perceive the artefact perceiving her; and the artefact can perceive the person perceiving it. Their perceptions of each other cross.

The interaction with *PeP*+, behaving *explorative*, shows the interplay of attraction and escape that characterises perceptual crossing. The feeling of involvement of the person is highest when this play can happen and their perception crosses. The movement plots of the interaction between person and artefact visually show the moments that the play of attraction and escape takes place. Furthermore, the experiment shows that the *explorative* behaviour is preferred over the *following* behaviour because of its playfulness and own initiative. People feel more involved because *PeP*+ is asking more from them. It is playfull and does not just watch them. Moreover, the qualitative data shows that the person feels less involved when *PeP*+ behaves *active,* as they find its behaviour ignorant compared to the *explorative* behaviour. Both observations strongly correspond with the design variables, and underpin that the person feels engaged in a rich perceptive interplay with *PeP*+.

The design notions Recognise Explorative Behaviour Subject and Remember and Anticipate Perception over Time especially developed in this last iteration. This is the last iteration of *PeP*. The other two tracks will show how I iterate over different artefacts: for example, *PeR* and *PeR*+ in the second chapter.

The process of designing and evaluating the *explorative* behaviour brings forward several insights that inform future work. The transition between the different behaviours of *PeP+* in time can especially be considered. Although the dynamics of the light body in the *explorative* behaviour invite the person in a play of attraction and escape, *PeP+* is not aware if the play happens or not. The tracking of the person is used to calculate the angle between person and artefact, which animates this awareness. Rather a variable, such as the probability of *PeP+* being explored, should be introduced for *PeP+* to appreciate it is engaged in the play of attraction and escape.

The probability that *PeP+* is being explored becomes effective when it exceeds a certain threshold. This creates an abrupt transition between its *active* and *explorative* behaviour. A transition such as this could be desirable, but should not be the limitation of the algorithm. To further build the intelligence of the artefact, variables such as the probability of being explored and the appreciation of the play of attraction and escape should directly influence the behaviour of the light body. This is complex, as for example, the probability of being explored relies on variables that are characteristic for the active behaviour. They will also change when *PeP+*'s behaviour changes.

Next is another part of the leitmotiv. In this last iteration the design notions Recognise Explorative Behaviour Subject and Remember and Anticipate Perception over Time developed. Therefore, only these two design notions are discussed. The definitions and relevance based on theory and examples (both in italic) are discussed, as well as the implementation in the explorative behaviour.

The perceptive activity of the person should become meaningful to the artefact in the course of the interaction.

We are living organisms showing active and explorative movements to perceive. In the course of the interaction, the artefact should be enabled to detect this perceptive activity of the person. In the context of their interactive interplay, these actions become meaningful to the artefact. Therefore the light body in the following and active behaviour is already sensitive to changes in sensor input. Being still for too long will result in no longer being detected as an intentional subject (perceiving the lived-body), but as an object in the environment (perceiving the body-as-an-image). Perceptual crossing can no longer occur and the light body loses its focus.

When we engage in a rich reciprocal interplay of perceiving and being perceived, I see you, you see me, I see you perceiving me, and you see me perceiving you. So far, *PeP+* did not appreciate that it is being perceived. In the explorative behaviour, not only *PeP+* is sensitive to the movement of the person, but also appreciates if this movement is explorative in relation to itself or not. Variables that are intrinsic to *PeP+*'s behaviour influence its feeling of being perceived or not. When the person actively explores, it will get more certain it is being explored in the course of the interaction and adapt its behaviour.

When we engage in a dialogue we are sensitive to things that happen around us, and we will react to this when it happens suddenly. Nonetheless, when we strongly engage in the dialogue, our interest in the things around us diminishes. When *PeP+* is certain it is being explored, it adapts its behaviour from exploring the space to actively focusing on the person and exploring their direct interaction space. It is less interested in exploring the environment as it does in the active behaviour (related to Focus the Senses and Show Explorative Behaviour).

The artefact gets, as it were, an experience; it is aware of bygone perception and anticipates future perception.

The notion of Remember and Anticipate Perception over Time refers to experience. Time is here considered to be a subjective experience, a continuum of activity. In line with this, experience is here considered the continuum of perceptions, and thus the awareness of bygone perception and the anticipation of future perception (Schutz, 1967). It is in this design notion that the artefact, as it were, builds an 'experience' based upon other design notions.

Perceptual crossing is characterised by a play of attraction and escape. When we are engaged in a dialogue, I will catch your eyes and escape from them again; you will do the same. It is in this play that our perception of each other crosses, that I understand that I affect your perception and you affect mine and the other way around. We actively focus on each other; we do not stare. The implementation of the design notion Recognise Explorative Behaviour Subject closely relates to this design notion. In the course of the interaction, *PeP+* experiences it is being perceived and adapts its behaviour. The light body will actively focus on the person; try to lure the person along without letting the person out of focus. The light body exists out of two layers that form one body. A tension exists in the light body as the first layer sets out to focus in the direction of the person, and the second layer explores the direct interaction space. By these dynamics the light body anticipates on the activity of the person and influences it at the same time. When the light body moves too far away from the person as she does not follow or when the person escapes from its perception, *PeP+* sets out to explore the environment by behaving active again.

This is the second of three chapters that is structured around the leitmotiv. This chapter deals with an explorative investigation into the relevancy and extensibility of the theoretical findings (cf. first chapter) for design practice. I show that the theoretical background and findings put forward high-quality and innovative design opportunities exceeding functional innovation. Design knowledge is applied in the field of intelligent interior textiles. In this chapter, the artefacts propose that the way we interact with our environment can change. Through two iterations of designing and developing an interactive and intelligent carpet, I show that both the theoretical findings and the practical implementations are relevant and extensible in design practice. Moreover, the spatial qualities of these artefacts support the development of a vision of designing for perceptive qualities in systems of interactive products. I work towards a proposition that articulates the opportunities of perceptive qualities to design for systems that are perceptible to, and evolve around, its users.

second chapter: applying design knowledge into design practice

an investigation into the relevance and extensibility of theoretical findings for the practice of design

The introduction of flexible and largely invisible systems in our environments asks for a reconsideration of how we interact, not only functionally but also aesthetically, with our environment. The theoretical starting point and findings provide concrete handles to consider the intelligence of such systems. How can the activity of such a system become meaningful to the person? Moreover, how does the activity of the person become meaningful to the system? This invites application of the theoretical starting point and findings in a more spatial setting. A real-life anecdote sketches the design space for designing systems of interactive artefacts. Furthermore, I apply my theoretical findings to PeR, short for 'perception rug', to validate the relevancy, for and extensibility in, design practice of the theoretical knowledge.

Publications on this sub-chapter:
Deckers, E.J.L., Wensveen, S.A.G., Overbeeke, C.J. (2010). PeR: Designing for perceptive qualities. Proceedings DeSForM 2010, 68-70

Deckers, E.J.L., Wensveen, S.A.G., Overbeeke, C.J. (2011). PeR: Designing for perceptive qualities. Proceedings Extended Abstracts CHI2011, 491. ACM Press.

designing *PeR*

The interest in intelligent and interactive interior textiles connects to the question how people will interact with their environment when it becomes increasingly intelligent, and systems disappear to the background. How do we understand all these connections, different nodes and systems created in our environment, when they are invisible and highly flexible? Moreover, how do we design for such systems of intelligent and interactive products? Frens and Overbeeke (2010) state different challenges to design for systems. They propose that there is a need for loci of interaction, both to control and to perceive what a system is capable of. Besides, a new dynamic form language is required that accommodates action-centric interaction.

Weiser (1991, 1993) already proposed in the 1990s the concept of context-aware computing. Context-aware computing involves detecting, indentifying and locating users. This entails the user's movements, routines and actions in order to use this information to provide relevant data for the system to be meaningful to its user. Also the fields of Ambient Intelligence (Aarts & Marzano, 2003) and Pervasive Computing (Satyanarayanan, 2001) propose similar concepts. The crux is not in gathering information. It is about what, why and how events are relevant and meaningful to both system and user. I argue that meaning is in interaction, and that meaning is always directed to, and part of, the world. The information the system gathers and the activity it shows can also only become meaningful in the actual interaction. In the first chapter, I show how I form and frame the artefact's intelligence from an action- and quality-centred perspective. Both person and artefact come to appreciate they affect and are affected by each other. They perceive each other's perceptive activity and what it is directed towards.

In the first chapter, I focus on one-person one-artefact interaction, and deliberately chose a minimalist approach. The various prototypes of *PeP* are essentially research prototypes that are contextualised in this minimalist setting; they do not resemble any consumer product. The artefacts in this second chapter are not, in the first place, research artefacts, but can be used in context. Because textiles naturally shape and define the environment we live and work in, intelligent interior textile is an adequate field of focus for the research in this chapter. Designing textile artefacts explores how the proposed theoretical framework and the resulting design-relevant knowledge can be applied in our daily environment. The spatial qualities of interior textiles hint towards the implementation of the design notions in a more dynamic and complex setting, answering to the question how an artefact can evolve in time and adapt to multiple persons and events.

A personal anecdote illustrates the aforementioned developments. When I come home from work, Sjors is already home. He is listening to music, and in a lot of cases I want to turn the volume down. This is not as straightforward as it might seem. With the audio system we use in our home, music can be played from different devices and over different wirelessly connected speakers, which is very nice in principle. The music can be played from the laptop, from the tablet, or from the smartphone. There is a set of speakers in the kitchen, in the living room and in the bathroom. These connections in the system are not perceptible to me and are very flexible. When I find out today where to control the music, it does not mean I am prepared tomorrow. The moment I walk in, I bring in two more possible devices to play music from. A possibility I never use, however. Another feature of this system is that there is a cloud in which all music is accessible and to which all-present devices can connect, a feature that only Sjors uses. This creates new, flexible connections and possibilities that are not directly perceptible. Although this is only a relatively small audio system, it might already confuse or disorientate the user. Actually besides the audio features, the system in this example is also wirelessly connected to a TV screen. Photos and movies from all these devices can also be shown on this screen. This data is also shared and collected in the cloud. Yet, this example does not incorporate sensing capabilities in relation to the user besides direct control. There is a continuing trend towards the introduction of flexible and largely invisible connections in our environments. The fact that these are invisible and highly flexible asks for a reconsideration of how we interact, not only functionally but also aesthetically, with this environment (Ross, 2008; Vlist et al. 2012). How can we design for the aesthetic qualities in this system that I have in my home? How can we take into consideration the spatial, contextual qualities of the system? How can I appreciate these qualities and perceive the loci of interaction?

One way to approach the interaction in such a system is a screen-based, centralised concept in which one device becomes the control for everything in this system. My phone connects to the system, and I can control everything from that device. When designed carefully it might be a workable solution, but it does not exploit the aesthetic and functional possibilities of an open and growing system. It does not allow for the system to evolve around me. It merely builds on my cognitive skills and the control device is decontextualised. And so my actions become decontextualised as well. Moreover, if I like to control the music, the light, and the temperature, we again head towards a hierarchal, cluttered, universal remote control that only exploits our cognitive skills. These developments invite me to apply the theoretical starting point in a more spatial setting, compared to *PeP*.

The artefact I develop in this sub-chapter is named *PeR*, short for 'perception rug'. Through designing and showing *PeR*, I explore how theory can be applied in our daily environment. The process inspires system thinking and designing for systems. Knowledge and insights gained in the first chapter are applied in several iterations of *PeR*. And in turn insights gained in the process of designing *PeR* feed back to the process of designing *PeP*: for example, insights on the integration of, and balance between, the aesthetics of material, technology and behaviour. The integration of conductive and optic fibres enables *PeR* to, respectively, sense the touch of a person and to let a light body behave within the surface of the rug. The prototype is hand-knotted and electronic components are integrated by hand also. *PeR* portrays high-level integration of textiles, electronics and behaviour. The aesthetics of the material and the electronic properties reinforce each other. Designing *PeR* is a parallel process to designing and evaluating *PeP*.

PeR is a carpet with integrated sensing and actuating capabilities. It is able to detect the touch of the person and a light body behaves in the surface of the rug. The following behaviour that is described in the first chapter is implemented in *PeR*. The light body follows your touch. A little change in the algorithm means that the light body follows your touch on a humble distance and shyly moves away from your hand when you directly touch it. Although the change in implementation is minimal, the effect appears to be rather fascinating. Moreover, the dynamic qualities and appearance of the light body are easily altered: for example, a big and slow body influences the interaction tremendously compared to a small and quick body. The light body is sensitive to contextual noise: for example, when two conductive threads touch each other, this influences the input. Reflect Contextual Noise in this case amends the behaviour of the light body and the interaction. The person tends to caress the light body when it does not follow, resolving the contextual noise.

Figure 38. Impression of *PeR*

technique

I knotted the basic carpet following a traditional manner of working known as Smyrna. The technique for non-woven handmade carpets goes back to the 16th and 17th centuries. The technique thanks for its name the Turkish city Izmir, the ancient Smyrna. Specific patterns characterise the original handmade Smyrna carpet. This changed when the Turkish merchants shipped the carpets to Europe. Their customers had a different taste for decoration and furnishing. When industry emerged, the so-called needle-punching techniques were automated. These techniques originated in Germany in the 1850s, but were only fully automated between 1950 and 1970. The modern yet traditional automated technique for creating a carpet like *PeR* is called 'tufting'.

electronics

Conductive fibres integrate with the threads of the basic rug. These yarns are the sensor areas that connect to fifteen capacitive sensors (QProx, qt110). The sensors are placed in a static grid of three by five under the carpet. The conductive yarns are spread throughout the carpet, and one sensor area is about 150mm x 150mm. The capacitive sensors detect a change in electronic charge when the person touches, or comes in near proximity of the carpet (depending on the choice of electronic components). Next to the conductive yarns, the rug holds nylon fibres. This fibre has optic properties and is able to conduct light. The soft feel, transparency and flexibility of the nylon fibre mean that it integrates well with the basic rug. Next to the sensors, the carpet holds a grid of 60 (6x10) LEDs. The nylon fibres are spread throughout the carpet and are bundled under the carpet. One LED emits light into over twenty nylon fibres. Although the nylon fibres integrate well with the basic carpet, the feeling when you touch it is somewhat scratchy. The behaviour of the light body is determined in an algorithm very similar to the algorithm of *PeP*.

Figure 39. *PeR* at ID09, photo Joris Zaalberg.

insights

I like to consider *PeR* as a platform for designing perceptive behaviour. A little change in the algorithm strongly influences the interaction and experience. The dynamic qualities that inform the algorithm, such as the speed at which the light body moves, its size, shape, focus and direction, can be further exploited. Its size and the integration of sensing and actuating allow for this. Changing these characteristics over time in relation to the person's activity enriches the reciprocal perceptive interplay (Remember and Anticipate Perception over Time). In addition, the sensor side can be further enriched. *PeR* is not sensitive to the dynamics by which it is touched; it makes no distinction between you gently stroking or hitting it. Properties as location, size of the touching surface, speed, direction or rhythm can become meaningful to *PeR*. These ideas are reflected in the design notion Recognise Explorative Behaviour Subject. As the different chapters are strongly intertwined, designing and interacting with *PeR* supports the advancement and formulation of the design notions in the first chapter.

Where the first chapter provides a firm theoretical body of knowledge, this exploration enriches the design notions as it exploits different sensorial modality and action possibilities. *PeR* portrays high-level integration of textiles, electronics and behaviour. The aesthetics of the material and the electronic properties reinforce each other. This level of integration enhances the experience as the light body moves in the carpet. People feel to touch the light, not the threads. Based on these insights that especially refer to the design notion Subtleness of Movement, I designed the top surface of *PeP*+. As the process of designing *PeP* and *PeR* was partly a parallel process, the insights gained by designing *PeR* are reflected in the design notions, and have inspired the design of *PeP*+.

validity

PeR and its successor have been presented at several exhibitions: design and design-research-oriented exhibitions, as well as material and textile-related exhibitions. Also, *PeR* has been the subject of academic and glossy publications. Its contribution to different fields is versatile. Design suggests that the everyday as we know it could be different, that things could change (Dunne, 2007, p. 10). Design implies that things can be used and that we ask questions, questions about the here and now (Raby, 2008, p. 65). This is what differentiates *PeR* from *PeP*, as the latter is mostly treated as a research-artefact. Through *PeP*, I inform and investigate; through *PeR*, I propose that an everyday artefact can change. *PeR* appeals to people and they can imagine using it. The aesthetic qualities of form and behaviour are high. The exhibitions and publications are an argument for this.

In this perspective, it is not so much desirable that I validate *PeR* from a more scientific point of view: *PeR* validates the relevancy for and extensibility in design practice of the more theoretical knowledge.

In this light, the collaboration with an industrial partner is highly valued. Such collaboration shows the feasibility and the value for the market of the design-relevant knowledge generated in the broader design-research project. Therefore I established a joint project with the international flooring company DESSO. Although the theoretical background of the design-research project may not be the main driver of this collaboration, it is the starting point for putting forward high-quality and innovative design opportunities. Exploring meaningful and aesthetic interaction is also in this collaboration paramount and drives the decision-making process. Besides the core research topic of the design-research project, a considerable amount of knowledge is generated on textile materials, on the integration of electronics, and on the innovation process in the rather traditional textile industry. The artefact created in this collaboration is referred to as *PeR*+. To show the extensibility of the more practical implementations, the algorithm of the *active* and *explorative* behaviour of *PeP*+ is transferred to *PeR*+.

Figure 40. *PeR* in View Textile Magazine.

In this sub-chapter, I show the feasibility and the value for the market of the generated design-relevant knowledge. Through collaboration with the international flooring company DESSO, it becomes clear that the approach and outcomes of the broader design-research are of interest to industry. The more theoretical findings are at the core of bringing forward high-quality and innovative design opportunities. The designed artefact exceeds functional innovation and makes experienceable a new perspective on how we could interact with systems of interactive products. Again, the practical implementations are considered. This discussion on the functioning of the artefact portrays the feasibility of implementing the physical and technical requirements for designing for perceptive qualities in an artefact, which is used in context and produced using existing manufacturing techniques.

Publication of this sub-chapter:
Deckers, E.J.L., Stouw, van der, B., Peutz, J. (2012) Development of an Intelligent and Interactive Carpet. Role of design in a textile innovation project. Research Journal on Textile and Apparel 16(4), 14-20.

designing *PeR+*

Besides exploring how theory can be applied in our daily environment, in this sub-chapter the collaboration with an industrial partner investigates the feasibility and value for the market of the generated design-relevant knowledge generated. The collaboration with DESSO, an internationally operating flooring company, to develop the interactive and intelligent carpet further, started in the course of the first year of the doctoral project. How people structure and experience space is also a key question for the designers at DESSO. Moreover, textile innovation in the somewhat traditional and unwieldy textile industry has captured the interest of large international companies, such as DESSO. The role of the handmade prototype of *PeR* was paramount to bringing about the collaboration, as the more theoretical considerations are directly experienceable.

DESSO considers three drivers for innovation: namely, design driven innovation, functional innovation, and the cradle-to-cradle philosophy. The company strives to implement this sustainable approach by 2020. An example of recent functional innovation is the Airmaster® carpet. This innovative product contributes to cleaner air in your home, and is available in a broad range of designs (DESSO, 2012). These innovations fit the needs of today and tomorrow. Moreover, the company focuses on the broader future of carpets. Over the last decades, the use of carpets in our homes decreased significantly. It is requisite to rethink how carpets are used and experienced. How do consumers use and experience space, and how can the carpet support this? The way to succeed in the future is to build on internal specialism, implement external expertise and research, and combine techniques and knowledge. For this reason, DESSO invests in collaboration with research institutes and companies outside the textile industry.

In the collaboration, DESSO supports the development of *PeR+* by sharing their skills and knowledge of designing and producing carpets. The goal is to use existing production techniques to create *PeR+*. The integration of conductive and light-transmitting materials in the production process and the functional integration of electronics are both explored. *PeR* nourishes this process; the outlines of this iteration are sketched, but not limited by this starting point.

Although different handling processes are considered, the main focus for developing *PeR+* is on the tufting technique. The tufting technique for broadloom carpets encloses a set of needles, distributed over the width of the carpet (4-5 metres), that pinch through a tuft-cloth over the length of the carpet. Different

tuft-clothes are available, such as woven and pressed materials. The needle pinches the thread through the cloth and a looper picks it up; the looper creates a loop. A loop-pile or bouclé refers to a carpet that exists out of loops of thread. Another possibility is to cut the loop with a knife, creating a cut-pile. The thread is fed into the needles from a big rag holding the spindles. To create stronger and fuller threads, or to create colour effects, two threads are twined. In the twining process, the threads are literally twined and set by a thermal or chemical procedure to prevent unravelling.

The distance between the needles, called 'gauge', determines the number of threads over the width of the carpet. Besides the gauge, the stitch length and height of the loop can be adjusted. With the machines used for producing broadloom carpets, it is not possible to create a pattern over the length of the carpet. In other words, one thread is fed through a needle over the whole length (figure 41). There are smaller machines available, mainly to create rugs, that do offer this possibility. The possibilities for patterns over the width of the carpet are endless.

It is possible to use coloured threads, or to dye the carpet afterwards. The bonding of the dye to the thread depends on different forces such as hydrogen, ionic, or chemical bonding (Moody & Needles, 2004). The physical properties of the threads in the carpets can be varied. In this way, the dye colours the threads

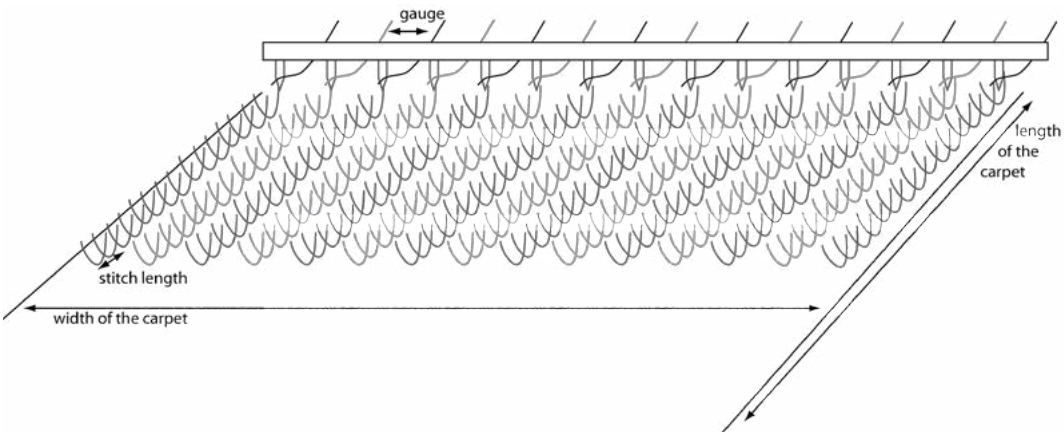


Figure 41. Simplified overview of tufting process.

differently, whcih creates a variety of effects. After tufting, the carpet (which can be easily over 100 metres in length) is guided through the dye bath. The carpet needs a tough backing to ensure high endurance. The backing holds the thread in place. The context of use determines the backing material. To apply the backing, the carpet goes through another machine that spreads the liquid backing material over the back of the carpet.

Designing and making carpets is a skill: it requires craftsmanship. Although I have mastered several textile-processing techniques, I had to get acquainted with this specific skill. It is not sufficient to be introduced to the technique to be able to grasp all facets and see the possibilities and limitations for creating *PeR*+. Feeling the materials, viewing the actual process up close, and making, for example, *PeR* by hand yields sensitivity to the skill required and for the end product. In turn, the designers at DESSO had to get acquainted with the work on interactive and intelligent systems, and more specifically with the integration of electronics in textile material. The use of the sampling machine makes it possible quickly to create samples that are directly combined with the electronic components. This active approach of making and doing makes ideas experienceable. The experienceability advances the process of understanding and building upon one another's skills. The repertoire of skills brought in by the designers at DESSO and by me do not cover the repertoire needed to develop *PeR*+. Material experts and electro-technicians are involved in the process. The different viewpoints enrich and widen the solution domain of the design challenge (Frens & Overbeeke, 2010). This multidisciplinary approach asks for the designer to communicate with a variety of experts, to appreciate and to comprehend their skills.

The tufting process is rather straightforward. Nonetheless, it entails several procedures and components that can vary. The integration of electronics widens the design scope, but also makes the process more complex. Making and doing is a valuable tool to lay open and understand this complexity. Several aspects of *PeR*+, such as different sensing and actuating capabilities, were explored before integrating them. It is crucial that the designer looks ahead: what works perfectly for sensing the person might interfere with the actuating requirements. On the other hand, it is a pitfall to narrow down your vision too much to the production process, skills and knowledge at hand. The open approach towards *PeR*+, likewise *PeP* and *PeP*+, is valuable to grasp the complexity and drive innovation. The process of designing and building *PeR*+ yields knowledge that exceeds functional innovation. The focus is on the perceptive qualities of the carpet, and the results propose and inspire more functional applications.

Figure 42. Broadloom tufting maching, photo: The Bandy Heritage Center for Northwest Georgia

PeR holds capacitive sensors that make the carpet sensitive to the touching activity of the person. The characteristics of a capacitive sensor make it especially fit to process a digital signal: being touched or not. Although one can generate analogue input, it is not possible to distinguish different perceptive actions. Indeed a bigger change in the input might indicate that someone uses the whole hand instead of just a fingertip; nonetheless, it can also be that this person has clammy hands. The capacitive sensor determines the capacitance of the sensor area. When the person touches the surface, she introduces an external capacitance that affects the capacitance of the sensor area. The conductivity of the body is used. Therefore the sensor is not suitable to detect people walking on the carpet with rubber soles. On the other hand, the immediate input gained when the person gently touches the carpet amends the reciprocal perceptive interplay. To detect both the gentle touch and the step of a person, *PeR*+ also integrates resistive sensors that detect pressure differences on the carpet. This is very suitable to detect the person walking on the carpet. Moreover, this enriches the detection of perceptive activity of the person. *PeR*+ can distinguish if it is gently touched or more roughly stroked, or even hit. To gain rich and dynamic input, the focus is not on implementing a wide variety of sensors or a high resolution of sensors, but on the placement, integration and type of input.

The integration of behaviour, electronics and material is strong in *PeR*. Nonetheless, the integration of the electronics is not suitable for a carpet that is used in context. *PeR*'s height is not desirable, and one cannot walk on it without damaging it. The thick nylon threads provide a strong visual effect, but the haptic experience has to be revised. *PeR* does not feel like a carpet, as it is somewhat scratchy. The embodiment of sensing and acting, i.e. the fact that the light body moves in the carpet, means that people feel they touch the light and not the threads. This level of embodiment has to be applied in *PeR*+. Therefore it is not an option to just place lights under the carpet, although this would have most certainly simplified the design challenge.

In the process, aspects such as extensibility (size), stability, durability and also sustainability are considered. The cradle-to-cradle philosophy that DESSO pursues does not directly apply here. Nonetheless, the disassembling and amount of components used in *PeR*+ are taken into account. Also the cost aspect is not paramount at this stage. However, expensive materials are replaced by alternatives, and the number of components is reduced.

PeR+ incorporates the soft and comfortable character of a carpet. It feels pleasant to touch and is suitable to walk on. The carpet is made using existing manufacturing techniques. Both the threads for the sensing and actuating capabilities of the carpet are integrated using the tufting technique. Conductive yarns are twined with the basic yarns of the carpet. Light-transmitting fibres are fed into the carpet combined with a basic yarn. The dark colour of the basic carpet is in contrast with the light. This emphasises the light effect. Nonetheless, the carpet can be created using different types and colours of basic thread.

PeR+ is sensitive to the touch, as well as to the pressure applied by the person. The integration of two types of sensors means that the carpet can recognise various perceptive activities of the person. It differentiates between being gently stroked and being hit. On a bigger scale, it could be sensitive to whether you are walking over the carpet quietly or hastily. Similar to the light body of *PeP*, *PeP+* and *PeR,* the light body of *PeR+* is also positioned in relation to the sensor input. The behaviour of *PeR+* builds on the *active* behaviour as designed in *PeP+*. Furthermore, it integrates concepts from both the *explorative* behaviour and the perceptive qualities portfolio.

Figure 43. Impression of *PeR+*

The person explores *PeR*+ by touching it. This modality means that there is a direct relation between the person's activity and the awareness of *PeR*+ being explored. This relation is more direct compared to *PeP*+. It appears more complex to detect whether the artefact is being explored based on the person's activity in space (*PeP*+), than the person's activity of directly touching the artefact (*PeR*+). *PeR*+ is sensitive to a change in sensor input. Therefore the person has to be active for *PeR*+ to detect her as an intentional subject. When the person actively touches it, *PeR*+ is certain of being explored.

The activity of the person directly and continuously influences the behaviour of the light body. The behaviour is inspired by the behaviour of the light body of LUMA, described in the perceptive qualities portfolio (cf. Portfolio, design-research projects, p. 198). The manner of touching *PeR*+ influences the uncertainty of the light body and the speed at which the light body moves. When you gently stroke *PeR*+, the light will be calm and follow your movement. On the other hand, when you apply more pressure, the uncertainty and speed will increase. The light body moves more quickly and is less likely to stick with you.

Next I discuss the practical implementations of *PeR*+. The development of *PeR*+ is an iterative process. It is out of my scope here to document the process in detail. However, the discussion on the functioning of the prototype portrays the feasibility of implementing the physical and technical requirements for designing for perceptive qualities in an artefact that is used in context and produced using existing manufacturing techniques. The technical specifications of this interactive and intelligent carpet obviously differ from other artefacts: for example, the wayfinding system that I present in chapter 3 (cf. Portfolio, p. 204). Nonetheless, these physical and technical requirements reflect the meta-level considerations that the design notions convey.

Figure 44. Impression of interaction with *PeR+*

As explained earlier (cf. Considerations, p. 158), to detect a person *PeR+* holds both capacitive and resistive sensors. These sensors respectively detect touch and pressure. The electronic components needed for sensing as well as actuating capabilities are embedded in a subfloor. This subfloor is about 5mm thick and holds a grid of printed circuit boards. The layout of the subfloor prevents the electronic components to be subject to pressure when a person walks on the carpet and prevents the prototype to heat up. The carpet is placed on the subfloor. The pattern of conductive and light-transmitting material in the carpet matches the layout of the printed circuit boards and their placement in the subfloor (Figure 45). The weight of the carpet provides the conductive connection between the carpet and the subfloor. The conductive yarns that are twined with the basic yarn of the carpet ensure a stable conductive connection. To separate the different sensor areas from each other, these conductive yarns and a conductive backing are applied locally.

All electronic components are soldered on the underside of the printed circuit board (Figure 46, left). The sensor area for both the capacitive and resistive sensor are located on the topside of the printed circuit board (Figure 46, right). The sensor area exists out of two electrodes that are connected by the carpet.

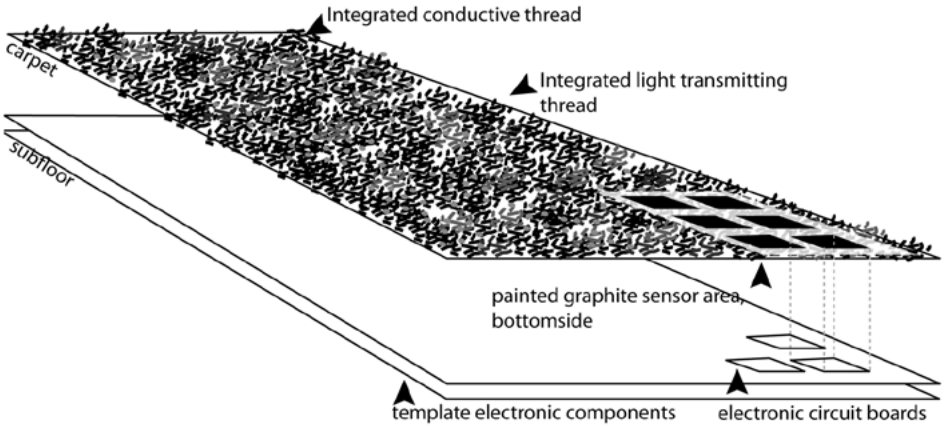


Figure 45. The carpet is placed on the subfloor. The layout of the subfloor matches the integration of the light-transmitting and conductive threads.

The resistive sensor is, in fact, a simple voltage divider. The pressure applied to the carpet influences the resistance between the two electrodes. By placing two resistors in series, of which one is variable and subject to the pressure applied, a change in potential over the circuit can be measured. The electrodes cannot be used for both the resistive and the capacitive measurement at the same time. The use of a voltage divider means that a current runs through the electrodes continually. In this situation, it is not possible to measure a change in capacitance. The capacitive sensor relies on charging the electrodes on the printed circuit board, of unknown capacitance, to known potential. The resulting charge is transferred into a measurement circuit that is integrated in the sensor. The capacitance of the sensor area can be determined after one or more of these charge and transfer cycles (Atmel, 2012). When a person touches the carpet, she introduces external capacitance to the sensor area. This external capacitance affects the flow of charge at that point, which is detected as a touch. To make it possible to read out both the capacitive and resistive sensors, they are activated alternately.

The initial aim was to use the manufacturing machines for tufting broadloom carpets. This technique is suitable for making carpet on the running meter. As explained earlier (cf. Techniques, skills, complexity, p. 154), with this technique it is not possible to create patterns over the length of the carpet. This is problematic

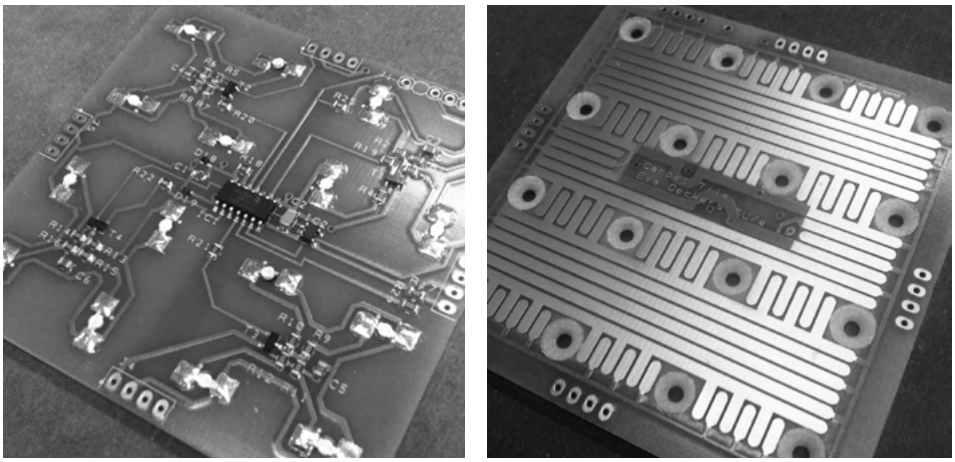


Figure 46. Left: underside printed circuit board with electronic components. Right: topside printed circuit board with electrodes for sensing and holes for LEDs.

as the conductive yarns cannot be applied locally and thus the sensor areas cannot be separated. The implementation of a nylon fibre to transmit the light is certainly possible using this technique. We successfully experimented with twining and tufting these stiff nylon fibres. Nonetheless, the feel of the carpet is not optimal using these stiff fibres. Therefore the use of an elastic nylon fibre is preferred. This elastic fibre cannot be tufted with the machine for tufting broadloom carpets, as these cannot be cut. I switched to using a hand-tufting pistol that relies on airpressure (Figure 47). For production, tuft robots that employ this technique are available. The elastic nylon fibre is easily fed into the hand-tufting pistol, and the conductive thread can be applied locally.

Similar to the tufting technique for broadloom, the hand-tufting pistol also creates loops that are cut to create a cut-pile (cf. Techniques, skills, complexity, p. 154). This also means that the nylon fibres are looped and cannot be bundled. In *PeR,* the nylon fibres are bundled under the carpet. The LEDs are all dedicated to a bundle of fibres. The light enters at the cutting face of the fibres. In *PeR+,* the light enters at the loop, which is not as efficient. Not bundling the light under the carpet has the advantage that the carpet is completely created using the hand-tufting pistol. The carpet is thin and suitable for walking on. It is crucial that the nylon fibres align with the LEDs on the printed circuit board. Beside,s the resolution of the nylon fibres has to be rather high to make sure that sufficient light transports to the surface of the rug. Like all the other electronic components, the LEDs are mounted on the bottom side of the printed circuit board. They direct their light upwards through a hole in the board (Figure 46, right). For the light to spread better, this hole is drilled out under an angle. The circuit board is a little thicker than usual.

The printed circuit boards are about 70mm x 70mm. Each circuit board has one sensor area connected to both the capacitive and resistive sensors, one microchip that reads out the sensors and sets the brightness of the LEDs, and sixteen LEDs that operate in groups of four. The microchips communicate via an I^2C-bus with the process unit. They send the sensor data to the processor and receive the brightness value for the LEDs from the processor. The fact that the microchips are suitable for touch detection, pressure detection and brightness control is an advantage, as the communication over the I^2C-bus is limited. The prototype of *PeR+* holds 35 circuit boards in a grid of 7 by 5.

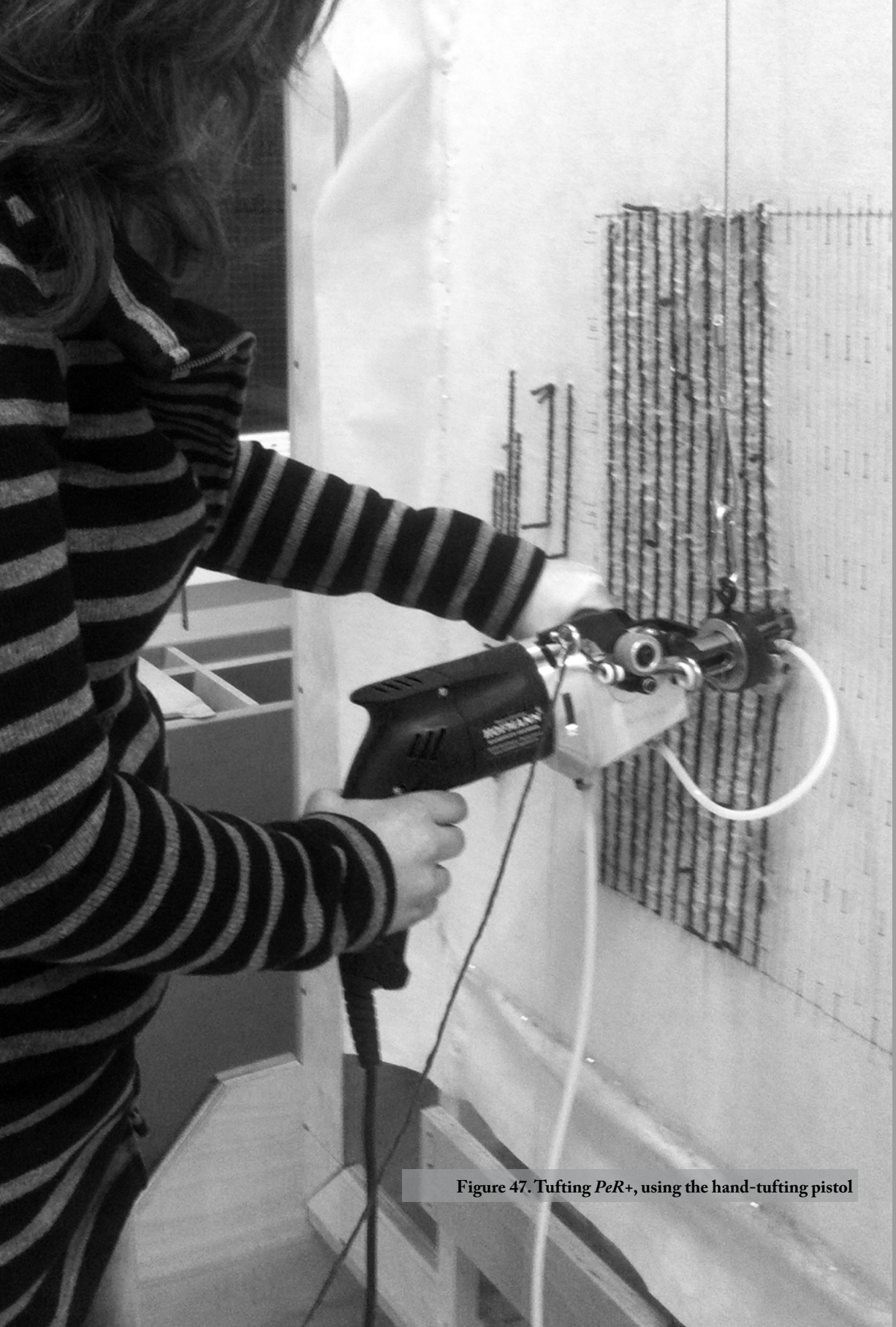
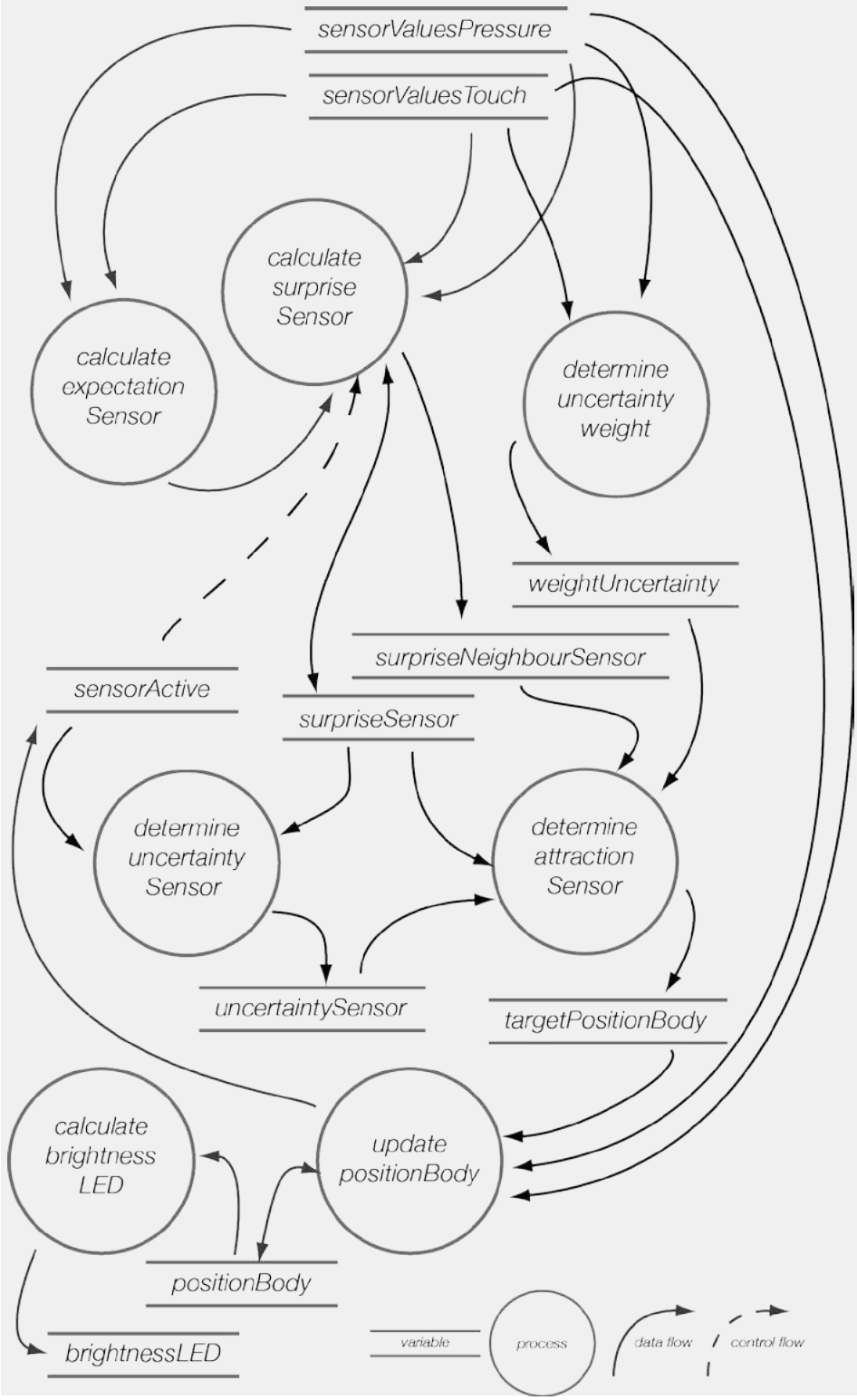


Figure 47. Tufting *PeR+*, using the hand-tufting pistol

The algorithm that determines the behaviour of *PeR+* strongly builds on the algorithm of the *active* behaviour of *PeP+*. Not only does the sensor input determine the position of the light body, but also the position of the light body determines the input. The light body has to move to explore the environment. Over time, *PeR+* becomes uncertain or curious. The light body sets out to explore sides of the carpets it did not visit for a while. The implementation of this short history is subjective to the activity of the person, because the uncertainty is partly determined by the last input on this part of the carpet. Furthermore *PeR+* is sensitive to a change in sensor input. This implies that the person has to be active to draw the light body's attention. It builds an expectation based on a short history. The more the new input deviates from this expectation value, the higher the surprise is on this part of the carpet. Please refer to Designing *PeP+*, pp. 63-87 for a thorough description of the *active* behaviour and the algorithm.

The input of both the capacitive and resistive sensor determines the surprise measured on a sensor. Besides determining the expectation and the surprise on each sensor, the sensor input directly affects the behaviour of *PeR+* in two different manners. When the person gently strokes *PeR+* (capacitive input), the light body becomes less uncertain. Its motivation to explore other parts of the carpet is rather low. When the person interacts with the carpet more roughly (resistive input), the light body gets more uncertain. Its motivation to explore other parts of the carpet is rather high. Moreover, the sensor input directly influences the speed at which the light body moves. Caressing it slows it down, and touching it less carefully increases the speed at which it moves. Over time, the person can calm the light body down or make it more nervous. As the sensor input is stored, it will keep behaving calmly or nervously when the person does not touch *PeR+* anymore. Its behaviour invites different activity from the person.

The data flow diagram on the right describes the algorithm of the behaviour of *PeR+*. It shows how the activity of the person (sensor input) is of influence on the behaviour of the light body. The behaviour of the light body can evolve in a continuous manner. In the explorative behaviour of *PeP+*, the switch between showing *active* and *explorative* behaviour is abrupt. The manner of behaving is a predefined decision. The behaviour of *PeR+* shows how different behaviours of the light body are a direct result of the activity of the person, and the other way around.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sensorValuesTouch
calculate surprise Sensor
calculate expectation Sensor
determine uncertainty weight
weightUncertainty
surpriseNeighbourSensor
sensorActive
surpriseSensor
determine uncertainty Sensor
determine attraction Sensor
uncertaintySensor
targetPositionBody
calculate brightness LED
update positionBody
positionBody
brightnessLED
variable
process
data flow
control flow

The aim of designing *PeR* and *PeR+* is not to further elaborate the theoretical foundations of the design notions. Rather, *PeR* and *PeR+* embody the design notions at different stages of the process. Nonetheless, the process of designing these artefacts also reflects in designing *PeP+* and formulating the design notions. The aesthetics of, and experience with, different materials, modalities and affordances reinforce the process described in the first chapter. For example, the opportunity to distinguish between different activities of the person (Recognise Explorative Behaviour Subject) was more evident in *PeR* than in *PeP*. Reconsidering the sensory capabilities in *PeR+* nourished the process of implementing and advancing the design notion Recognise Explorative Behaviour Subject in the explorative behaviour of *PeP+*. In addition, the integration of materials, electronics and behaviour is perceivably stronger in *PeR* than *PeP*. When interacting with *PeR,* people feel they interact with the light, not with the threads of the carpet. This informed the design of *PeP+*. In *PeP+*, compared to *PeP*, the light has more body and seems to move in the surface. Both *PeR* and *PeR+* exemplify the design notions.

The collaboration with the international flooring company DESSO provides insights on the relevancy and extensibility of the theoretical findings. The theoretical background is not the main driver in the collaborations. It is, however, at the core of putting forward high-quality and innovative design opportunities. The exploration of aesthetic and meaningful interaction is paramount and drives the decision-making process. In addition, the collaboration pivots around action and quality, rather than functionality. As a result, *PeR+* exceeds pure functional innovation. The carpet does not have a specific preset function, like, for example, fall detection for the elderly. Nonetheless, knowledge to design for this specific situation is generated, both from a conceptual and practical point of view. The project yields more than a solution for a single issue.

Throughout this dissertation the practical implications are discussed, as I believe that design-relevant insights can for a great deal be found in these practical implications. Through *PeR+* the practical and technical feasibility of designing for perceptive qualities is explored. *PeR* proposes that an everyday artefact can change. *PeR+* changes an everyday artefact. The prototype is created by using existing manufacturing techniques, can be scaled up, and is suitable for use in context. Although this carpet is by no means ready for production, it is very well possible to create a full-scale, functioning prototype.

PeR was paramount bringing about the joint project. My perspective on designing for perceptive qualities can be experienced. The prototype was paramount in articulating what my interests and motivations are in this project. It is a tangible starting point for the collaboration. The experienceability of not only the artefact, but also ideas and concepts, proved to be valuable throughout the project. Making and doing allowed me to become acquainted with the repertoire of skills to design carpets. Moreover, it meant that the designers at DESSO were able to understand my point of view. By trying out ideas, we got into a rich dialogue of sharing knowledge and skills. For example, feeling the materials, viewing the actual process up close, and making by hand are all needed to grasp the manufacturing and the design process of carpets. Moreover, this is needed to become sensitive to the material qualities. By showing samples and making quick, simple prototypes the interaction is directly experienceable. Making and doing were also paramount to understanding and tackling the complexity of this project. On paper, it is not possible to catch all elements that work together in *PeR*+. By trying out several ideas by hand, and with the available sampling machine, it is possible to get a hold on all these elements.

While developing *PeR*+, the idea to apply perceptive qualities in our homes became tangible. However, so far the behaviour of the light body focuses on the direct interaction between person and artefact without considering its spatial, contextual and functional qualities. Next to *PeR*+, work in the Perceptive Qualities Portfolio (cf. 3rd chapter) inspires a consideration of the carpet at the base of a system of interactive products.

Here I show how the work from the first, current and third chapters inspires designing for systems. This sub-chapter feeds back to the situation sketched in the introduction to systems of interactive products. In this introduction, I describe an audio system in which multiple music sources, such as laptop, tablet and smartphone, wirelessly connect to multiple speakers. PiA, short for 'perceptive intelligent audio', is an astute proposition to design for perceptive qualities in such a system of interactive products. I work towards this proposition through three examples. These three concepts are all supported by an experienceable artefact from the current and third chapters.

systems of interactive products: a proposition

introduction

In this sub-chapter I build towards a proposition to design for perceptive qualities in a system of interactive products. This astute proposition is a direct result of the work in both the first, current and third chapters. The results from designing, building and evaluating *PeP*+ show how the intelligence of an artefact builds in the course of the interaction. This action- and quality-centred approach strongly shows in the proposition. The spatial qualities of the perceptive behaviour are further investigated in the two iterations of *PeR*. *PeR*+ can be scaled up, is produced by using existing manufacturing techniques and is suitable for use in context. These characteristics inspire to consider the carpet in the home environment, at the base of an intelligent lighting system. The perceptive qualities portfolio (cf. Third Chapter) also brings forward examples that inspire system thinking and designing for systems. The work on an interactive, context-aware and context-creating artificial turf induces the concept of an intelligent training system for soccer. The third example is an intelligent audio system in which the behaviour of a sound body is investigated. An exploration of the behaviour of the sound body is part of the perceptive qualities portfolio (cf. Third Chapter). My proposition strongly builds on this last example.

an intelligent lighting system

The aim of creating *PeR*+, and the line of approach in the collaboration with the industrial partner is to explore the integration of the perceptive qualities in full-scale rugs, or even broadloom carpets. The goal is to create a carpet that can be placed in our living rooms and work environments. The practical implementations of *PeR*+ mean that the prototype can be scaled up. These spatial qualities of *PeR*+ and the reflections on system thinking (cf. Insights, p. 216) inspire to consider the carpet in context, at the core of an intelligent lighting system.

In this system, the lighting conditions in the home environment are directly related to the activity of its users. The anticipation of the system as to what could happen next becomes evident and functional. The light not just follows its user through her home, but anticipates by lighting the way. In other words, the light does not just turn on when you enter a room but it moves in a continuous manner to support your activity. On some occasions, a small and brisk body is appropriate. But when the light follows the person through the house, it is bigger and slower. This calm body has a supporting character and lightly sweeps through the house.

The carpet differentiates between different activities. It directly anticipates the person's activity, instead of memorising and reacting to pre-programmed

situations. Similar to the placement of sensors and actuators in a virtual grid, other light armatures are also positioned within the algorithm. Other light armatures are located in relation to the carpet. Indicating in this grid which sensors and actuators are in which part of the house contextualises the activity of the person. This does not mean that the algorithm literally draws the outline of the house, but that different sensor areas are sensitive to other activities and events. Activity in the kitchen demands other lighting conditions than activity around the dining table. The sensitivity and activity is context-dependent. The light body can shrink, expand and split. The light subtly concentrates around you when you are watching television or having dinner. As the system's intelligence builds on the direct course of interaction with the person, the person can always be of direct influence on the behaviour of the light by actively engaging in the interaction. For example, the person can draw the light body's attention by being active, or can escape from its perception. On the other hand, the light body can also draw the person's attention, and even lure the person to follow.

The development of *PeR+* in combination with Wonderturf, an artificial turf described in the perceptive qualities portfolio (cf. Portfolio p. 200), is at the base of an intelligent training environment. Soccer club PSV Eindhoven has shown interest in this work to create an intelligent and interactive training environment. The techniques for creating artificial turf are similar to creating carpets. Moreover, the quality- and action-centred approach towards the intelligence of, and the interaction with, the field closely connects to the wish to intervene directly in exercises and practice. The theoretical and practical implementations of *PeR+* and Wonderturf inform this concept. Wonderturf shows and makes experienceable the direct coupling between the activity of the person and the field. Therefore it is, like *PeR* in the collaboration with DESSO, paramount in bringing about the project. I briefly describe the concept of this intelligent training environment to show the interest in, and more functional possibilities of, the action- and quality-centred approach, and the knowledge the doctoral project yields.

The intelligent training environment supports the direct coupling between the players' actions and the activity of the field. The field provides the individual player and the team with immediate feedback, and gives the coach the opportunity immediately to intervene in the game. The field can make an exercise dynamic by directly and locally adjusting to the individual skill of the player. For example, in an exercise for passing the ball, the field can adjust the area in which the ball has to land. The better the player, the smaller the light spot will get. The field

adjusts the exercise to the skill of the player. To support the recovery of an injured player, the field can monitor and anticipate, for example, the speed at which the player executes an exercise. In the game, it can directly give feedback and provide suggestions about the position of the players.

Parallel to rounding of the prototype of *PeR*+ and forming the concept of the intelligent lighting system, a student explored designing for perceptive qualities in sound. The design assignment for the student builds closely on the anecdote that introduces the sub-chapter 'Designing *PeR*' (cf. page 145). The audio system described in this introduction holds several wirelessly connected devices from which the user can play her music. Speakers are located throughout the house. A private cloud makes it possible to play all music from all devices over all speakers.

The student was challenged to design local nodes, or an artefact with a more spatial character, that engages in a reciprocal interplay with its user, and support the use of the audio system. The student has built a minimal set-up, holding a few sensors and piezoelectric speakers that produce a low-resolution beeping sound. The components have been placed close together in a grid. Similar to the light body of *PeP*+, a sound body follows the hand movement of the person. Regardless

Figure 48. Impression of Surfacing Sound by student Adriaan de Regt.

of the small scale, the movement of the sound body is quite easily perceptible. The student's work has inspired me to try the installation with actual music and to scale it up. A quick exploration, on full-scale and using music, pointed out that the effect of the music following you is rather catching.

This exploration and the student work lead to designing an intelligent audio system. In this system, the music can follow the person throughout her house. The music or other sound the person plays is considered as a body of sound. The system exists out of a set of speakers. Close to each speaker, an ultrasonic sensor (Devantech Ultrasonic Ranger, SRF04) is placed that detects the activity of the person. The volume of the music that each speaker produces is altered based on the sensor input. The volume can be digitally set using a potentiometer (Dallas, DS1802). This potentiometer has a logarithmic scale, and is therefore very suitable to adjust the volume of the sound. The volume of the sound that each speaker produces can be separately adjusted. Through a shift register, it is possible to connect multiple music sources to the system, and to play different music over different speakers. Together with the student, I built the system that holds up to ten speakers and sensors. The stands for placing the components are modular, so the speakers and sensors can be separately placed at different heights and distance from each other. To explore the behaviour of the sound body, the student worked on an installation called Surfacing Sound (cf. Portfolio, p. 198).

PiA

Based on the installation and the explorations of the student, I propose PiA short for 'perceptive intelligent audio'. The person can directly interact with the music: she interacts with the actual sound. To describe my proposition, I place it in the same context as the anecdote that introduces the interest in designing for systems of interactive products (cf. page 145). In this anecdote I set apart the situation as it is at my home at the moment. Next I will picture the situation when PiA is installed.

When I come home from work, Sjors is often already at home. He, without exception, is listening to music. He can use different wirelessly connected devices to play the music from. The location of the device at first determines the location of the sound body. When Sjors uses his smartphone or tablet to play music from in the kitchen, the music starts playing in the kitchen. When I enter the house, the sound body will shift its focus to this new person (me). As the social situation changes, the volume will adjust to a level appropriate for conversation. The music shifts its focus to me and will move along through the living room to the kitchen,

where Sjors is preparing dinner. The activity lures the sound body to the kitchen. We have an open kitchen and when one of us moves to the living room, the sound body adjusts its position and size, so that the music plays in both the kitchen and living room, possibly at different volumes.

Later that day, I walk out of the living room. The sound body has the urge to follow me. However, if I do not actively lure it along, it will not move too far away from Sjors. When I shortly engage in an active interplay with the sound body, I can lure it along with me. Moving too far away from its initial position, where there is still activity, the system creates two sound bodies. Activity, such as closing the door behind me, will make this split more abrupt. We now both listen to the same music in different locations of the house.

Of course, it can also be that I would like to play different music. When I take a device to play music along with me, I can play different music in different areas of the house. The location of the device contextualises its use. Although the speakers are all connected to the same system, I can play different music over each speaker. In other words, different sound bodies can play different music. Upon returning to the living room, the new sound body I created likes to follow me along. However, the music that Sjors plays in the living room overrules, as it has been playing for a while and was turned on in this area of the house. I can now change the music, but have to interfere through direct control of the smartphone or tablet from which the music is played. This again seizes on the contextual qualities of the physical control. The sound body that I was listening to before will turn off, as it does not detect any activity anymore.

The work in the second chapter is strongly intertwined with the first chapter. In particular, the process of designing the different iterations of *PeP* and *PeR* feed back to each other. As explained earlier (cf. Designing *PeR*+, p. 168), the development of *PeR* and *PeR*+ is reflected in the development and formulation of the design notions in the first chapter. The concepts and proposition for systems of interactive products also very closely connect to the work described in the third chapter. In this chapter, the experience with and aesthetics of different modalities, materials and affordances is explored that reflect in the design notion Subtleness of Movement. Moreover, the work on designing for systems provided new insights on the design notions Recognise Explorative Behaviour Subject and Remember and Anticipate Perception over Time. The following leitmotiv-part considers these three design notions. The design notions are firstly described again (in italic) before discussing the new insights.

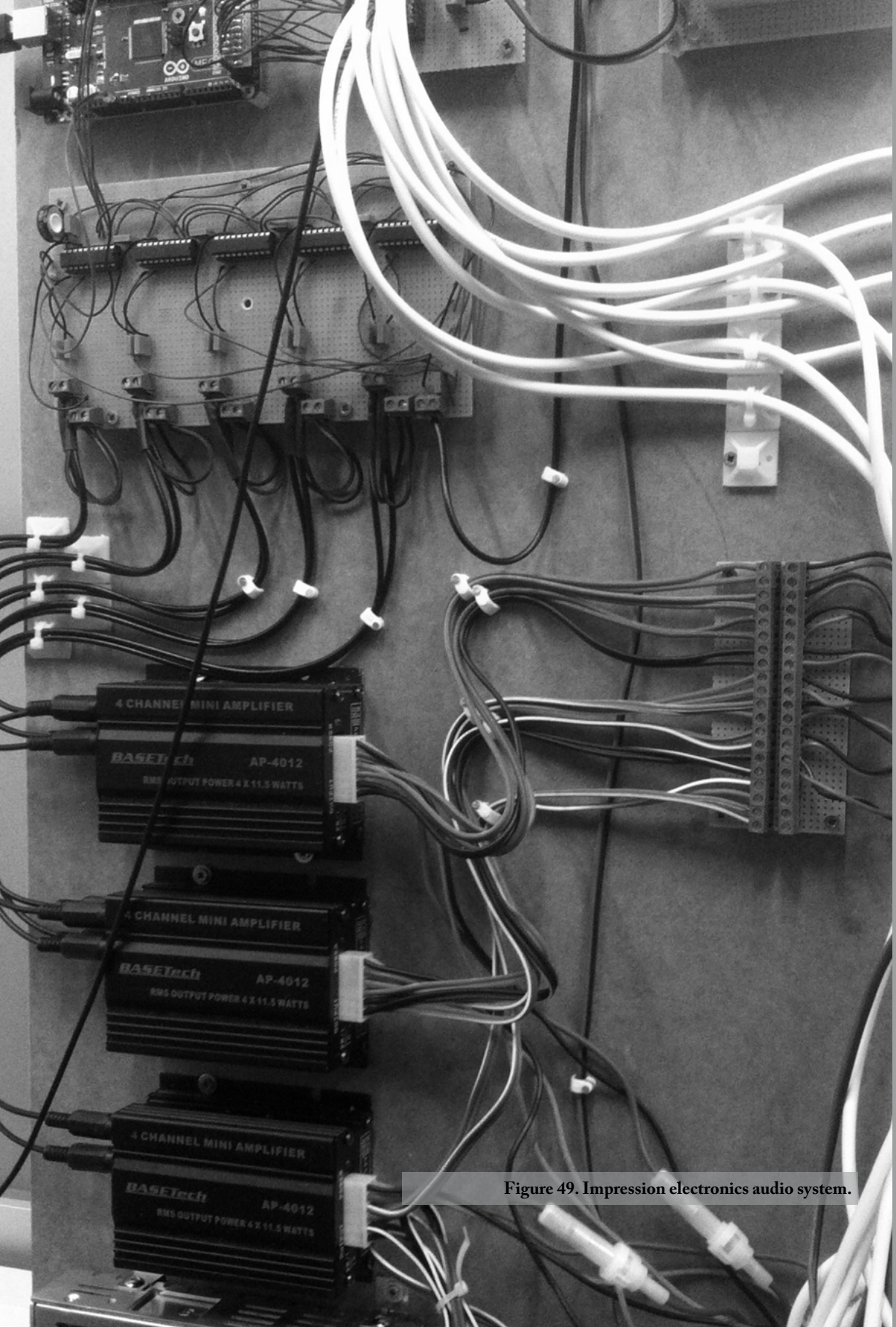


Figure 49. Impression electronics audio system.

subtleness of movement

When designing for perceptive activity, the subtleness of the physical appearance, the actual movements, and their integration should all be considered. The actions we undertake to perceive are smooth: we turn our head in a continuous and sustained movement to look at what is behind us. Both in the physical appearance and in the algorithm, subtleness should be created by taking into account this sustained continuous nature of perceptive actions.

The perceptive body can be perceptible through different modalities. The light bodies of *PeP* and *PeR* are perceptible visually. The detection of the person by the artefact is, in the case of *PeP*, comparable to visual input. This detection is tactile in *PeR*. The sound body in PiA and Surfacing Sound (cf. Portfolio, p. 198) is perceived auditory. BeTouched! and Manoeuvre (cf. Portfolio, p. 190, p. 206) portray how an artefact can actively touch the person. In all these examples, the subtle and continuous nature of perceptive behaviour is evident and crucial. For example, *PeR*+, Surfacing Sound and Manoeuvre show that the approach of designing and programming the behaviour of the perceptive body is also applicable in other artefacts than *PeP*. Moreover, they show that it is applicable for artefacts that exploit different sensorial modalities and action possibilities.

recognise explorative behaviour subject

We are living organisms showing active and explorative movements to perceive. In the course of the interaction, the artefact should be enabled to detect this perceptive activity of the person. In the context of their interactive interplay, these actions become meaningful to the artefact.

The type of sensor used for the detection of the activity of the person influences the implementation of this notion. *PeR*+ shows that differentiating touching activities of the person is rather straightforward. Detecting explorative behaviour from the person is more complex in the case of *PeP*+. In both cases, the possibilities are not yet fully exploited. For example, *PeP*+ is sensitive to movement of the person, but does not take into account whether this movement is towards or away from it. *PeR*+ does take into account the difference between gently being stroked and more roughly being touched. Nevertheless, it does not incorporate more complex concepts that are applied in *PeP*+. Probabilities of it being hit, being leaned on, or being poked can be implemented.

Both the concept of the intelligent lighting system and the intelligent audio system add a contextual component to this design notion. Awareness of the location of the activity in the context enriches the input. The activity around the dining table demands different lighting conditions than the activity in the kitchen. Shutting the door between two areas of the house can direct the sound body not to follow the activity of the person. It is paramount not to base yes or no decisions on the location, but to alter the sensitivity of the sensors to their location.

remember and anticipate perception over time

The notion of Remember and Anticipate Perception over Time refers to experience. Time here is considered to be a subjective experience, a continuum of activity. In line with this, experience here is considered the continuum of perceptions, and thus the awareness of bygone perception and the anticipation of future perception (Schutz, 1967). It is in this design notion that the artefact, as it were, builds an 'experience' based upon other design notions.

PeR+ showcases the strong connection between this notion and the notion Recognise Explorative Behaviour Subject. The activity of the person is of direct influence on the explorative behaviour and dynamic qualities of the light body. The light body in time calms down or gets nervous based on the perceptive activity of the person. In the behaviour of *PeR+*, there are no hard switches between the different behaviours. The behaviour of *PeR+* changes continuously and is directly coupled to the activity of the person.

The proposition of a system of interactive products introduces the social character of the system. The sound body is part of, and creates, new social situations. PiA adjusts the volume of the music to the presence of multiple people in a room. It apparently values the conversation between the persons and lowers its volume. When one of the persons brings a new sound body into the room, there is a social hierarchy to which music will continue playing. Through engaging in an active reciprocal interplay with the system or by direct control, the person can influence this behaviour. It becomes paramount that the behaviour not only evolves in the direct interaction, but also over a longer period of time. The system evolves around its user.

This third chapter, which is structured around the leitmotiv, presents student work that is inspired by, and synthesises from, the generated design-relevant knowledge. The work in both the first and second chapters describes my approach, the artefacts I designed, and the findings that result from this process. These two chapters have a distinct first-person character. In this third chapter, the work of the students corroborates my findings. Their third-person perspective on the broader design-research validates and adds to my findings. In this chapter, the theoretical findings are further opertationalised. The student work exemplifies the design knowledge and adds to it by proposing new forms, materials, functionalities and contexts.

third chapter: applying design knowledge to design education

an annotated portfolio of theory-inspired student work

Before presenting the perceptive qualities portfolio, I elaborate on the added value of the student work to the broader design-research project. Different from the first and second chapters, the students provide a third-person perspective on the theoretical background and the generated design-relevant knowledge. The quality of the work is guarded by a group of experts that coach, support and assess the work. The students participate in different projects and classes. The nature of these projects and classes is also discussed.

introduction

In the first chapter I chose a minimalist approach in implementation and context. In the second chapter I investigate the added value of the theoretical findings for designing. I focus on one artefact, which makes it possible to thoroughly examine the artefact. In the current chapter, the added value of the theoretical findings for designing is more broadly explored. The third chapter builds on the work of bachelor's and master's students from the Department of Industrial Design at Eindhoven University of Technology.

Several student projects and shorter classes showcase different aspects of the broader design-research project. My first-person perspective on the approach and theoretical background is validated and extended by the third-person perspective of the students. All projects start from the same theoretical background, are inspired by the design-relevant knowledge generated in the first and second chapters (which is open for questioning), and build from the same sources (which students are allowed to reject as well as extend). Design-relevant knowledge is especially in the experience of the artefacts. I consider the work to be valuable

Figure 50. Students explored how their actions change, when their viewpoint on the world changes. Impression of a quick exploration with mirrors (module).

iterations and valid argumentation for the relevance and the extensibility of the generated knowledge. As discussed earlier (cf. Process p. 31), this portfolio annotates different aspects of the broader design-research. The following aspects have come forward: (1) aesthetics and integration of material, electronics and behaviour; (2) embodiment of sensing and acting; (3) system thinking; and (4) context and functionality. The work exemplifies the generated design knowledge, and adds to it by proposing new forms, materials, functionalities and contexts.

The portfolio holds artefacts that are the result of either an individual design project, an individual design-research project, or a one-week team project referred to as a module. The design and design-research projects run in the educational theme Wearable Senses (Bhömer & Versteeg, 2013). Several experts, who in various degrees are familiar with the doctoral project, coach the students. These experts bring in a broad repertoire of skills and knowledge of the different aspects such as phenomenology, autonomous behaviour and materials. Next to their personal coach, the students get feedback from other coaches, design-researchers and design-practitioners. All the work is exhibited in an educational context at the end of the semester or module to receive feedback and to be assessed. The team of experts oversees the quality of the work. Moreover, the quality of the work shows in the fact that several students exhibited their work, one student won a design award with his work and results are published at academic venues.

Over two years, we ran about eleven individual design projects at both bachelor's and master's levels, eight individual design-research projects at master's level, one individual final master's project and gave three one-week modules for master's students. In each module, about eighteen students participate and work in groups of three or four people. This results in about 30 artefacts, of which 20 are of sufficient quality to be considered. However, only the projects that bring new elements to the discussion are showcased in the perceptive qualities portfolio.

In the design projects, the focus is on exploring the sensing and actuating qualities of (textile) material to create perceptive behaviour. The students are challenged to explore these qualities in context. The anecdote of the media system (cf. Systems of interactive products p. 144) related to intelligent environments in several cases is used to sketch a possible context. In the design-research project, the students investigate the reciprocal perceptive interplay between person and artefact, and between artefacts. The students focus on different aspects such as moving or static placement of sensors, inviting or defending behaviour, the dialogue between

artefacts, the placement of an artefact such as *PeP* in context, and escaping from the person's perception. In the one-week module, the final assignment is to design an artefact that engages the person in a rich reciprocal interplay, focusing on a specific sensorial quality. In all projects, making, doing and experiencing are paramount in the process. The students are urged to take on an active approach and go through several iterations of making, trying, experiencing and designing.

In all cases, the students are introduced to the theoretical background and the generated design-relevant knowledge at the start of the project or module. This generally happens through a short introduction from my side and a questions and discussion session. The students are referred to the work of Lenay et al. (2007, 2010) and to publications from this dissertation (plus accompanying movies) that were available at that time. The students are free to add sources or reject them. On several occasions, the students got the opportunity to experience the interaction with *PeP*+ and *PeR*. In the first chapter, the focus is on designing for perceptive qualities and, more specifically, designing for perceptual crossing. In the second and particularly in this third chapter, the focus is on designing for perceptive qualities more broadly. To the students I emphasise that perceptual crossing is not a goal *PeR* se. The phenomenon itself and the generated design-relevant knowledge in the first and second chapters offer a design space for the students to explore.

In the next sub-chapter the portfolio is presented. The work is divided into three sections: namely, module work, design project and design-research projects. The left page of the spreads holds the name and description of the artefact. The right page of the spread presents a picture of the work and the names of the student(s) who designed the artefact. For each piece I firstly describe the work, and secondly I discuss the insights gained. The QR-code guides you to an accompanying movie. The photo, description and movie present the third-person perspective of the students on the theoretical background. The insights gained are my reflections upon dialogue between the students, coaches and experts involved in the projects and me. Following the portfolio, more general insights gained from the work are discussed, leading to an advancement of the design notions. The claims made in this section and in the description of the artefacts are to a great extent inherent to the experience of, and interaction with, the artefacts. Therefore the verification of these claims might require actual interaction with the artefact. In other words, the text and the movies might not be enough to verify all the claims I make.

Figure 51. Impression of student exploration in the process of designing Little One (cf. Portfolio, p. 194).

The portfolio exists out of a broad range of artefacts that explore different aspects of the broader design research. The portfolio articulates the breadth of the theoretical exploration. It shows that students are inspired and can synthesise from the generated design-relevant knowledge. The wealthy collection of artefacts is an argument for the consequence of theory in designing for interactive products and related systems. Moreover, it shows how context is required to operationalise the design-relevant knowledge further. The portfolio annotates four main aspects, namely (1) aesthetics and integration of material, electronics and behaviour; (2) embodiment of sensing and acting; (3) system thinking; and (4) context and functionality. A reflection on these aspects is presented in the last section of this sub-chapter. In this reflection it becomes evident that the descriptive theoretical model (cf. theory, p. 18) is extensible for designing for systems of interactive products.

Publications on this sub-chapter:

Deckers, E.J.L., Lévy, P.D. (2012). Designing for perceptive qualities: 7 showcases. Proceedings DIS2012, 496-505. ACM Press.

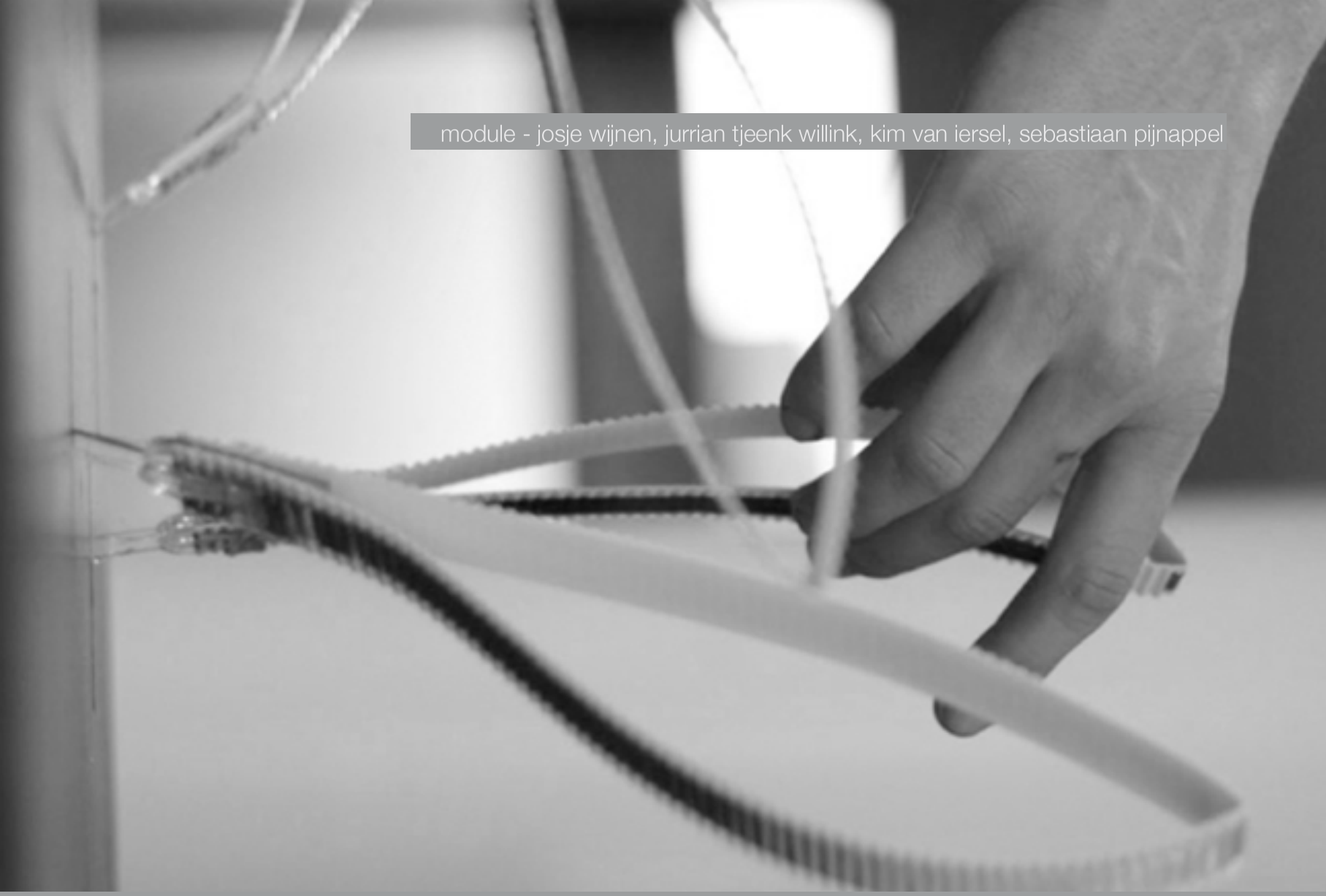
Lévy, P.D., Deckers, E.J.L., Restrepo, M. (2012). When movement invites to experience: a kansei design exploration on senses' qualities. Proceedings KEER2012, 366-372.

perceptive qualities portfolio

BeTouched! engages the person in a rich experience of the reciprocity of touch with an artefact. The students explore the interplay of touching and being touched. The artefact exists out of several flexible bodies. All these bodies are touch-sensitive at the front and backs. The bodies act by moving back and forth. When you touch the body on the front, the body lets itself actively be stroked. It moves forwards in the direction of your hand: it touches back. At the back the body is more ticklish. The body moves away from your touch. When you touch one body, the other bodies try to draw your attention. The other bodies also want to be touched.

The material characteristics beautifully support the reciprocal interplay of touching and being touched. The shape and material properties enhance the dynamics of moving back and forth tremendously, and make the body move in a sustained and continuous manner. The way the material bends along your hand when you touch it means that the body actively lets itself be stroked and caresses you. Sensing and acting are strongly embodied: the sensor moves along with the body. When it is ticklish, it literally moves its sensor away from the hand. When the body likes to be touched it moves its sensors towards the person, moving the whole length of the sensitive area along the hand. Like a cat that moves her whole body along your hand.

The bodies all show active behaviour to draw attention. This activity gets more intense when you touch one of the bodies, almost jumping for your attention. At some point, one of the bodies did not work, as it broke and lay down in-between the other bodies. It is remarkable that this non-functioning body actively participated in the interplay. Its behaviour is meaningful in the sense that it seems actively to withdraw from the interaction. The perceptive relation between person and the different bodies and between the bodies is simple but powerful. When the person engages with one of the bodies, the other bodies detect this event. In turn, their activity, asking for attention, is perceptible for the person.



module - josje wijnen, jurrian tjeenk willink, kim van iersel, sebastiaan pijnappel

ShyLight

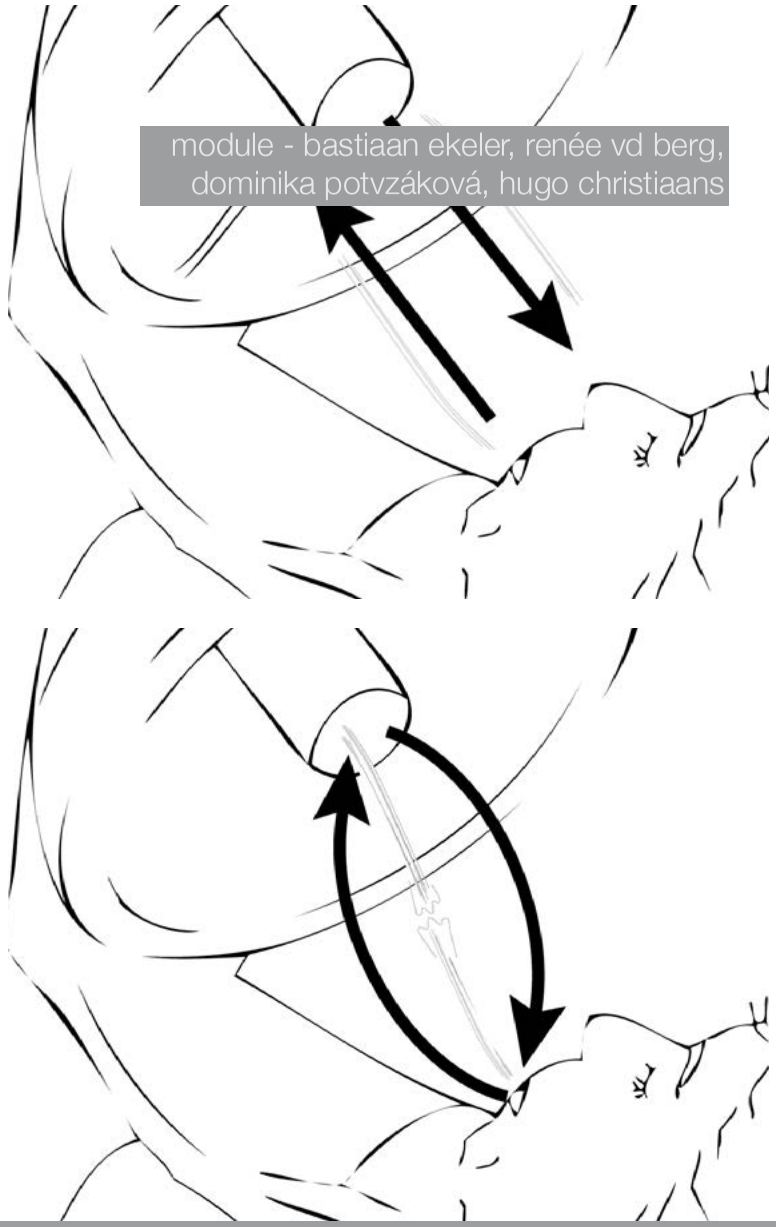
The light is, on the one hand, curious and sets out to find the person but gets shy when the person comes closer. When the person directly looks at it, the light turns off. The light cannot see the person, as it needs its own light for a webcam to detect the person. In addition, the person will not see the artefact that well in this situation. To try and see if the person is still there, the artefact has to turn on its light or it can move and dare to look in another direction. The webcam turns along with the light, and sensing and acting are embodied.

This implementation of the webcam and the light is rather fascinating, as when the light turns off it literally escapes from perceiving the person. It uses a webcam to detect the person, and will not see the person in the dark. Although the fact that the webcam moves along with the body embodies sensing and acting, the pitfall of making an 'eye' lures. The perceptive qualities that are intrinsic to turning off the light are more refined than letting the sensor literally move along with the body. This opens a new perspective on the embodiment of sensing and acting. Sensing is dynamic, but the sensor does not necessarily move.In the discussion on the embodiment of sensing and acting and the use and placement of sensors, ShyLight is a subtle example.

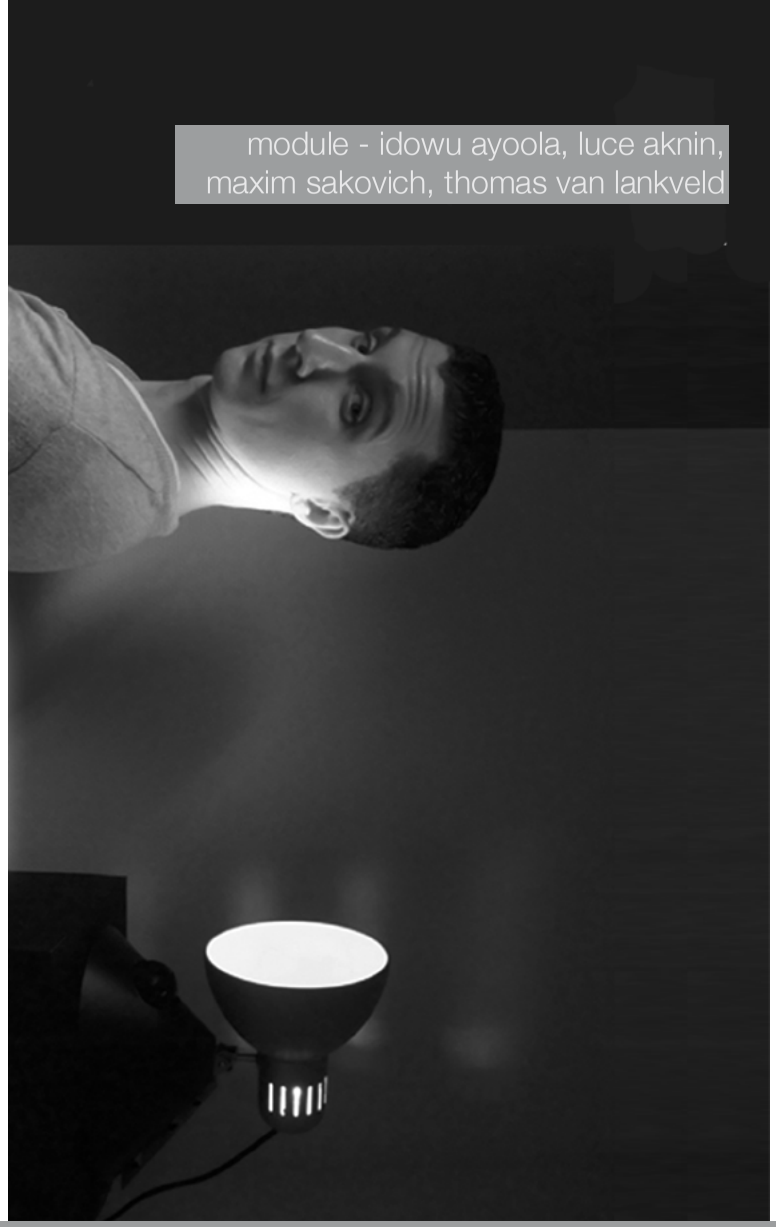
Blow!

The students who designed Blow! explored the experience of reciprocal touch on a distance, using air as a mediator. The artefact is a bowl that you hold in your arms. The bowl integrates a hairdryer, and so the artefact can blow at you. By means of a bending sensor, the artefact detects when the person blows at it. This sensor is placed directly under the hairdryer.

The placement of sensor and actuator disembodies sensing and acting. As you blow just under the hairdryer, the air hits your forehead instead of the two streams of air actually meeting each other. When you blow where the artefact acts, the two forces meet. It is in this resistance that perceptual crossing can happen. In other words, when you blow you could feel the artefact touching you, even on a distance. Although the students did a fair attempt, the reciprocity of touch cannot truly be experienced. The embodiment of sensing and acting, or the lack thereof, is frequently a topic of discussion in the students' work. In some cases, such as BeTouched! and ShyLight, students explore and investigate surprising approaches regarding this topic. On other occasions, the lack of embodiment is a point of discussion. Often the placement of the sensors is at the root of this issue.



module - bastiaan ekeler, renée vd berg, dominika potvzáková, hugo christiaans



module - idowu ayoola, luce aknin, maxim sakovich, thomas van lankveld

LittleOne

LittleOne is an endearing artefact that likes to be touched, but only gently. The body moves in the vertical plane, and by engaging in an active interplay the person might be able to lure it towards her hand. As soon as the person moves too abruptly or the movement is too big, the body jumps upwards. Basically, the body is a ball on a string, but as soon as the students draped the fabric around it the body started to behave.

Although the focus in the design assignment is on the dynamic qualities, LittleOne shows how the physical appearance reinforces these dynamic qualities. The fabric is only loosely draped around the body. When the body heavily shies at the person's movement, the fabric gets in front of the sensor. The fabric covers the sensitive area of the artefact. By gently moving the fabric out of its 'face', you can get the body to move towards you again. You care for it.

Shy Mirror

In this case the students make the mirror an active entity. You are engaged not only with the activity of the mirror, but also with your own image. Normally you cannot escape from the mirror, if you look in the mirror your image looks back. In this case, the mirror can actually move away from you, and so your body-image escapes along with it. Catching the mirror again is also catching yourself.

The intriguing aspect of this artefact is the integration of a mirror. The mirror is a special case in the story around perceptual crossing. It is in the mirror that you see your own face. This mirror normally is a rather static object: its activity is caused by the context it is in, by what it reflects. You interact with the artefact, but also with your own image. The subtlety, or the lack thereof, of the Shy Mirror's movement and the embodiment of sensing and acting mean that this experience is a bit rough at the moment. The sensor is positioned on top of the mirror, detached from the rest of its body. When the sensor is embodied, the person interacts truly with the mirror (not with the sensor), and at the same time engages in a novel interaction with herself.

module - jelle dekker, roos flapper, robert noome

module - meerthe heuvelings, dennis de klein, rob van kasteren

Dawe, a paper sheet, is sensitive to the contextual lighting conditions, and acts by making sound. The student crafted the paper himself, seamlessly integrating the sensors and actuators: they are one body. Valle is Dawe's opponent. Valle has two slender limbs that end in a round-shaped form that faces Dawe. Valle is also made of paper. Valle acts by wiggling in different directions and causes a shadow by a light that is positioned behind it. It is sensitive to sound. Dawe randomly produces long musical notes, and when the light conditions change it crackles: its sound is more evident. Valle moves around, triggered by the sound, and its shadow caresses Dawe. When the sound is more evident, Valle becomes more active and the light conditions change more rapidly.

Dawe and Valle are in an active dialogue that is perceptible for the person, who is a third participant in this reciprocal interplay. The presence of the person immediately influences the interplay, as she causes the light conditions to change. The person can engage in the interplay by making sounds or touching the bodies. When the person interacts with one of them, the other is always involved. Although Dawe and Valle is a rather poetic installation, it persuasively shows how the dynamic force between them is meaningful and engaging. People who tried the installation indicated that they felt like interrupting the two in their dialogue. To engage in an active interplay with one of the two, if not both, the person has to act

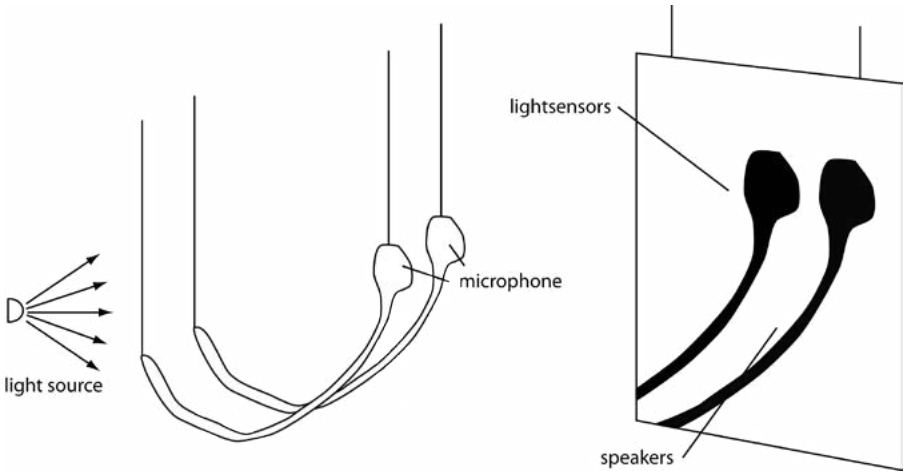
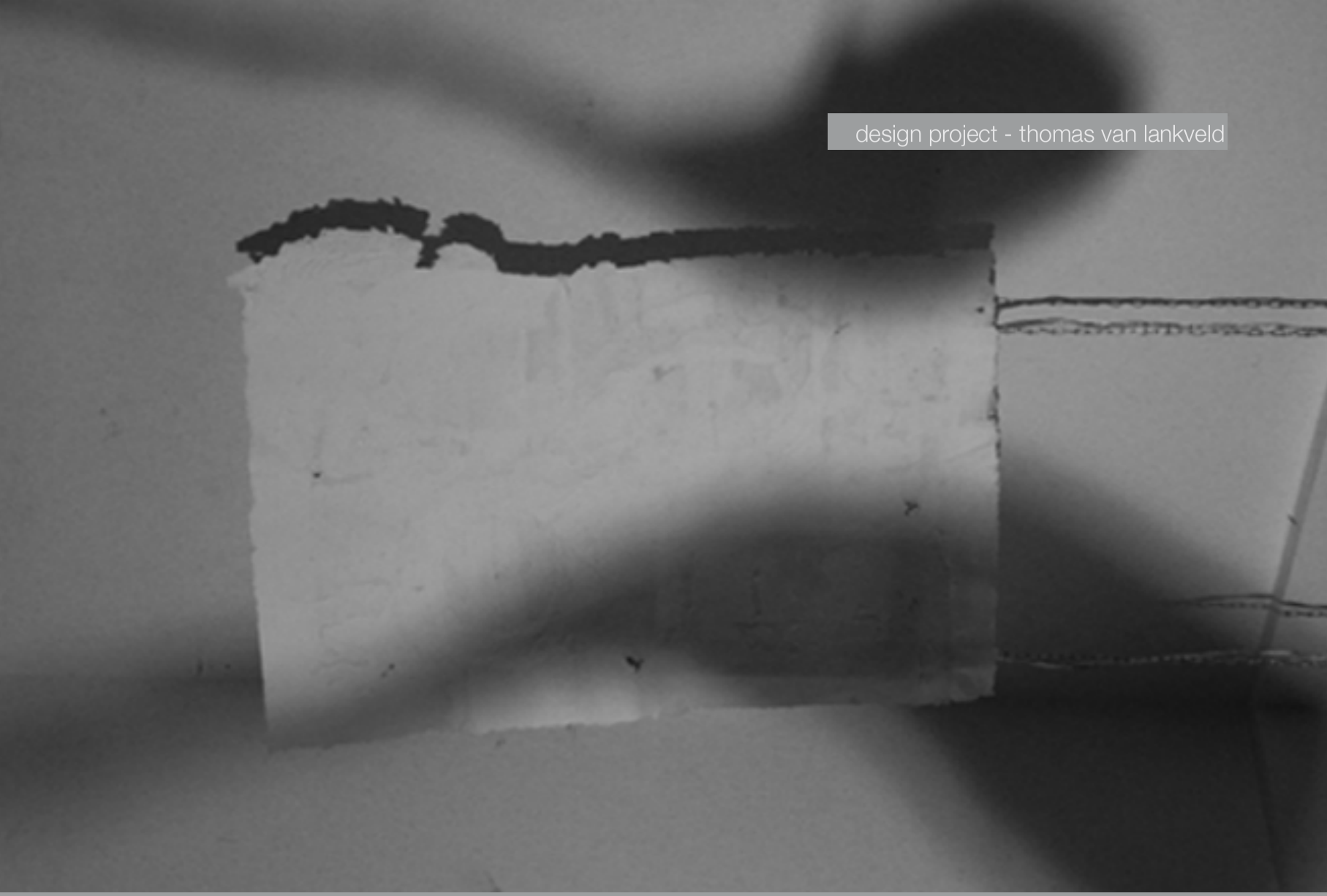


Figure 57. Overview of the installation Dawe and Valle.



In this project the student explores designing for perceptive qualities in sound. Similar to the light bodies in *PeP* and *PeR*, music is treated as a sound body. The student uses the installation I developed and describe in the intelligent environments chapter (cf. Designing for systems of interactive products; a proposition p. 144). The student and I built the installation together. The appearance and behaviour of the system described here are the student's contribution.

Surfacing Sound holds eight speakers evenly placed over a five-metre width. The sensors are placed under the speakers. The artefact detects activity of the person, and directs its sound body towards the person. Both the movement and the distance towards the wall influence the position of the sound body. When you walk along the wall the sound body convincingly follows you.

The relation between the position of the sound body and the person appeared to be very subtle. When the sound body follows you too directly, and, so to say, walks in pace with you, the movement of the sound body is hard to perceive. However, when the sound lingers just a little bit behind you, it creates a very strong experience of following you. The auditory experience is surprising. When interacting with Surfacing Sound people tend to look to the wall to somehow also see the movement of the sound. However, there is no perceptible visual effect. The situation in which a second person steps in and attracts the sound body therefore is a startling experience. It strongly feels like the sound body is pulled away from you.

design project - adriaan de regt

Wonderturf, an artificial turf, is sensitive to the activity of people using it. It is able to distinguish whether the person just wanders around, or plays, for example, soccer. When a person or a group of people walks onto the turf, a body of light welcomes them and playfully moves along. The body invites the person actively to use the turf. For a group of people it might create a private space in which they can have a lazy afternoon. It can also invite or support play by providing appropriate lining for their ball game.

Wonderturf shows how an environment can adapt to various people and events, and can evolve over time. It can engage in meaningful interaction with more than one person and even groups at a time. It portrays its perceptive qualities by engaging in an active reciprocal interplay when the person walks onto the turf but provides more functional support when it detects other activity. It evolves in time, as the detection of activity is very direct. When you lie down, it provides a private space to rest; when you get up it can immediately anticipate. It might even, every now and then, try if you are not interested in playing. The turf is context-aware (Recognise Explorative Behaviour Subject) and context-creating (Show Explorative Behaviour). It very clearly hints at context and function for the generated design-relevant knowledge in the broader design-research project in the fields of leisure, sports and play.

Wonderturf is a very successful project. Student Robin Brouns exhibited his work at multiple occasions, including the Dutch Design Week 2011 and events in the Evoluon exhibition centre in Eindhoven. The potential of the phenomenological approach in sports and play shows, for example, in the interest of soccer club PSV to collaborate and bring about an intelligent training environment. Wonderturf is the catalyst for this collaboration as it is an experienceable and tangible starting point, like *PeR* in the collaboration with DESSO.

design project - robin brouns

IN2WACO

IN2WACO is an INflatable and INteractive WAll COvering. The textile material holds inflatable chambers. A body moves through the textile surface. The chambers are divided into different sections, and the air pressure can vary over the surface. For example, a wave can move through the surface. The air chambers are well-integrated into the textile surface.

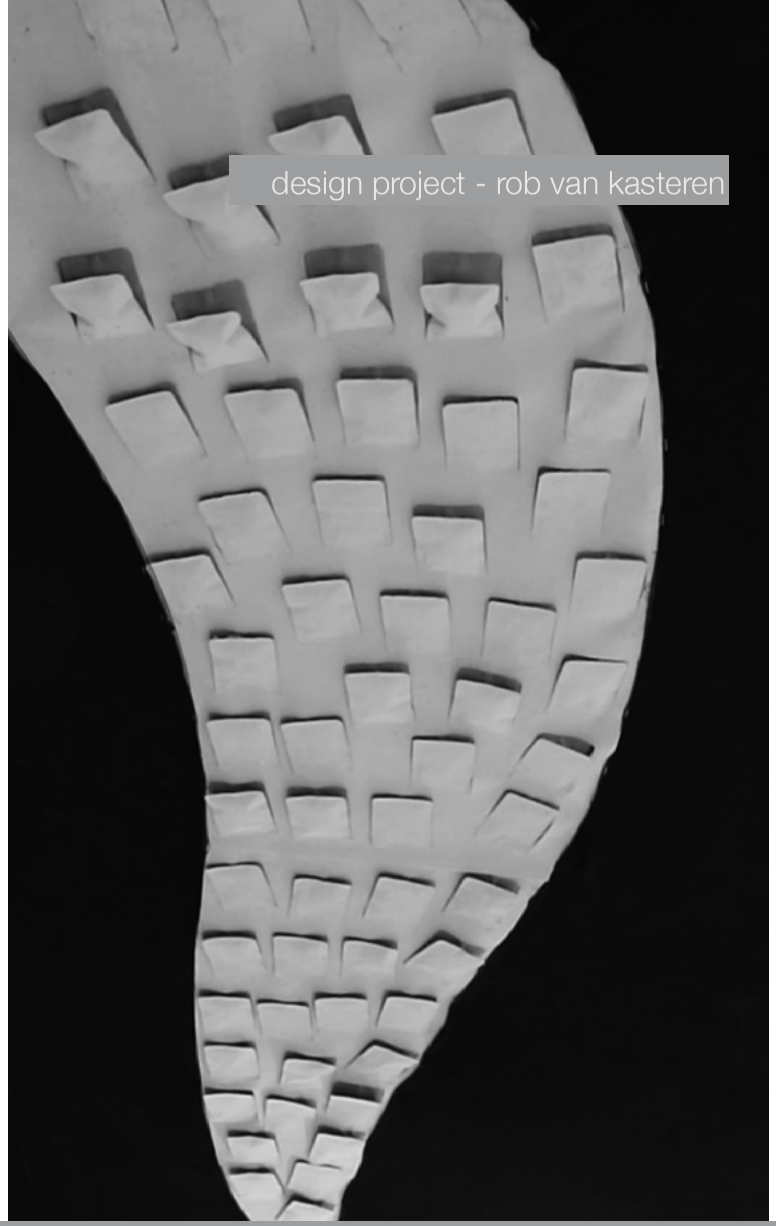
A rich palette of dynamic qualities can be found in the way the chambers inflate, and the relation between their activity. The body can move staccato or very fluently. Blowing the air in at once creates a quick and explosive movement. Slowly filling the sections creates a harmonious flow. The student especially explored the aesthetics of the dynamic qualities. The active characteristics of IN2WACO are rather convincing. The sensing capabilities, on the other hand, stayed behind. The student struggled with the implementation of the sensors. The placement of the light sensors, which detect the activity of the person, separately from the textile surface makes the artefact very reactive and not perceptive. Placing the sensors along the sides of the textile surface amended the interaction and the experience of the person. Yet the placement of the sensors on or under the inflatable chamber might evoke more engaging and surprising behaviour.

Frings

Frings is the handle of, for example, a drawer or a door. By its activity it invites or prevents you from opening it. The handle is a wire frame. When the wires are wound up you can open the drawer. It is then a firm handle that you can easily grasp. When it opens up, the handle grows bigger and cannot be easily used to open the drawer. When you approach the handle, it might wind up or open up: inviting or preventing you from opening the drawer.

The student who designed Frings explored the experience people have with daily objects in their house. Can these objects attract attention when, for example, you did not use them for a longer period of time? What is notable about this work is the direct relation between the behaviour of the handle and its functionality. The way it closes under your hand when you approach it is natural and very supportive behaviour.

design project - michiel kersteman


design project - rob van kasteren

WWIJZ is a signage system that incorporates perceptive qualities to support the wayfinding process in hospitals. Signage systems in hospitals are often extensive and cluttered. Moreover, the visitors often feel a bit uneasy or nervous. The project is carried out for the Catharina Hospital in Eindhoven. The student builds on the existing routing system and sets out to amend the interaction with it. WWIJZ welcomes the visitor, and, in the course of the interaction, it points out the direction in which the person needs to go. A body moves, as it were, through the index board. All the signs are actuated and act in the horizontal plane. A gentle wave moves through the board to make its presence perceptible. When the person walks by, it will welcome the person by following her. The body focuses on the person by moving the signs the person is standing in front of. When the person focuses on one of the signs, the board only acts locally: it shows the person that it perceives what she is looking at. From this focus point, WWIJZ redirects the focus of the person onto the actual direction the person has to go. The body moves through the index board towards the directional signs that guide the person through the building. Directional signs that the person encounters on her route show subtle active cues to confirm that the person is going in the right direction.

WWIJZ in the first place tries to welcome people and invite them calmly to find their way. The system reassures the visitor that she has found the right direction by strongly connecting the index and directional signage. The index board is, as it were, the locus of interaction where the person gets an overview of the system. WWIJZ accommodates an action-centric interaction to support the wayfinding process. The perceptive qualities are a personal and dynamic layer that evolves around the visitor.

Student Sippe Duisters exhibited WWIJZ at the Dutch Design Week, and was awarded the second prize in the Social Design Talent Award put up by the Eindhoven municipality. The jury articulated the potential of such a system not only for wayfinding in the hospital, but also and especially for the city in general. The jury emphasised their interest in the personal and supportive character of the interaction.

design project - sippe duisters

Manoeuvre is an interactive table, a design-research artefact to explore and compare the implementation of static and moving sensor(s). The interactive table top holds a flexible wooden strip in which a body, a wave, can move. Capacitive sensors that react upon touching the body are integrated twofold. Two sensors are placed on the moving body, the part that moves under the wooden strip and creates the wave. These sensors move along with the body. A static grid of sensors is placed in the table. The reciprocity of touch between person and artefact is explored. The person touches the wave and tries to lure it along. The body moves gently through the table. It can move both in the horizontal and vertical plane.

In the different iterations, *PeP* and *PeR* follow a minimalist approach, and the artefacts make use of a static grid of input and output. In a reoccurring discussion in the course of the doctoral work, the point is whether the implementation of moving sensors naturally embodies sensing and acting, and therefore is preferred. As discussed earlier (cf. Design Notions, p. 97), the design of the algorithm becomes significant when designing for perceptive behaviour when relying on a static grid of sensors. However, this implementation opens up a wider range of design applications: for example, carpets. The emphasis is truly on the dynamic qualities and not on the anthropomorphic form of the artefact. Manoeuvre integrates both approaches. The student compared the two implementations in an experiment. Movement plots visually show, that in the moving sensor condition, the dynamic interplay between person and artefact is clearly richer compared to the static condition. Nonetheless, this interplay is shown to be very unclear to participants, which means that they find the static condition more pleasant. The development of the algorithm at that stage was at the level of the *following* behaviour. Later the student worked on implementing the algorithm of the *active* behaviour in Manoeuvre. The algorithm, developed for *PeP*+, is transferred almost one-to-one and significantly improved the interaction.

The material choice is paramount. The wood is engraved, which makes it flexible and lets the wave run through the table in a continuous and sustained manner. The stiffness of the material, on the other hand, means that the wave is distinct, and the person clearly interacts with this body. The wave can also move in the vertical plane, and grow when the person actively touches it. This freedom makes the body very expressive.

All the experts involved very enthusiastically received Manoeuvre by Jorg de Bont, and he exhibited his work during the Dutch Design Week 2012.

design-research project - jorg de bont

KiK

KiK is an example in which the student explored non-verbal communication between person and artefact. The light armature twists its body to cover and expose its light. The intensity of the light changes in relation to the person's activity. KiK explores inviting and defending behaviour. In the first case, it likes you to turn the light off; in the second, it does not like that. The light switch is placed in the armature and can only be reached when the armature twists to open up.

The student argues that the body language of a product may convey a great deal of information about the product's state or internal process, without need for strong and disturbing signals. The resulting behaviour is rather strong, and in a small experiment the student conducted, he shows that participants perceive the different messages the lamp conveys. Terms such as body language, communication and information are not terms that I necessarily prefer in line with the broader design-research project. Although they factually do not per se refer to cognitive skills, they elicit more cognitive terms and associations compared to referring to perceptive activity and dynamic qualities. On the other hand, making the link to the body language of products meant that the student chose to reconsider an existing product: a light armature. People seem to associate this artefact quite easily with a context and function.

Kinetic Folds

Kinetic Folds is an origami paper artefact that shrinks and expands in relation to you approaching and touching it. Kinetic Folds explores the salient phenomena in which an animal, such as a cat, tries to retrieve from being seen by freezing. In this position, it observes its opponent and tries to dissolve from her perception by standing absolutely still as if it were an object in space.

This appeared to be a difficult assignment. Before this activity becomes meaningful to the person, before the artefact can try to retrieve from your perception, you have to engage in a reciprocal interplay, or at least appreciate that you could engage in it. Although the experience of the artefact freezing and observing you is not completely achieved, the direct interaction with the artefact is rather fascinating. The aesthetic qualities of the folded paper, the way it moves, is very subtle. The artefact distinctly shows both smooth and abrupt movements.

Students Erik Swaagstra and Kevin Andersen respectively showed KiK and Kinetic Folds at the Dutch Design Week 2012.

design-research project - kevin andersen

design-research project - erik swaagstra

LUMA holds a light body that moves in a one-dimensional plane from left to right. It detects the touch of a person. The student explores whether over time the mood of the artefact can change, subjective to the person's activity. When the person touches the light body swiftly, the excitement level of the light body rises. The touch of the person has to be directly related to the light body, as LUMA is only sensitive where the light body is. The excitement level (arousal) is a variable that continually adjusts over time. This variable is directly used to determine the size of the light body and the speed at which it moves. The excitement level keeps increasing as long as the person touches LUMA swiftly. At a certain moment, the light body has had enough; it needs to calm down. It will retrieve from the interaction and hold still in one place. Only when the person gently caresses the light body will it calm down again. Just placing the hand on the light body is not enough to calm it down. The person has to gently, but actively, caress it from left to right to affect it. The excitement level decreases. When it reaches a comfortable level, the light body behaves more swiftly again. This implementation also works the other way around. When the light body feels the person is not active enough, and thus the excitement level is low for a longer period of time, it will try to invite the person to engage in a more active play.

The student who designed and evaluated LUMA sets out to explore and investigate the idea of mood of an artefact with perceptive qualities. The student chose a minimalist approach. Designing a light body and the minimalist approach is a deliberate choice. The student directly builds on the findings and practical implementation of *PeP* and *PeR*. The student implements the *active* behaviour almost one-to-one and builds upon the resulting behaviour. The direct relation between touching the artefact and its activity from left to right provides a rather immediate experience of the play of attraction and escape. The way the student implemented the excitement variable is very continuous and direct. For now there is still a harsh switch when changing its behaviour; this can be improved.

The student did an experiment to see if the person indeed excites the light body and calms it down again. The data clearly shows who initiates the interaction. Both artefact and person appear to take the initiative. The person follows the lead of the light body.

design-research project - koen beljaars

PeP+ side table

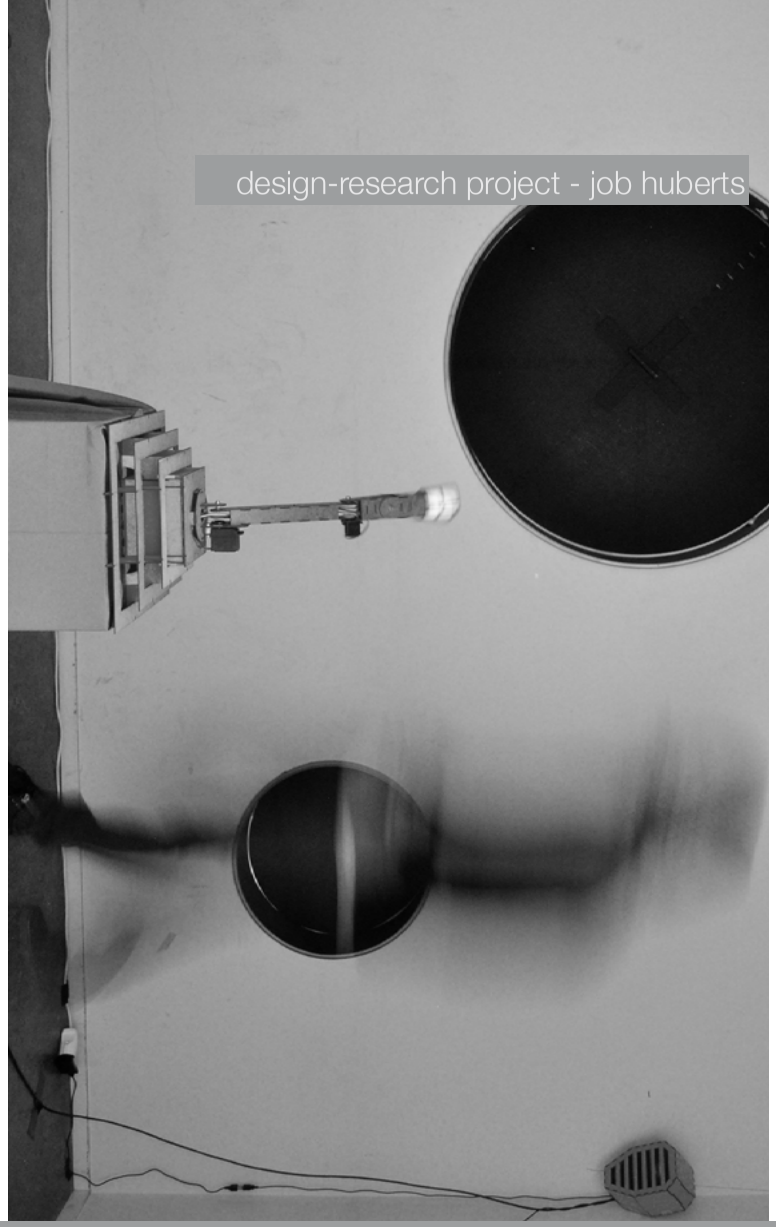
The student in this design-research project was particularly interested in conducting a field study in relation to designing for perceptive qualities. In the limited time of her project, designing and evaluating the artefact over a longer period of time in the participant's natural environment are out of scope. Therefore she converted *PeP+* to a side table. Three identical tables with different behaviours are placed in the living room of three different families for three weeks. The random, following and active behaviours are applied in the *PeP+* side table.

The realisation of the three tables and initiating the actual study in itself were a valuable iteration. *PeP+* transformed into a functional object with perceptive qualities. One participant was really exited about her participation, and the student almost felt guilty to leave the table with the random behaviour at her house. The family quite quickly found out that its behaviour was random, found a spot for the side table, and left it there. As the student expected, they were rather disappointed. The following and active behaviours evoked more interactions. One family tried to trick the light body by placing it in a corner, blinding it at two sides. The second family had a pleasant experience when the little girl next door visited them and was fascinated by their table. The families lost their daily interest in both the following and active table after about a week; nonetheless, it was the active table that over the three weeks drew most attention.

Semre & Mesro

In this design-research project the student is captivated by the experience that Dawe and Valle accomplish. The student sets out to investigate the perceptive connection between artefacts with perceptive qualities further. The result is named Semre and Mesro. Mesro explores the environment by listening to the soundscapes of Semre. Mesro is not directly sensitive to the activity of the person. The soundscape of Semre does adjust in relation to the presence and activity of the person. This in turn invites Mesro to explore different sides of the room.

As the student shows in a qualitative experiment, people feel actively engaged in a reciprocal interaction with Mesro, although it is not Mesro but Semre that is sensitive to the activity of the person. Participants are aware that they influence the soundscape of Semre. Through Semre, the person engages in a rich interaction with Mesro.



design-research project - job huberts

design-research project - sanne kroon

aesthetics and integration

The portfolio holds several wealthy explorations into the aesthetics and integration of material, electronics and behaviour. It strongly portrays the sensitivity that is requisite to design for subtle, sustained and continuous behaviour. Kinetic Folds explores the dynamic qualities of paper using origami. For creating Dawe and Valle, the student had to master the craft of making paper to integrate sensor and actuators seamlessly. Manoeuvre shows the flexibility yet manipulability of wood. The material properties of BeTouched! mean that the artefact actively touches you. IN2WACO provides a rich palette of dynamic qualities that can be exploited. The fabric draped around LittleOne reinforces its endearing character. Although the focus for designing perceptive behaviour is on the dynamic qualities of the artefact, its appearance and the integration of both should not be downplayed. The aesthetics and integration of material, electronics and dynamics are crucial. When designed well, the appearance of the artefact reinforces the behaviour tremendously. The integration of the sensing capabilities of the artefact appears to be crucial for person and artefact to engage in an active, reciprocal interplay. The portfolio exemplifies how the aesthetics and integration of different forms, materials and electronics influence the experience, of and interaction with, the artefact with perceptive qualities.

embodiment of sensing and acting

Several artefacts presented in the portfolio showcase the influence of the embodiment of sensing and acting (or the lack thereof) on the interaction and on the person's experience. The discussion on the use of a static grid of sensors or the use of moving sensors reoccurred throughout the project. The latter approach naturally couples sensing and acting: whereas, in the former approach, sensing and acting need to be coupled in the algorithm. Despite this need for a more complex algorithm, the use of a matrix of static sensors is preferred as it covers a wider range of design applications. Moreover, by not using moving sensors but a static grid of sensors, the shape of the artefact does not lead to anthropomorphic attributions. The emphasis is really on the artefact's dynamic properties and its behaviour, rather than its appearance. ShyLight illustrates that the pitfall of making an 'eye' lures. On the other hand, the portfolio shows several novel and rather beautiful ways to couple sensing and acting. ShyLight turns off its light and is no longer able to 'see', as it needs its own light for this. The combination of material and placement of sensors and actuators in BeTouched! means that the bodies touch you back. Manoeuvre integrates the two approaches in one body. This artefact clearly shows the immediate reciprocal interplay when sensors and actuators are physically embodied. Besides, Manoeuvre shows that the

embodiment of sensing and acting in the algorithm provides for more freedom to design different behaviours. In both of the two approaches, the placement of sensors is crucial. Blow! and IN2WACO clearly show how the disintegrated placement of the sensors and body means that the perception of person and artefact cannot cross. The placement and integration of the sensorial capabilities are crucial for the experience of the person and the interaction. However beautiful the dynamic qualities are, the experience is most influenced by the direct coupling of sensing and acting of both person and artefact.

The wayfinding system WWIJZ is an example of designing for perceptive qualities in context, and has a clear function. In the hospital, many people interact with the system and often pass by quickly. The student argues that, in a case like this, it is preferable to have a complete overview all the time. In other words, all sensors are active all the time. This complete overview is not desirable to engage the person in the supportive interplay with WWIJZ. Instead of creating a system that is sensitive in all directions all the time, it might be interesting to create more than one body in the system. Then these bodies can direct their attention to multiple users. Moreover, in multi-user interaction, it becomes paramount that the person perceives the interaction between another person and the artefact. The notion that an artefact can have multiple perceptive bodies is also evident in Wonderturf, which can support the activity of multiple persons. WWIJZ also showcases the thin line between showing active behaviour and being confusing. The active behaviour, when focusing on the person, should be local and clearly directed towards the person. Active behaviour to trace the environment is paramount for the person to appreciate the presence of the perceptive artefact, but should be limited when engaged with a person.

Dawe and Valle strongly illustrates that a person appreciates the presence of the artefact (i.e. recognises its ability to perceive) in its active and explorative behaviour. The active behaviour of both Dawe and Valle allows them to engage in a rich dialogue. A person who interacts with or even just observes Dawe and Valle does not perceive action and reaction: she perceives the dialogue between them. There is a perceptible play of attraction and escape between the two bodies. For both the person and the artefact, or the artefacts to engage in an active play of attraction and escape, active behaviour or own initiative is paramount. For example, Blow! in the first instance did not show any initiative. It did not invite the person to interact and just blew back. When the artefact incorporated active behaviour, the interaction became much more playful. Blow! then, as it were, invites the person to blow back.

Wonderturf informs how the activity of multiple people and different events can become meaningful to the system in the course of the interaction. The concept articulated the need to develop the design notion Recognise Explorative Behaviour Subject for designing the explorative behaviour of *PeP*+. The concept of a context-aware and context-creating artefact contributes to the discussion on designing systems of interactive products. The student shows how a static grid of sensors is used to detect the presence and different activities of people. Wonderturf proposes a context of use, and sketches a clear scenario in the fields of leisure, sports and play. The artificial turf invites physical activity. The detection of multiple persons and multiple activities they undertake invites one to use the proposed theoretical model for the notation of this system. Figure 68 is a proposition for the notation of the system Wonderturf, using the theoretical model. The description of perceptive connections between artefact(s), person(s) and event(s) articulates their position and their role in the system from an action-centric perspective.
Dawe and Valle propose a dynamic form language between two artefacts that is

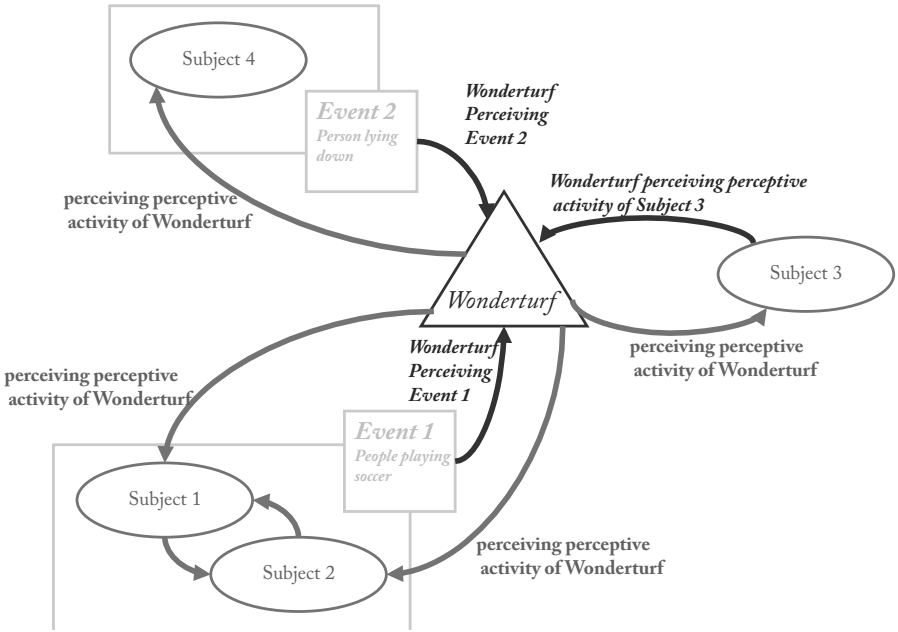


Figure 70. Descriptive theoretical model Wonderturf.

meaningful to the person. Figure 66 shows the notation of this installation using the descriptive theoretical model. I consider the artefact's perception of another artefact with perceptive qualities as a reaction to an external event. Therefore, the notation in Figure 69 combines the triangle (object with perceptive qualities) and the rectangle (event). However, in the case of Dawe and Valle, this does not cover its potential, as Dawe and Valle are in direct reciprocal interplay. This differs from BeTouched!, where the bodies do not perceive each other but perceive the event of the other being touched (Figure 70). This suggests that artefacts can be sensitive to, and appreciate, each other's presence. In this line of thought, the addition the design notion 'Recognise Explorative Behaviour Objects' is a valuable addition. This extension supports system thinking and when developed further can be a source of inspiration and a means of synthesis for designing systems. The reflection on the system qualities of some of the showcases portrays the extensibility of the descriptive theoretical model as proposed in the first chapter.

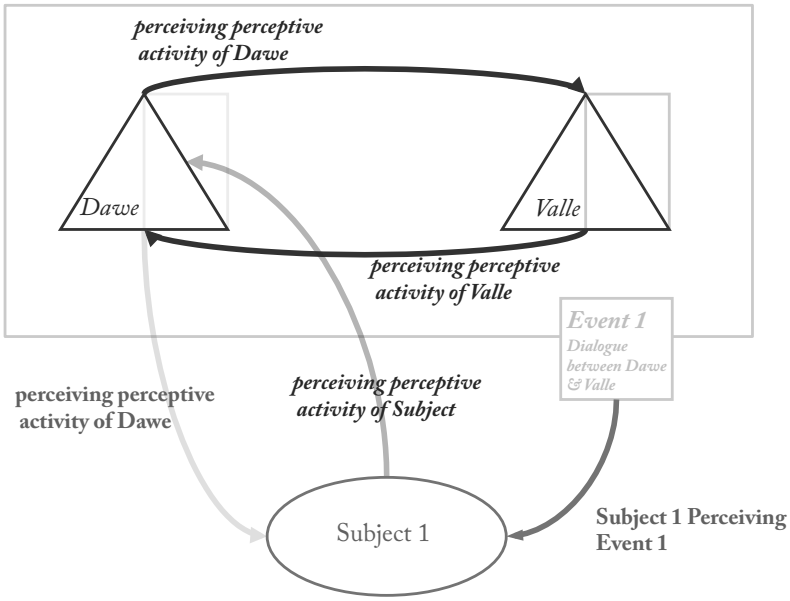


Figure 71. Descriptive theoretcial model Dawe and Valle.

The theoretical background and particularly its implications for designing are not quickly and easily comprehended in depth. It asks a great deal from both the students' abstracting and synthesising skills to truly catch its meaning, richness and sensitivity. For students to explore the aesthetics of the perceptive behaviour and its dynamic qualities, they needed the freedom to move away from requirements set by context and function. The students who did apply the design-relevant knowledge in context did not fully develop the dynamic qualities.

WWIJZ and Wonderturf in particular bring forward convincing contextual and functional concepts in relation to designing for perceptive qualities. These projects strongly feed back to the proposition for systems of interactive products in the second chapter. Examples such as KiK, a light armature with different behaviours, Frings, a drawer handle with a mood, and *PeP+* side table show how objects in our daily environment obtain perceptive qualities. The portfolio further operationalises the design knowledge by considering context and function.

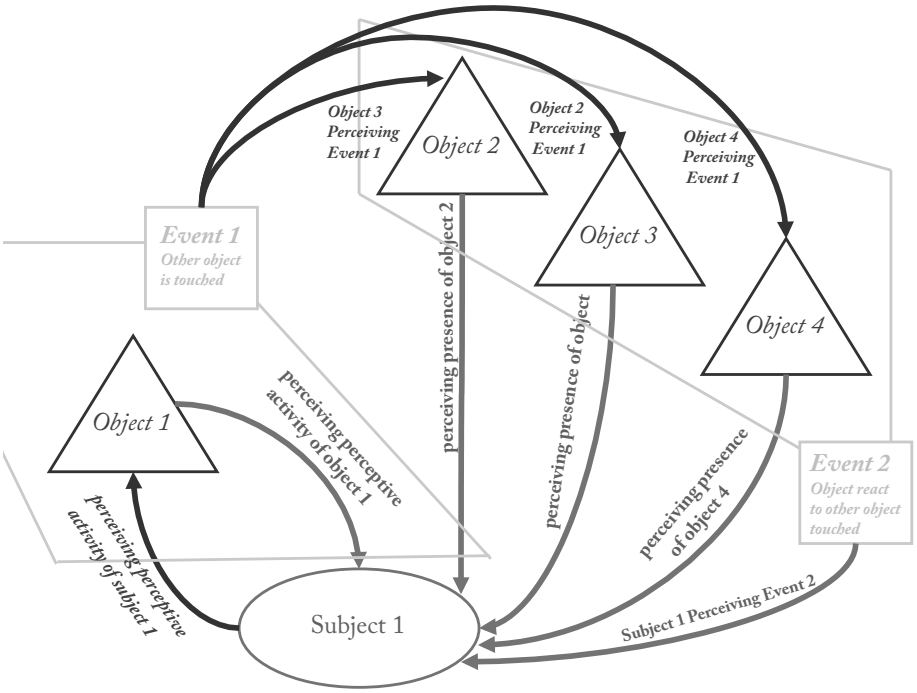


Figure 70. Descriptive theoretical model BeTouched!.

In respect to designing for systems of interactive products, the evolvement of the artefact in time is a functional requirement, especially when it is used over a longer period of time by the same person(s). LUMA thoroughly explores how the behaviour or even mood of the artefact evolves in time, subjectively to the person's activity. The way both person and artefact are able to excite or to calm each other down shows how the artefact shows and detects different meaningful behaviours. This work inspires the behaviour of *PeR*+.

The aim of this chapter is to corroborate my findings through the third-person perspective of the students on the theoretical background and design knowledge. The variety of material, aesthetic, behavioural and contextual qualities shows the breadth of the theoretical exploration. The design notions inspire and support a broad range of new designs. The portfolio advances the design notions, as they exemplify and verify the design knowledge formulated in the design notions. Moreover, they add a more practical level to the design notions. What is most advanced from a theoretical point of view is not always desirable for a specific function or context. Next, as part of the leitmotiv, the design notions are represented. The formulation now focuses on the insights gained from the perceptive qualities portfolio. For ease of reading, the design notions are briefly reintroduced (in italic font).

For living organisms, it seems natural to concentrate their senses in the direction of the stimuli: e.g. you close your eyes and turn your ear in the direction of the sound so as better to perceive the acoustic event. Sensing and acting are embodied. In other words, perception is active and is the result of actions we undertake and the sensory feedback this results in, and the other way around. For the artefact to be more than a following artefact, the idea of literally focusing the senses should be integrated.

The perceptive qualities portfolio strongly communicates the necessity of embodiment of sensing and acting. The physical embodiment is not necessary, but can happen in the algorithm. When they are physically embodied, the pitfall of creating anthropomorphic shapes lures. The emphasis then is no longer on the dynamic qualities. Nevertheless, there are different ways to directly couple sensing and acting. An example is a light armature that needs its own light to detect the environment and the persons in it. And so when it turns its light off, it is literally not able to 'see'. Although the use of a moving sensor creates a very immediate play of attraction and escape, a static grid of sensors provides more freedom to design different behaviours. Moreover, it covers a wider range of design applications.

The integration of the sensors is crucial. When the sensors are perceivably disembodied from the acting body, the artefact is a reactive, rather than perceptive, entity. The person literally directs her activity to the sensor, instead of to the apparent sensing body of the artefact. Most people who interact with *PeP+* feel that they are interacting with the light. They direct their activity around the light, not towards the sensors. The placement of sensors apart from the acting body means that perception of person and artefact cannot cross. However beautiful the dynamic qualities are, the experience is most influenced by the direct coupling of sensing and acting of both person and artefact.

Designing for perceptive qualities in a more functional setting requires the artefact to be aware of its environment. This relates to the idea that, although it seems natural to concentrate our senses in the direction of the stimuli, this does not mean that we purely perceive in the direction in which our senses are focused. What is behind me is not visually absent (Merleau-Ponty, 1958, p. 6). In a situation with multiple users in a short time period, high sensitivity to activities outside the focus of the artefact can be desirable. The artefact can also have several bodies that can direct their attention to different persons.

The artefact should be motivated to explore. This way it becomes possible for a person to perceive its presence and engage in an active interplay of attraction and escape. Perceptual crossing depends heavily on explorative movements such as the ability to escape from, or to attract, each other's perception (Lenay, 2010). By the implementation of this design notion, the artefact is capable of "perceptually motivated perceptive activity". If an artefact is just a following entity, this might indicate that the body is indeed sensing and acting, but it is questionable if such an artefact can be described as a perceiving body. Two kinds of active, explorative behaviour are considered. (1) The artefact should adopt active and explorative behaviour to scan the environment. This is like living organisms that can scan the environment for events: e.g. you turn your body and head to look around the room to see whether someone is there. This is the kind of movement that makes an observer aware of the other's ability to perceive. The observer perceives the other's presence, as it were, even though no interaction has yet taken place between the observer and the entity under observation. (2) The artefact should also adopt this explorative behaviour when focusing on something. For example, to experience the surface of the table top, one will not just touch it but also move one's fingers over it in an exploratory fashion. In a similar way, our eyes are always in action to perceive. Perception is active (Gibson, 1986).

Several projects in the perceptive qualities portfolio show the need for this active exploration of the artefact. When the artefact does not show any motivation to explore, it does not invite the person to engage in the interaction. It is in the explorative movements subjective to the environment that the person recognises the artefact's ability to perceive. The motivation to explore both the environment and the person are essential for person and artefact to engage in a rich reciprocal interplay of attraction and escape. An artefact can also show explorative behaviour in relation to other artefacts with perceptive qualities. The active behaviour means that two artefacts can engage in an active dialogue. The person perceives the crossing between them.

In a very dynamic context, too much activity can be confusing. Movements to explore the environment rather than the person can especially be distracting. The active behaviour of the artefact when focusing on the person is desirable, as it defines its focus by being active. This local activity reassures the person that the artefact focuses on her.

subtleness of movement

When designing for perceptive activity, the subtleness of the physical appearance, the actual movements and their integration should all be considered. The actions we undertake to perceive are smooth: we turn our head in a continuous and sustained movement to look at what is behind us. The designer has to take into account the sustained and continuous nature of perceptive actions to create subtleness in both the physical appearance and the algorithm.

The perceptive qualities portfolio showcases several examples of rich and sensitive explorations of integrating materials, electronics and behaviour. It is a comprehensive collection that serves as an inspiration for the use of materials, dynamic possibilities, and the integration of electronics. The influence of the subtleness on the behaviour and thus the experience is paramount.

For example, servomotors that allow for precise control of angular positions are often used. The advantage of this motor is direct control of its position, but the motor adjusts its position in steps, and is not per se intended to create smooth continuous movements. In many projects, the jerky movement of the motor is not suitable for the dynamic qualities and experience the students are after. On other occasions, students cleverly combined such a motor with other materials. The material properties of BeTouched! mean that the person is actively touched back by the artefact. The subtle movement of BeTouched! means that the body lets itself been stroked and moves the sensitive part of its body along the person's hand.

react to external event

The addition of an external event amends the reciprocal interplay, as it allows for sharing a common space. The addition of an external event will enrich the common history a person can establish with the artefact in the course of their interaction. When we interact with someone, events in the environment shape and influence the interplay: e.g. music, noise, light or objects can influence our interaction with someone. The artefact is able to perceive an event and show perceptive activity in relation to this.

In both Wonderturf and WIJZZ, it shows that this design notion is at the basis of the functionality of an artefact with perceptive qualities. For example, WWIJZ redirects the focus of the person from the index-sign to the directional-sign to support the wayfinding process. This touches upon the idea that a person can perceive, as it were, through the artefact and become aware of events that

she cannot directly perceive herself. Wonderturf engages in a direct reciprocal interplay with the person, and detects the activity of one or more persons as an event.

The installation Dawe and Valle brings forward a new point of discussion in relation to this design notion. The installation shows a rich reciprocal interplay of perceiving and being perceived between two artefacts. The dialogue between the two artefacts is perceptible and meaningful to the person. The interplay between the artefacts might be considered an event from the person's point of view. From the artefacts' point of view, this does not justify the qualities of the artefacts. For example, the bodies of BeTouched! do not perceive each other, but perceive the event of an other body being touched. Dawe and Valle are in a direct reciprocal interplay. To extend the work further in order to inform system thinking and designing for systems, the development of the design notion 'Recognise Explorative Behaviour Object' is a valuable addition.

recognise explorative behaviour subject

The perceptive activity of the person should become meaningful to the artefact in the course of the interaction. We are living organisms that use active and explorative movements in order to perceive. In the course of interaction, the artefact should be enabled to detect this perceptive activity. In the context of interactive interplay between an individual and an artefact, these actions become meaningful to the artefact.

The perceptive qualities portfolio shows an example in which this design notion is exploited. By detecting and differentiating different activities and supporting these, Wonderturf adapts to multiple people and events. The portfolio also shows how the behaviour of an artefact is influenced by the activity of the person in time. The person can take the lead and get LUMA more active or calm it down. Moreover, LUMA shows that the person also follows the excited activity of the artefact. By its behaviour it elicits active behaviour from the person.

Contextual noise can be reflected in the perceptive activity of the artefact to create behaviour that is not anticipated, but that is a natural result of the context. When we are in dialogue with someone else, our perception is focused on the other. However, this does not mean that there is no contextual sensory input, nor does it mean that we don't undertake any action to get other sensory input. This is especially true when sensory input reaches a certain level: for example, when something makes a lot of noise or moves suddenly and quickly.

The reflection of contextual noise, which is often intrinsic to the type of sensor, can add ambiguity to the behaviour that amends the aesthetics of the behaviour. Many students used the reflection of contextual noise to let their artefact naturally move when not interacting with the person. In this case, they did not deliberately implement explorative behaviour of the object, but used its sensitivity to the noise in the environment to show the person its perceptive capabilities. WWIJZ shows that this behaviour that is not anticipated can be distracting and confusing, in a more functional and dynamic context. In this scenario, the control one has over the artefact is more significant.

Many students questioned the difference between the notion Reflect Contextual Noise and the notion React to External Event. Unlike the events described in React to External Event, the algorithm does not anticipate the events that are regarded as contextual noise.

remember and anticipate perception over time

This notion refers to the awareness of bygone perception and the anticipation of future perception. The artefact gets, as it were, an experience, and relies on history and anticipates what could happen next. Based on other design notions, the implementation of this notion will enhance the richness of actions and expressivity of the artefact in relation to the person's activity.

Especially the artefact LUMA, presented in the perceptive qualities portfolio, explores this design notion. The student implemented an excitement variable that continuously changes depending on the person's activity. This variable is of direct influence on the dynamic characteristics of the body. If the person swiftly touches the body, its behaviour adjusts in a sustained and continuous manner.

In a more dynamic and public context, the time people interact with the artefact is often short. In this case, this notion will be less effective in the direct person-artefact interaction. On the other hand, this notion becomes more significant from a functional perspective. The artefact can learn from its perception and interaction with different people to optimise and to adapt its behaviour to the situation. Instead of anticipating all possible situations beforehand, which is not possible in a very dynamic and/or public environment, the artefact will learn over time.

The 'leitmotiv' parts are a connecting thread through this dissertation. This part closes the project by reflecting on the initial theory, the approach and the outcomes. I elaborate that my minimalist approach in context and implementation was paramount to bring forward fundamental design-relevant knowledge. It is because of this approach that I could formulate a set of design notions that is meaningful and clear to practising designers and broad enough to inspire a wide range of new designs. Furthermore, I reflect upon my statement that by designing for perceptive qualities, ultimately one could design for intentionality. PeP+ shows that both person and artefact appreciate and show that they are affected by each other. As final though,t I consider the social qualities of the artefacts described in this dissertation. My study suggests the subjectivity of an artefact.

leitmotiv:
coming full circle

reflections and insights on approach and theory and practice

The main objective of the first chapter was to investigate whether it is possible and how to design for perceptual crossing between person(s) and artefact(s). Through three iterations of designing, building and evaluating *PeP*, I show that the perception of person and artefact can cross. I made the theory operational in a set of design notions.

In the second chapter, I set out to investigate the added value of the theoretical findings for designing. I applied design knowledge into design practice. The recognition of *PeR* by an industrial partner, at several exhibitions and academic venues is an argument for the relevancy and extensibility of the design knowledge. Moreover, the development of the artefact in collaboration with the industrial partner showed the feasibility of designing for perceptive qualities in design practice. Finally, through this exploration and the work in the third chapter, an astute proposition for designing for systems of interactive products was developed. In this proposition, the activity of the system is meaningful to the person, as well as the activity of the person is meaningful to the system. This proposition suggests a clear direction for further development of the design-research.

The third chapter made a strong argument for the breadth of the theoretical exploration. The theoretical background and generated desig-relevant knowledge inspired and supported a broad range of new designs. Different aspects of the broader design-research were explored in depth. The portfolio showed that design students were inspired by, and were able to synthesise from the generated knowledge. The value of the theoretical approach for designing meaningful interactions and the intelligence of an artefact were articulated.

I formed and framed a new perspective on designing an artefact's intelligence from a quality- and action-centric approach. To design for artefacts and systems that are perceptible to, and evolve around, the user, the intelligence of the artefact has to build in the course of the interaction. Both the person and the artefact appreciate that they affect each other and can anticipate each other's activity. In this manner, the intelligence of the artefact is not the result of a predefined mechanism, but is actually dependent on the situation and the actual user. The person engages in a meaningful and aesthetic interaction with the system, causing her to feel involved in the situation with the artefact.

approach

The first chapter describes the in-depth investigation into whether and how to design for perceptive qualities in artefacts, for perceptual crossing between artefact and person to happen. More generally this Research through Design process sets out to bring forward a new perspective on forming and framing an artefact's intelligence from an action- and quality-centred approach, rather than a functional approach. The design-research therefore pivots around action and quality, rather than functionality, which decontextualises the designing. Although I show in the first chapter that perceptual crossing can happen between person and artefact, on this basis of this I cannot directly claim that this goes for any context or functionality. On the other hand, because of this approach it was possible to generate fundamental design knowledge that is a source of inspiration and means of synthesis for a broad range of new designs. My work on *PeR* and *PeR+* and the perceptive qualities portfolio investigate and are an argument for the relevance and the extensibility of the more theoretical findings.

For me, the phenomenon of perceptual crossing is a catalyser to design for perceptive qualities. The design-relevant knowledge is on designing for perceptive qualities and perceptive product behaviour. Although the implementation of the knowledge can be to design for perceptual crossing, this is not necessary. The student's work on wayfinding in hospitals shows that the complexity of, for example, the explorative behaviour of *PeP+* is neither needed nor wanted for this context and functionality. The proposition for systems of interactive products, however, asks for further development, particularly of the design notions Recognise Explorative Behaviour Subject and Remember and Anticipate Perception over Time. As the design notions are not to be seen as separate from each other, their development might influence or ask for the advancement of other notions.

intentionality

In the introduction of the theoretical model on perceptual crossing between person and artefact, I introduce several challenges for designing successful intelligent systems that evolve around its user and are embedded in the background of our environment. The challenge for designers is to create dynamic interfaces for more than one function that evolve over time and adapt to multiple users and events. Ultimately, if the artefact is able to detect perceptive activity of the person and show meaningful perceptive activity in relation to this, both person and artefact perceive intentionality. The work described in the first chapter touches upon designing for intentionality. As we have seen earlier (cf. Designing for perceptive qualities, p. 18), awareness is always awareness of something, which is part of

the world and oriented towards the world. Intentionality is the directedness of meaning. It relates to the appreciation that we affect, and are affected by, each other and our common space.

Do both person and artefact appreciate and show that they are affected by each other? Do they recognise each other as intentional entities? Does the artefact truly direct its activity towards the person and the environment? *PeP*+ directs its activity to the person in the *explorative* behaviour. It appreciates that it is affected by the person as it becomes certain the person is exploring it. Upon this, it directs its activity to the person. In the *active* behaviour, *PeP*+ directs its activity towards the environment. *PeP*+ has to focus its light body in a direction to get sensory input on this side. Moreover, over time it becomes uncertain when it does not look in a direction for a while. This uncertainty is subjective to events in the environment, as *PeP*+ has a short memory. *PeP*+ actively directs its light body towards the environment and is affected by events in it.

Both in the proposition for intelligent environments and in the reflection on the perceptive qualities portfolio, I discuss how the work inspires system thinking. Through analysing the students' work, the proposed design-relevant theoretical model is expanded to describe systems. I like to stress the role of the individual subjectivities and events for the constitution of the system. I am inspired by the phenomenological discussion on the role of the individual subjectivities in sociology. The phenomenological stance is a first-person one. It does not obviously review social interaction. However, as Overgaard and Zahavi (2009, p. 93) set apart, phenomenological sociologists stress the role of individual subjectivities for the constitution of the social world. Although social reality cannot be reduced to relations between individual subjects, without inter-subjectivity there is no social reality. Rather it is a product of our activity (Spurling, 1977, p. 85). Building on Husserl's ideas of intentionality and life-world, phenomenological sociologist Schutz argues that the social world makes itself evident in various intentional experiences. We are aware of bygone perception and anticipate future perception. There is a need to examine the subjects of the social world, as these subjects and their interactions constitute its meaningfulness (Overgaard & Zahavi, 2009, p. 99).

Although the proposed theoretical model offers a way to create an overview of the interaction and also of a system, it emphasises the first-person perspective of all the subjectivities and events in it. The dynamic nature of all perceptive connections

in the theoretical model allows one to add to and describe the flexibility of the system. The artefacts in the three chapters show different perceptive connections between persons, artefacts and events. In the perceptive qualities portfolio, different projects also address the perceptive connection between two or more artefacts. These projects show that the dialogue between different artefacts can be perceptible and meaningful to a person.

The experiments and experiences with the different artefacts I describe in this work suggest the subjectivity of the artefact. Participants who interact with *PeP+* feel themselves to be perceived by the artefact. Moreover, there is an active engagement of perceiving and being perceived. The discussion of intentionality and social conduct raises the question if the designed artefact with perceptive qualities can be treated as a subjective entity from a phenomenological point of view. I do not attempt to answer this question here. I pose it as a final pondering and leave my work as input for this discussion.

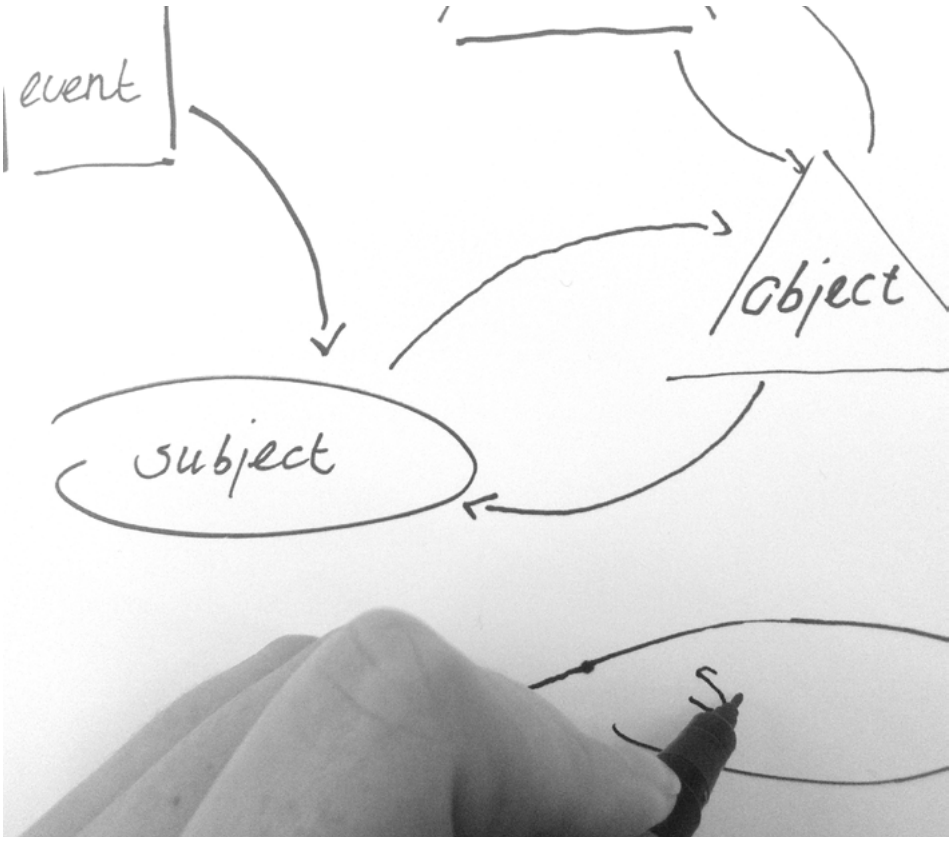


Figure 71. The theoretical model describes the flexibility of the system.

summary

The main objective of this doctoral work is to bring forward a new perspective on forming and framing an artefact's intelligence from an action- and quality-centred approach. The artefact shows meaningful behaviour to the person, and moreover the activity of the person becomes meaningful to the artefact in the course of the interaction. The work is inspired by, and directly synthesises from, the phenomenology of perception (Merleau-Ponty, 1945) and ecological psychology (Gibson, 1979). This theoretical background and the generated fundamental design-relevant knowledge are a leitmotiv through the work. The theoretical background is the introduction of this dissertation. The generated design relevant knowledge in the form of design notions reoccurs several times throughout the text. A reflection on theory closes the work. Around this connecting thread three main chapters are structured. The project follows a Research through Design approach. In each of these chapters, designing plays an essential role. In the first chapter, a minimalist approach applies in implementation and context in order to bring forward fundamental knowledge for designing. In the second chapter, the added value of the generated knowledge for designing is investigated and a step towards design practice is made. In the third chapter, a third-person perspective corroborates the first-person approach and finding of the first two chapters. The three chapters inform, inspire and validate each other.

Perception is here considered active. It is the result of the actions we undertake and the sensory feedback this results in, and the other way around. To experience the surface of the table top I will not just touch it but also move my fingers over it in an exploratory fashion. We access the expressive qualities, i.e. the meaning of the world, by means of our body (Overbeeke, 2007). The discussion of Merleau-Ponty's phenomenology of perception (1945) brings forward that perception is inherently interactive and participatory. It is a reciprocal interplay between the perceiver and the perceived (Abram, 1996). We are only able to touch because our body is a touchable thing. To touch is also to feel oneself being touched, and to see is also to feel oneself seen. Recently, researchers at the Compiègne University of Technology (France) made this reciprocal interplay operational for the perception between two human subjects (Lenay et al., 2007). In their work they describe two kinds of perception over time: perceiving the other as part of the environment (perceiving the body-image) versus perceiving the perceptive activity of the other perceiving me and the environment (perceiving the lived-body). It is the reciprocal nature of perception that means that we recognise others as intentional subjects. This phenomenon is referred to as perceptual crossing; and in simpler words, I perceive the other perceives me and the other perceives me perceiving her. We attract and escape from each other's perception. We catch each other's sight to

let go of it again: our perception of each other crosses. We share a common space in which we can build a history in our course of interaction (Lenay, 2010). This constitution of the other's viewpoint is essential to get a feeling of sharing the common space: to feel involved.

The work in the first chapter investigates whether and how to design for perceptive qualities in artefacts. By designing perceptive qualities in the artefact, person and artefact hypothetically are able to engage in a rich reciprocal interplay of perceiving and being perceived. Perceptual crossing happens between them, and they share their perception of their common space. They can build a common history which positively influences the person's feeling of involvement. In the course of their interaction, both person and artefact come to appreciate each other's viewpoint; they appreciate that they affect each other. The intelligence of the artefact is built in the course of this interaction. Through several iterations of designing, building and evaluating *PeP* and *PeP*+ (Perception Pillar (Plus)), it is shown that person and artefact can engage in this reciprocal interplay of perceiving and being perceived. The research artefacts function has physical hypotheses. Different behaviours of *PeP* and *PeP*+ are compared and evaluated in three experiments. Throughout this process a set of design notions developed that inform design-researchers and design-practitioners on designing for perceptive qualities. The different iterations showed the state of the art of the development of the design notions at that moment of the process. The phenomenon of perceptual crossing between person and artefact, and whether or to what extent the rich reciprocal interplay happens is shown and closely investigated. In the first chapter, the artefact, its behaviour, the practical implementations, and the evaluation are all discussed in detail. Next a definition of the seven design notions is given. The work in the second and third chapters adds to the development of the design notions.

Focus the Senses: Sensing and acting have to be embodied together in order for the artefact to naturally focus its senses and to become more than just a following entity.

Show Explorative Behaviour: The artefact should be motivated to explore. This way, the person is able to perceive its presence and to engage in an active interplay of attraction and escape.

Subtleness of Movement: To preserve the continuous nature of perceptive activity the subtleness of the physical appearance, the actual movements and their integration should be considered.

React to External Event: sharing perception of the common space, by making the artefact sensitive to external event(s), amends the reciprocal interplay.

Recognise Explorative Behaviour Subject: For the perception to be reciprocal the perceptive activity of the person should become meaningful to the artefact in the course of the interaction.

Reflect Contextual Noise: contextual noise can be reflected in the perceptive activity of the artefact to create behaviour that is not anticipated but a natural result of the context.

Remember and Anticipate Perception over Time: the artefact gets, as it were, an experience; it is aware of bygone perception and anticipates future perception. In this manner it can adapt and evolve over time.

The work in the second chapter investigates the added value of the generated fundamental knowledge for designing. The various prototypes of *PeP* (first chapter) are essentially research prototypes; they do not resemble any consumer product. The artefacts in the second chapter are not, in the first place, research artefacts, but can be used in context. The findings are applied in the field of intelligent textiles. Because textiles naturally shape and define the environment we live and work in, intelligent interior textile is an adequate field of focus for the research in the second chapter. Designing textile artefacts explores how the proposed theoretical framework and the resulting design-relevant knowledge can be applied in our daily environment. The spatial qualities of interior textiles lead towards the implementation of the design notions in a more dynamic and complex setting. This answers the question how an artefact can evolve over time and adapt to multiple persons and events.

The textile artefacts developed in this chapter are *PeR* and *PeR*+ (Perception Rug (Plus). These carpets have sensing and actuating characteristics. They are sensitive to the touch of people, and a body of light behaves in the surface of the carpet. Their behaviour directly builds on the behaviour developed in *PeP* and *PeP*+. The aesthetics and level of integration of behaviour, electronics and material in these artefacts are high. The first prototype, *PeR*, is completely hand-knotted, and electronics are integrated also by hand. The second prototype, *PeR*+, is developed in collaboration with international flooring company DESSO. This collaboration with an industrial partner investigates the feasibility and value for the market of the design-relevant knowledge. Although the theoretical background is not the main driver in this collaboration, it is the starting point for putting forward high-quality and innovative design opportunities. Besides the core research topic of

the project, a considerable amount of knowledge is also generated in the field of textile materials and how to combine them with electronics. Moreover, it provided insights on the multidisciplinary innovation process. Both *PeR* and *PeR+*, their behaviour and the practical implementations, are extensively described in the second chapter. The chapter concludes with an astute proposition for systems of interactive products. Three concepts, that are a direct result of the work in both the first, current and third chapters support the proposition. All three concepts build on experienceable artefacts. The behaviour of the artefact is sketched in a more spatial and functional context.

The third chapter describes the perceptive qualities portfolio. The first-person perspective on the approach and findings of both the first and second chapters is validated and extended by the third-person perspective of the students. All student projects and shorter classes start from the same theoretical background, are inspired by the design-relevant knowledge generated in the first and second chapters, and build from the same sources. Design-relevant insights are especially found in the experience of these artefacts. The work is considered to be valuable iterations and valid argumentation for the relevancy and extensibility of the generated knowledge. The portfolio annotates different aspects of the broader design research. It explores the aesthetics and integration of material, electronics and behaviour. It showcases influence of the embodiment of sensing and acting. It inspires system thinking and designing for systems. And it proposes context and functionality. Seventeen showcases are presented, which result from individual design projects at bachelor's and master's level, from individual design-research projects at master's level, and from one-week team projects in the form of a module at master's level.

This work shows how to design for perceptive qualities in systems of interactive products. The intelligence of an artefact is formed from an action- and quality-centred perspective. The work in the first chapter shows that perceptual crossing can happen between person and artefact. The minimalist setting of this investigation means that the claim that this goes for any context or functionality cannot be directly made. However, this approach made it possible to generate fundamental knowledge for designing that is a source of inspiration and a means of synthesis for a broad range of new designs. The work on *PeR*, *PeR+* and the perceptive qualities portfolio investigate, and are an argument for, the relevancy and the extensibility of the more theoretical findings. The operationalisation of theory results in a set of design notions that is meaningful and clear to both design-researchers as design-practitioners.

De belangrijkste doelstelling van deze doctoraatsstudie is het, vanuit een actie- en kwaliteitgerichte aanpak, aandragen van een nieuw perspectief op de vorming en raming van de intelligentie van een artefact. In de loop van de interactie, toont het artefact betekenisvol gedrag aan de persoon, en wordt de activiteit van de persoon betekenisvol voor het artefact. Het werk is geïnspireerd door, en synthetiseert rechtstreeks uit, de fenomenologie van de waarneming (Merleau-Ponty, 1945) en ecologische psychologie (Gibson, 1979). Deze theoretische achtergrond en de gegenereerde fundamentele kennis voor ontwerpen zijn een rode draad door het werk. Het theoretisch kader is de introductie van dit proefschrift. De gegenereerde kennis, in de vorm van noties voor ontwerpen, komen verschillende keren terug in de dissertatie. Een reflectie op de theorie, de aanpak en de resultaten sluit het werk af. Rond deze verbindende draad zijn drie hoofdstukken gestructureerd. In elk van deze hoofdstukken speelt ontwerpen een essentiële rol. In het eerst hoofdstuk geldt een minimalistische aanpak. Deze aanpak maakt het mogelijk om fundamentele kennis voor ontwerpen te genereren. In het tweede hoofdstuk wordt de toegevoegde waarde van deze kennis verder onderzocht, en wordt er een stap naar de ontwerppraktijk gemaakt. In het derde hoofdstuk bevestigt een derde persoon-perspectief op de bevindingen en aanpak, het eerste persoon-perspectief van zowel het eerste als het tweede hoofdstuk. Het werk in de drie hoofdstukken is sterk verstrengeld en informeert, inspireert en valideert elkander. Het project volgt een 'Research through Design' aanpak.

In dit werk wordt de actieve aard van perceptie benadrukt. Perceptie wordt hier beschouwd als het resultaat van de acties die we ondernemen en de zintuiglijke feedback waarin dit resulteert, en omgekeerd. Om het tafelblad te ervaren zal een persoon het niet alleen aanraken, maar zal zij ook haar vingers verkennend over de oppervlakte bewegen. Op eenzelfde manier, zijn onze ogen altijd actief om te kunnen zien. We kunnen de expressieve kwaliteiten, ofwel de betekenis van de wereld waarnemen, omdat we een lichaam hebben. Betekenis kan niet losgekoppeld worden van actie (Overbeeke, 2007). De bespreking van Merleau-Ponty's fenomenologie van de waarneming (1945) brengt de interactieve aard van perceptie naar voren. Perceptie is een wederzijdse interactie tussen de waarnemer en het geen dat waargenomen wordt (Abram, 1996). Onze directe zintuigelijke ervaring bestaat alleen vanwege deze wederkerigheid. Dat wil zeggen, het is alleen mogelijk om iets aan te raken omdat ons lichaam tastbaar is. Aanraken is ook zelf aangeraakt worden. Zien is ook voelen dat je gezien wordt.

Onlangs maakten onderzoekers aan de Technische Universiteit van Compiègne (Frankrijk) deze wederzijdse interactie operationeel voor de perceptie tussen twee mensen (Lenay et al. 2007, Lenay, 2010). In dit werk beschrijven de onderzoekers twee soorten van waarneming in de loop van de tijd: (1) het waarnemen van de ander in de wereld, en (2) het waarnemen van de activiteit van de ander, waarmee hij mij en de wereld waarneemt. Doordat de waarneming wederkerig van aard is, kunnen we de intentionaliteit van anderen herkennen. Hierin onderscheiden we het waarnemende lichaam van het lichaam als object. Dit verschijnsel wordt aangeduid als het kruisen van de perceptie (perceptual crossing), en beschrijft in meer eenvoudige woorden dat - ik kan zien dat je mij ziet en jij kan zien dat ik jou zie -. We trekken elkaars perceptie aan, om er vervolgens weer aan te ontsnappen. We vangen elkaars blik, om deze vervolgens weer los te laten: onze waarneming kruist zich. We delen een gemeenschappelijke ruimte waarin we, in de loop van onze interactie, een gedeelde historie opbouwen (Lenay, 2010). De erkenning van het perspectief van de ander is essentieel om je deel te voelen van de gemeenschappelijke ruimte; om je betrokken te voelen.

In het eerste hoofdstuk wordt onderzocht of het mogelijk is perceptieve kwaliteiten in een artefact te ontwerpen, en hoe dat te doen. Door perceptieve kwaliteiten te ontwerpen in een artefact, zou het hypothetisch mogelijk zijn dat een persoon en een artefact betrokken worden in een rijk wederzijds samenspel, van waarnemen en waargenomen worden. De perceptie van elkaar kruist zich en de persoon en het artefact delen de perceptie van hun gemeenschappelijke ruimte. De persoon en het artefact bouwen een gezamenlijke historie op, hetgeen het gevoel van betrokkenheid van de persoon positief beïnvloedt. In de loop van de interactie zullen zowel de persoon als het artefact begrijpen en appreciëren dat ze elkaar beïnvloeden. De intelligentie van het artefact bouwt op deze wederzijdse interactie, en kan zich in de loop van de interactie ontwikkelen.

Door verschillende iteraties van het ontwerpen, bouwen en evalueren van onderzoekontwerp *PeP* (kort voor Perception Pillar) en *PeP+* te doorlopen, wordt er aangetoond dat persoon en artefact kunnen deelnemen aan deze wederzijdse interactie van waarnemen en waargenomen worden. Het onderzoeksontwerp geldt als fysieke hypothese. De verschillende gedragingen van *PeP* en *PeP+* worden vergeleken en geëvalueerd in drie experimenten. Gedurende dit proces werden de van noties voor ontwerpen, die zowel ontwerper onderzoekers als ontwerpers in de praktijk informeren over het ontwerpen voor perceptieve kwaliteiten, geformuleerd en verdiept. De verschillende iteraties demonstreren en evalueren de noties voor ontwerpen in verschillende fases van het traject. De wederzijdsheid

van de perceptie tussen persoon en artefact wordt nauwkeurig onderzocht. De drie iteraties waren nodig om te formuleren welke noties voor ontwerpen relevant zijn, en om te weten te komen hoe de noties verder verdiept kunnen worden. In het eerste hoofdstuk worden het artefact, het gedrag, de praktische implementatie en de evaluatie in detail besproken. Hieronder worden de noties voor ontwerpen kort gepresenteerd. Het werk in zowel het tweede als het derde hoofdstuk dragen bij aan de ontwikkeling van de noties voor ontwerpen.

Focus de Zintuigen: Zintuiglijk vermogen en actie moeten worden geïntegreerd, opdat het artefact zijn zintuigen kan richten. Alleen op deze manier zal het artefact een perceptieve en niet een reactive entiteit worden.

Toon Exploratief Gedrag: Het artefact moet de persoon en de ruimte verkennen. Op deze manier kan de persoon de aanwezigheid van het waarnemende lichaam waarnemen en kan er een wisselwerking van aantrekking en ontsnapping ontstaan.

Subtiliteit van Beweging: Om de continue aard van perceptieve activiteit te waarborgen, dient subtiliteit van de fysieke verschijning, het gedrag en de integratie van beiden in acht te worden genomen.

Reageer op Externe Gebeurtenissen: Het delen van de perceptie van de gemeenschappelijk ruimte, door het anticiperen op externe gebeurtenissen, verrijkt de wederzijdse interactie.

Herken Exploratief Gedrag van het Subject: Om de wederkerigheid van de perceptie te bewerkstelligen dient de perceptieve activiteit van de persoon betekenisvol te worden voor het artefact tijdens de interactie.

Reflecteer Contextuele Ruis: Om gedrag te creëren waarop niet van te voren geanticipeerd is, maar een natuurlijk gevolg is van de context, kan contextuele ruis worden weerspiegeld in de perceptieve activiteit van het artefact.

Herinner en Anticipeer Perceptie in de Tijd: Het artefact krijgt, als het ware, een ervaring. Het onthoudt voorgaande waarneming en anticipeert op toekomstige waarneming. Op deze manier kan het artefact zich aanpassen en ontwikkelen.

In het tweede hoofdstuk wordt de toegevoegde waarde van de gegenereerde fundamentele kennis voor ontwerpen onderzocht. De verschillende ontwerpen van *PeP* (eerste hoofdstuk) zijn in wezen onderzoeks-ontwerpen, die gecontextualiseerd zijn in een minimalistische omgeving. Ze lijken niet op consumenten producten. De artefacten in het tweede hoofdstuk zijn niet in de eerste plaats onderzoeks-ontwerpen, maar kunnen toegepast worden in een bepaalde context. De bevindingen uit het eerste hoofdstuk worden toegepast op het

gebied van intelligent interieurtextiel. Dit is een passend gebied, aangezien textiel vormgeeft aan de omgeving waarin mensen wonen en werken. Het ontwerpen van deze textiele artefacten onderzoekt hoe het voorgestelde theoretische kader ,en de daaruit voortvloeiende relevante ontwerpkennis, kunnen worden toegepast in de ontwerppraktijk. De ruimtelijke kwaliteiten van interieurtextiel leiden tot een voorstel om de noties voor ontwerpen te implementeren in een meer dynamische en complexe omgeving. Dit voorstel beantwoordt de vraag, hoe het artefact of systeem kan evolueren in de tijd, en zich kan vormen om meerdere personen en gebeurtenissen.

De textiele artefacten, die in dit tweede hoofdstuk besproken worden, zijn *PeR* (Perception Rug) en *PeR*+. De tapijten hebben sensorische en dynamische kwaliteiten. Ze zijn gevoelig voor aanraking. Een lichaam van licht beweegt zich in de oppervlakte van het tapijt. Het gedrag van het licht bouwt direct voort op het gedrag dat is ontwikkeld in *PeP* en *PeP*+ (eerste hoofdstuk). De esthetische waarde en integratie van gedrag, elektronica en materiaal zijn van hoge kwaliteit in de artefacten. Het eerste prototype, *PeR*, is volledig met de hand geknoopt en de elektronica is ook met de hand geïntegreerd. Het tweede prototype, *PeR*+, is ontwikkeld in samenwerking met DESSO, een internationaal opererend bedrijf op het gebied van vloerbedekking. Door deze samenwerking met een industriële partner wordt de haalbaarheid en waarde voor de markt van de ontwerpkennis onderzocht. De theoretische achtergrond is niet de belangrijkste drijfveer is in deze samenwerking. Desalniettemin is het deze achtergrond die ervoor zorgt dat er mogelijkheden voor ontwerpen, die van hoge kwaliteit en innovatieve waarde zijn, naar voren worden gebracht. De interesse van de industriële partner, verschillende tentoonstellingen en academische publicaties tonen dit aan. Er wordt naast kennis, die direct van toepassing is op het onderzoek, ook een aanzienlijke hoeveelheid kennis gegenereerd op het gebied van de integratie van textiel en elektronica. Bovendien brengt de samenwerking een aantal inzichten in het multidisciplinaire innovatieproces naar voren. Zowel het gedrag als de praktische implementaties van *PeR* en *PeR*+ worden uitgebreid beschreven in het tweede hoofdstuk. Het hoofdstuk sluit af met een drietal concepten omtrent het ontwerpen voor systemen en intelligente producten. Deze concepten schetsen het gedrag van het artefact in een meer ruimtelijke en functionele context. Al deze concepten worden ondersteund door een ontwerp uit het tweede of derde hoofdstuk. Deze concepten werken toe naar een propositie voor het ontwerpen van interactieve systemen.

Het derde hoofdstuk beschrijft het zogenoemde 'Perceptive Qualities Portfolio'. Dit portfolio bevat het resultaat van verschillende studenten projecten. Het derde persoon-perspectief van de studenten bekrachtigt het eerste persoon-perspectief op de theoretische achtergrond en de aanpak. Alle studenten projecten en kortere lessen starten vanuit dezelfde theoretische achtergrond, zijn geïnspireerd door de gegenereerde ontwerpkennis en bouwen voort op dezelfde bronnen. Relevante kennis voor het ontwerpen is veelal terug te vinden in de ervaring met deze artefacten. De artefacten worden beschouwd als waardevolle iteraties en geldige argumentatie voor de relevantie en uitbreidbaarheid van de gegenereerde kennis. Zeventien voorbeelden, die voortkomen uit individuele ontwerp projecten op bachelor en master niveau, individuele ontwerp-onderzoeks projecten op master niveau en team projecten van een week op master niveau worden gepresenteerd. Het portfolio annoteert verschillende aspecten van het bredere onderzoek. Het portfolio onderzoekt en toont (1) de urgentie van hoge esthetische kwaliteiten en de integratie van materiaal, elektronica en gedrag; (2) de invloed van de integratie van zintuiglijke en dynamische kwaliteiten; (3) ondersteunt het ontwerpen voor systemen; en (4) stelt relevante contexten en functionaliteiten voor.

Deze dissertatie laat zien hoe te ontwerpen voor perceptieve kwaliteiten in systemen van interactieve producten. De intelligentie van de artefacten wordt gevormd vanuit een actie- en kwaliteitgericht perspectief. Het werk in het eerste hoofdstuk laat zien dat persoon en artefact betrokken raken in een rijke wederzijdse interactie van waarnemen en waargenomen worden. De minimalistische setting van deze studie maakt dat deze claim niet direct toepasbaar is voor elke context of functionaliteit. Desalniettemin maakte deze aanpak het mogelijk om fundamentele ontwerpkennis te genereren die een bron van inspiratie en een middel voor synthese is voor een breed scala aan nieuwe ontwerpen. Het werk omtrent *PeR*, *PeR+* en het portfolio onderzoekt en is een argument voor de relevantie en toepasbaarheid van de theoretische kennis. Het operationaliseren van theorie resulteert in noties voor ontwerpen die betekenisvol en duidelijk zijn voor zowel ontwerper-onderzoekers als ontwerpers in de praktijk.

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curriculum vitae

Eva Deckers was born in Heerlen on the 31st of May, 1986. In 2004 she obtained her VWO-diploma with honourable mention at the Bernardinus College, Heerlen. After her secondary education she studied Industrial Design at the Eindhoven University of Technology. She received her Master diploma Cum Laude in 2009. As part of the bachelor course she studied at RMIT University Melbourne, Australia. During her master education she was an intern at A1-productdesign in Cologne. After a half-a-year around the world trip, she continued her final-master project, on designing for perceptive qualities in products, in a doctoral project. This dissertation is the result of the doctoral work on 'How to design for perceptive qualities in systems of interactive products?'. During this three-year project, she worked with international flooring company DESSO to investigate the added value for design practice of the more theoretical findings of her research. Her work was shown at several exhibitions, and she was a finalist in the Nokia Ubimedia Design Awards. She strongly connected design-research and design-education, and is an experienced lecturer and coach. Since 2010, she is the chair of the Industrial Design alumni association IDEa. Together with the other members of the committee, she set up the association and IDEa became an official foundation in 2012.

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PeR+ at Moving Materials, Capital D, Dutch Design Week 2012
In 2013 Moving Materials will visit Kortrijk and Lancaster, *PeR*+ included.

PeR at DHUB Barcelona, Systems Design: The Eindhoven School, February 2012 to May 2012

PeR at Textileweekend Ronse, Opening CampusTIO3 Ronse - Smartroom, December 2011 - January 2012

PeR at ID'09, Eindhoven University of Technology, Dutch Design Week 2009

PeR at Design United, Delft University of Technology - World Usability Days, November 2009