The Color of Smell

A cross-modal interactive installation for individual expression

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Table of Content

1. Abstract .............................................................................................................. 5

2. Introduction ........................................................................................................ 5-6

3. Research Questions .......................................................................................... 6

4. Theory .................................................................................................................. 7-16
   4.1 The potential of smell: Psychological and physiological properties
   4.2 Olfactory communication in HCI
   4.3 The olfactory medium
   4.4 Smell in a cross-modal context
   4.5 Synesthetic Design - A cross-sensory approach
       4.5.1 Synesthetic perception
       4.5.2 Embodied Cognition in the context of synesthetic perception
   4.6 Cross-sensory connections for the creation of Synesthetic Design
       4.6.1 Cross-modal analogy
       4.6.2 Concrete association - iconic connection
       4.6.3 Symbolic connection
   4.7 The benefits of Synesthetic Design

5. Related work - relevant examples .................................................................... 17-20
   5.1 Lexus - A Journey Through the Senses
   5.2 Odor Emoticons, Olfacticons: An olfactory application that conveys emotion
   5.3 The Sound of Touch
   5.4 The I/O Brush: Drawing with Everyday Objects

6. Methods .............................................................................................................. 21-23
   6.1 Research Through Design
   6.2 Co-Design
   6.3 Prototyping
       6.3.1 The Wizard of Oz
       6.3.2 Rapid video prototyping
7. Design Project & Process

7.1 Smell Training
7.2 First intervention
7.3 Experiment 1: Testing smell associations
7.4 Iteration & Experiment 2: Testing cross-modal connections
7.5 Ideation
7.5.1 Concept development & methods
7.6 Video prototyping
7.6.1 Concept 1 - The Color of Smell
7.6.2 Concept 2 - The Smell Diary
7.6.3 Concept 3 - InsideOut
7.6.4 Concept 4 - CrosssDating
7.6.4 Ideation on the concepts
7.7 Workshops
7.7.1 Workshop 1: Color-smell mapping
7.7.2 Workshop 2: Smell-Brush & Interaction
7.8 Final concept
7.9 Final prototype
7.9.1 Context

8. Reflection

9. Discussion & Conclusion

10. Perspectives
1. Abstract

In this thesis the usage of smell as a medium enhancing synesthetic perception is discussed. Common cross-sensory connections and their relevance for interaction design are examined. The research is based on discoveries made in psychology, cognitive science and philosophy. Smell usage in a cross-modal context is believed to enhance engagement and enrichen the interactive experience. In several experiments a correlation between the perception of color shape and smell could be detected. An approach to include synesthetic mappings in interaction design is introduced, analyzed and discussed. Finally, the cross-modal interactive art installation “The Color of Smell” is presented.

2. Introduction

From the late 1950s to the late 1970s, the Digital Revolution has brought a change from mechanical and electronic technology to digital technology. One result was a loss of sensory qualities in products and newly developed multimedia applications which were mainly designed for visual and acoustic perception (Haverkamp, 2013) and led to overuse of these two modalities. Accordingly, designers became increasingly interested in haptic and tactile interaction interfaces (Ripener 2010 as cited in Emsenhuber, 2011). In the early 1990s, Durrell Bishop developed an answering machine that is considered to be one of the first Tangible User Interfaces. Even today, communication channels are mainly designed for the perception of sight, hearing and touch. Psychological investigations, however, show that “cognitive mechanisms have evolved for and are tuned to, processing multisensory signals.” Therefore, “unisensory processing is often suboptimal since it would correspond to an artificial mode of processing that does not use the perceptual machinery to its fullest potential” (Shams & Seitz, 2008, p. 5).

To reestablish a more natural mode of interacting with products and machines, marketing expert Michael Haverkamp views design as “a holistic task involving perception with all senses in all areas” in his book: “Synesthetic Design: A handbook for a multisensory approach” (Haverkamp, 2013, p. 413).

However, adding alternative modalities to the already existing ones needs to be handled with care to avoid sensory overload of information. Haverkamp suggests a synesthetic approach to design. According to him, Synesthetic Design “enables a maximum of multisensory perception to be offered with a minimum of stimuli input and information that needs to be processed”(Haverkamp, 2013, p. 430). For the creation of Synesthetic Design, he suggests strategies that enhance connections between the modalities (Haverkamp, 2013). The use of cross-sensory connections could thus allow for design that addresses the full potential of the perceptual machinery without producing a sensory overload.

The two modalities not yet commonly included in multi-media communication are taste (the gustatory sense) and smell (the olfactory sense)(Emsenhuber, 2011). The olfactory sense, specifically, is an interesting modality to work with due to its high definition. In comparison to
taste, which is divided into four primary categories, humans are able to distinguish between at least 1 trillion distinctly different smells (Bushdid, C., Magnasco, M. O., Vosshall, L. B. & Keller, A. as cited in Morrison, 2014). This is significantly more than was previously believed by researchers. This new discovery points to how little we still know about smell, as well as to the great potential for further exploration in this area.

Figure 1: How software sees us; shows the dominance of the visual, acoustic and tactile domain in digital technology

3. Research Questions

i. How can smell strengthen the perceptual ability to create cross-sensory connections?

ii. How can a synesthetic approach to design be included in interactions?

iii. How does a synesthetic design affect the interactive experience?
4. Theory

4.1 The potential of smell: Psychological and physiological properties

Due to the physiological position and the connections of the olfactory center to other brain areas, smell is hypothesized to be a valuable alternative interaction modality with respect to a cross-sensory approach.

The olfactory center, the bulbus olfactorius, and the limbic system, which is responsible for emotions, instincts and memories, are closely linked. Smell takes a unique route through the brain and affects one differently than other sensual stimuli. Especially in comparison to sight and hearing, the connection of olfactory receptors to the cerebrum is direct and avoids some intermediate steps in processing the signals (Haverkamp, 2013). In fact, smell often influences people's actions unconsciously as they are just being articulated on a conscious level (Amerongen, Vries, & Vroon, 1994). Smell bypasses the linguistic center in the brain. Eventually, though, smell information has to pass through the thalamus, the part of the brain that processes all sensory stimuli for conscious perception (Wicht, 2011).

![Figure 2: Simplified model of the cognitive process in the brain according to the processing of a visual, acoustic and olfactory stimuli (figure created by author)](image)

4.2 Olfactory communication in HCI

Smell can transmit information and is thus media – theoretically definable as a medium (Emsenhuber, 2011). The Shannon-Weaver Model examines olfactory communication in a Human Computer Interaction (HCI) context. Based on this model, the olfactory medium can be defined as a sender-receiver-based communication system. “According to Shannon’s information theory air would be the medium and odor the message” (Emsenhuber, 2011, p. 55). The author claims that “each message needs a syntax, semantic and pragmatic” (Emsenhuber, 2011, p. 55). Smell as a medium transmits information that needs to be decoded by the receiver according to the cultural background and individual experiences (Emsenhuber,
2011). However, it remains difficult to use smell as a distinct medium for communication because a common language does not exist and smell perception differs greatly across culture. Nevertheless, cultural differences aside, smell does play an important role in the environment.

The potential of smell interaction can be clarified with regard to the three interaction zones in HCI. Each zone is cut to address interaction with another modality. The first, defined as the interaction zone, requires physical interaction between system and user where information exchanges occur mainly on haptic and tactile interfaces. The second, the notification zone transfers visual information. Thirdly, when visual cues can no longer reach the user, acoustic and olfactory information can still be perceived: this zone of interaction is called the ambient zone and is the broadest of the three zones (Emsenhuber, 2011). Bernadette Emsenhuber allocates a particular importance to the role of smell within this zone in her article “The Olfactory Medium: Smell in Human-Computer Interaction.” She states: “...Smell can invisibly and spontaneously transmit information, which other media cannot” (Emsenhuber, 2011, p. 55). As transparent, emotionally-charged information carriers, the olfactory stimuli reach the recipient unconsciously but in a definite form.

![Shannon-Weaver Model for olfactory communication](image1)

**Figure 3: Shannon-Weaver Model for olfactory communication**

![Interaction zones in HCI (figure created by author according to Emsenhuber)](image2)

**Figure 4: Interaction zones in HCI (figure created by author according to Emsenhuber)**
4.3 The olfactory memory

Olfactory memory is another remarkable quality and a unique feature of smell. The ability of olfactory stimuli to trigger vivid memories is commonly known as the Proust Effect. Multiple experiments confirm this phenomenon by showing the effect of smell on highly emotionally-charged memories. Despite this, identifying the names of even familiar smelling odors remains difficult for most people (Chain, W.S. (1979) as cited in Gilbert, Martin, & E. Kemp, 1996). Lawless & Engen established the commonly used term tip-of-the-nose phenomenon to describe this difficulty of accessing semantic labels for odors (Gilbert, Martin, & E. Kemp, 1996). Smell memories are consequently not directly linked to their source, but rather to an emotional memory of the past. The difficulty of semantic labeling of olfactory stimuli is due to the fact that a major portion of the processing occurs within the limbic system. That makes smell particularly appropriate for binding associations. However, "the perception of smell is significantly influenced by associations of other sensory modalities” (Haverkamp, 2013, p. 90). Thus, "the olfactory system can easily be conditioned; in other words, it can be based on associative connections and evaluations” (Haverkamp, 2013, p. 90). All these aspects are essential to the recognition and immediate influence of perceived smells and thus are of specific interest for cross-sensory connections of olfactory stimuli (Haverkamp, 2013). (Cross-sensory connections are explained more thoroughly in the next part of this chapter). Smell, therefore, is expected to be a valuable medium in a multi-modal context.

4.4 Smell in a cross-modal context

Several studies have investigated the correlation between smell and other sensory stimuli. Gilbert & Kemp have explored the color of smell and found that “appropriate colors increase and inappropriate colors reduce the accuracy of odor identification” (Gilbert, Martin, & E. Kemp, 1996, p. 336). The authors suggest that color-odor links are based on cross-modal correspondences rather than on the phenomenon of synesthesia (Gilbert, Martin, & E. Kemp, 1996) that is explained in the next part of this chapter. Cross-modal interactions between olfaction and touch have been studied at the University of Oxford by Dematte et al. An influence of odor on the tactile perception of fabric softness was detected (Dematte, Sanabria, Sugarmen, & Spence, 2006). The team identified three main reasons for correlation. One possible explanation can be found in an associative mechanism whereby our minds create expectations about the co-occurrence of tactile stimuli. Another explanation might be the linkage of two stimuli by common features. Judgment could be biased by smelling a pleasant odor resulting in a soft tactile feeling and a pleasant experience. Dematte et al. suggest this “multisensory correspondence may derive from our everyday experience of intensely odorized household products that may create an association between pleasant odor = better product (i.e. most effective, softest, and cleanest)” (Dematte, Sanabria, Sugarmen, & Spence, 2006, p. 4). This suggestion assumes that such cross-modal correlations rely on previous experiences, rectius memories delivered through smell as we have seen in the previous part of this chapter. The third possible explanation for the identified linkage is a cross-modal perception taking place on a perceptual level such as the one described by Allen & Schwartz back in 1940 (Dematte, Sanabria, Sugarmen, & Spence, 2006). These two psychologists stated that the complete sensory apparatus
should be regarded as a unit that affects and influences other organs through several “aspects of its complete and complex function” (Allan & Schwartz, 1940, p. 121). This echoes Gestalt psychology “in which sensory presentations are not to be regarded as narrowly restricted phenomena of individual organs, but as perceptual patterns where now one and then another sensation predominates above the rest” (Allan & Schwartz, 1940, p. 121).

4.5 Synesthetic Design – a cross-sensory approach

“The whole is other than the sum of the parts”
- Kurt Koffka

In this part of the chapter, Synesthetic Design will be discussed: the term and its use, cross-sensory connections and their effects on human perception, and possible benefits to interaction design.

“The term synesthesia derives from the Greek word syn (together) and aisthesis (sensation)” (Haverkamp, 2013, p. 13), which explains the essence of its meaning. However, the term is used in distinctly different contexts by different authors. The word synesthesia is generally used to describe the neurological phenomenon in which stimulation of one sensory pathway leads to automatic, involuntary experiences in a second sensory pathway (Cytowic, 2002). This condition is common in relatively few human subjects. Richard Cytowic established the name genuine synesthesia to distinguish this biological condition from the use of the word synesthetic in other contexts.

The French phenomenologist Maurice Merleau-Ponty concludes his theory of perception with the claim that “synesthetic perception is (…) the rule” (Merleau-Ponty 1945 as cited in Haverkamp, 2013, p. 15), which indicates that, unlike others, he does not distinguish between all possible forms of cross-sensory connections (Haverkamp, 2013). On the other hand, Michael Haverkamp postulates a strict separation of genuine synesthesia from the common phenomenon of cross-sensory perception in his book “Synesthetic Design.” Both Haverkamp and Merleau-Ponty recognize the common ability in humans to establish connections between the senses. Likewise, psychologists Radar & Tellegen have reported certain synesthetic abilities to be continuously apparent in the population (Gilbert, Martin, & E. Kemp, 1996). Haverkamp, however, extends this theory by distinguishing between various mechanisms of cross-sensory connection within the perceptual system (Haverkamp, 2013). He suggests a systematic approach to Synesthetic Design based upon the different mechanisms of cross-sensory connections (Haverkamp, 2013).
The term cross-sensory perception does aim towards a synesthetic experience, but not towards genuine synesthesia as formulated by Cytowic. In fact, lines can be drawn between the cross-sensory perception which is experienced by a plurality of people and the elusive genuine synesthesia. “Although experienced as a unitary whole, synesthesia is composed of two interrelated components” (Grossenbacher & Lovelace, 2001, p. 36). Grossenbacher and Lovelace use the terms inducer and concurrent to refer to the inducing event and the synthetically induced sensory attribute(s), respectively” (Grossenbacher & Lovelace, 2001, p. 36). The inducer is a sensory stimulus and the concurrent is its respective association.

According to Grossenbacher and Lovelace, two types of synesthesia differentiated by sensory or conceptual inducers exist: “In synesthetic perception, concurrents are induced by perceiving particular sensory stimuli. In synesthetic conception, concurrents are induced by thinking about particular concepts” (Grossenbacher & Lovelace, 2001, p. 36). According to Grossenbacher et al., in synesthetic perception the primary perception and the secondary one, i.e. synesthetic perception, are sensory. An example of this kind of synesthetic perception could be a sound that triggers a secondary visual perception. However, this traditional notion of sensory-to-sensory synesthesia appears to be unsatisfactory for other forms of synesthesia (Ward and Simner, 2003; Ward, 2004; Simner, 2007; Nikolic et al., 2011; Mroczko-Wasowicz and Werning, 2012 as cited in Mroczko-Wasowicz & Nikolic, 2014). Therefore, many researchers suggest “(...) that a full account of the phenomenon should go beyond the standard sensory-sensory approach” (e.g., Dixon et al., 2000, 2006; Simner and Ward, 2006; Ward et al., 2006; Ward and Sagiv, 2007; Sagiv et al., 2011; Eagleman, 2012; Jürgens and Nikolic, 2012, 2014; Simner, 2012; Watson et al., 2012a, 2014; Mroczko-Wasowicz and Nikolic, 2013; Chiou and Rich, 2014; Brogaard, 2014; Brogaard et al., 2014 as cited in Mroczko-Wasowicz & Nikolic, 2014, p. 1). Grossenbacher & Lovelace indicate synesthetic conception as the second form of synesthetic perception. They mention the time period - location model as an example. Here “periods of time are conceptualized in a spatial layout” (Guilford, J.P. (1926), Galton (1880) as cited in Grossenbacher & Lovelace, 2001, p. 38), which means that the primary perception is of semantic or conceptual nature and the secondary perception is sensory. In this case, one example is the colored perception of a weekday or a month. Comparably, the inducer "A" can lead to the same sensory perception even if represented in different physical shapes, as, for example, the capital letter “A” or the lower case “a” or the different typographic outings in which the letter "A" can be expressed (Mroczko-Wasowicz & Nikolic, 2014). Depending on the respective inducer, sensory or conceptual, Ramachandran & Hubbard (2001) suggest categorizing synesthetes into two main groups, lower and higher (Mroczko-Wasowicz & Nikolic, 2014). “These two levels are often referred to as perceptual and conceptual (or cognitive), respectively” (Ward and Simner, 2003; Eagleman 2012; Simner, 2012; see also Evans, 1982 as cited in Mroczko-Wasowicz & Nikolic, 2014, p. 2), as also referred to by Allan & Schwarz (perceptual level) in Dematte et al. in the previous chapter. The categorization of lower and higher synesthetes relates to the occurrence of perceptual and conceptual perception, respectively. This labeling derives from the typical assumption of perception happening at an earlier and hence, more rudimentary stage of information processing than the activation and processing of semantic information which requires high-level cognitive representations (Mroczko-Wasowicz & Nikolic, 2014). This form of synesthesia requires knowledge of the meaning of the stimulus and is thus inevitably linked to a learning process.
This perspective on synesthesia is relatively new and has experienced a renewed interest in recent decades (Mroczko-Wasowicz & Nikolic, 2014). Danko Nikolic even goes so far as to propose that “synesthesia is exclusively a semantic induced phenomenon” (Nikolic 2009; Chiou and Rich, 2014 as cited in Mroczko-Wasowicz & Nikolic, 2014, p. 2) and hypothesizes that “synesthetic abilities are developed and modified by semantic mechanisms” (Mroczko-Wasowicz & Nikolic, 2014, p. 1). Mroczko-Wasowicz and Nikolic call it ideasthesia. As elaborated further in this thesis, the concept of ideasthesia is of great relevance for reassessing “the traditional distinction between perception and cognition assumed for a long time in philosophy, psychology and cognitive science” (Mroczko-Wasowicz and Werning, 2012; Mroczko-Wasowicz, 2013 as cited in Mroczko-Wasowicz & Nikolic, 2014, p.2).

As explained, a synesthetic perception can cover the same or different sensory modalities or even different domains as the cognitive, sensory and motor domains. On a conscious level, the resulting experience is typically phenomenally unified, “meaning that all the experiences at a given time are present simultaneously forming an overall phenomenal perspective – a single encompassing phenomenal state” (Mroczko-Wasowicz and Werning, 2012; Mroczko-Wasowicz, 2013 as cited in Mroczko-Wasowicz & Nikolic, 2014, p.2). Thus, synesthetic perception can be seen as a “subsuming state that has a joint phenomenal content” (Shoemaker, 1996, 2003; Bayne and Chalmers, 2003; Tye, 2003; Brook and Raymount, 2013 as cited in Mroczko-Wasowicz & Nikolic, 2014, p.2). Furthermore, all the experiences at a given time are closely linked with the perspective of the self and “consequently a person’s perceptual and cognitive states result in a synchronic phenomenal unity” (Raymont and Brook, 2009; Bayne, 2010; Mroczko-Wasowicz, 2013 as cited Mroczko-Wasowicz & Nikolic, 2014, p.2).

4.5.2 Embodied Cognition in the context of synesthetic perception

This incorporation of the perspective of self in the phenomenal unity resulting from synesthesia echoes Husserl’s transcendental phenomenology. Indeed, it recalls his theory of intentionality as expressed by the concept of noema and noesis, i.e. respectively the objects of our perception and the consciousness of our perception itself. “When I see a rabbit, I have not only recognized what I’m seeing as a rabbit, but what I’m doing as seeing it (as opposed to imagining or remembering it)” (Dourish, 2004, p. 105). However, at the same time, synesthesia overcomes the German philosopher’s dualism between the objects of perception and the acts of perception. As opposed to the division between noema and noesis posited by Husserl, synesthesia represents a subsuming phenomenon directly comprehensive both of the objects of our perception and of, to a certain extent, our mental experiences of these objects.

In addition, synesthesia highlights the nature of the two processes that occur within our interactions: the acquisition of stimuli through our senses and the classification of these inputs operated by our mind. Indeed, synesthesia challenges the traditional belief that classifying the stimuli is consequential to and occurs after their acquisition by hinting at the simultaneous nature of these two processes. In fact, our sensory perceptions are shaped by our conceptual
understanding of the world and the two aforementioned processes are so interconnected that one cannot exist without the other. “Without a preexisting network of interrelated and distinct concepts, our sensory experience of the world would be an undifferentiated mass other than the distinct objects we actually apprehended” (Nikolic, 2014, nenatv, sec. 4:53 - 5:03). This model, if proven true (e.g. if neuroscientists succeed in the task of uncovering this pre-existing conceptual network), would deeply affect the age long mind-body problem and could lead to rethinking the way we consider ourselves and our relationship to the world around us. Because of these implications, the characteristics of genuine synesthesia are also of interest in the context of cross-sensory perception – common throughout the population.

In conclusion, synesthetic perception can be divided into distinct forms. Haverkamp introduces a model in which he differentiates between six forms of cross-sensory connections. In the following part of this chapter, three of these connections are explained more thoroughly. The cross-modal analogy, as referred to by Haverkamp, relates to the perceptual or sensory perception as mentioned by Mroczko-Wasowicz & Nikolic, or the synesthetic perception, as Grossenbacher and Lovelace call it. Synesthetic conception (Grossenbacher & Lovelace) or conceptual perception (Mroczko-Wasowicz & Nikolic) relate to the mechanisms of associative connections introduced by Haverkamp. Mroczko-Wasowicz & Nikolic, as well as Haverkamp, regard cross-domain experiences as a general rule that should be applied also to non-synesthetic practices. “If this premise is accepted, synesthesia may be understood as utilizing mechanisms similar to those present in ordinary perception and imagery” (Ward et al., 2007 as cited in (Mroczko-Wasowicz & Nikolic, 2014, p. 9).

4.6 Cross-sensory connections for the creation of Synesthetic Design

Synesthetic Design can be achieved through the systematic connection of modalities addressing the “broad repertory of interconnecting sensory channels” that every person has at their disposal (Haverkamp, 2013, p. 139). Three different types of cross-sensory, or cross-modal, connections are brought forward.

Haverkamp indicates three connections as intuitive connections: the cross-modal analogy, the iconic connection (which is a concrete association), and the symbolic connection (Haverkamp, 2013). According to him, these interconnections are significant for the creation of an intuitive design that is easy to interpret and use, and thereby acquires a high user acceptance (Haverkamp, 2013). The cross-modal analogy and the iconic coupling are both, by definition, spontaneous and context dependent (Haverkamp, 2013), which means that perception is relative. The roughness of an object is not absolute, for example, but is perceived in relation to other rough structures or to the surrounding environment. Evidence for the differentiation between these connections can be found in phenomenological observations and in brain research.
4. 6. 1 Cross-modal analogy

The term analogy is commonly used to describe similarities and correlations appearing between two subjects and evaluating them for identification. The cross-sensory mechanism of a cross-modal analogy aims towards a synesthetic perception. It describes the ability of each person to detect correlations between the properties of different sensorial stimuli. In this way, various sensorial stimuli are associated by common attributes such as intensity, volume, brightness, density, roughness and sharpness, and by spatial qualities such as localization, expansion, depth and synchrony. These common attributes are accordingly assigned to a certain object. Unlike in genuine synesthesia, these connections are systematic and quantifiable (Haverkamp, 2013). Cross-modal analogies allow concrete associations to be created. This happens when the cross-modal analogy is established within the perceptual system (Haverkamp, 2013). By using the example of synchrony, this process can be explained. Two different sensory stimuli that are always perceived synchronous to each other – light and sound in the case of a siren – are likely to be coupled and associatively recognized together, even if only one of the stimuli is perceived.

4. 6. 2 Concrete association – Iconic connection

The cross-sensory mechanism of iconic connections is built upon associative information. Associations overlapping several modalities usually arise when elements have frequently been perceived together or when they show similarities in characteristic features. This can be the outcome of the learning process as stated by Mroczko-Wasowicz & Nikolic: “education and acquiring knowledge about the surrounding world should in some instances give rise to synesthetic associations” (Mroczko-Wasowicz & Nikolic, 2014, p. 8). Accordingly, iconic connections derive from previous perceptual experiences that are collected in the memory. Thereby, an index within the perceptual system is created in which references concerning a particular object are stored (Haverkamp, 2013, p. 210). “This form of coupling functions happens only in the case of known objects. For example, the recognition of a known scent instinctively leads to visualization of the source of stimulation” (Haverkamp, 2013, p. 210).
4. 6. 3 Symbolic connections

Symbolic connections are another form of conceptual perception which Haverkamp differentiates from iconic connections. Symbolic connections involve semantics of higher order as referred to by Barbara Flückinger (Haverkamp, 2013). Symbolic connections can only be identified when a certain code is initially learned, so the symbolic content implies knowledge of the meaning (Haverkamp, 2013). Here Haverkamp draws the same conclusions as Mroczko-Wasowicz and Nikolic.

4. 7 The benefits of Synesthetic Design

Lessons learned from synesthesia may be extended to the "ordinary world" of perception and help us develop an integrative approach to design (Mroczko-Wasowicz & Nikolic, 2014). However, it is not yet common practice to design for the whole range of human sensory capabilities. Designers still focus on designing for the senses of sight and hearing, and increasingly touch.

In his "Media Theory," Marshall McLuhan examines the effect of hot and cold media on human perception. In the context of communication, McLuhan claims that the domination of one sense leads to the torpidity or even the amputation of the remaining senses (Mulder, 2010). He calls media that enhance one single sense hot media. Cold media, on the other hand, dampen a single sense and thereby demand greater involvement of the other senses (Mulder, 2010). Here a connection can be drawn to Haverkamp's synesthetic approach to design mentioned earlier: "... Synesthetic Design enables a maximum of multisensory perception to be offered with a minimum of stimuli input and information that needs to be processed" (Haverkamp, 2013, p. 430). By expanding the use of sensory aspects – from vision, hearing and touch to the senses of smell and taste – the quality of experience can be altered and possibly improved. Visual stimuli are being processed in the part of the brain that is closely connected to the broca-areal, the language center. Therefore, visual media are generally warmer media than media that render information in a non-visual manner. In neurophysiological terms, it can be said that non-visual stimuli demand a higher degree of imaginativeness and involvement to achieve a conscious reaction. Through the stimulation of this inner process, information might be absorbed more thoroughly, thereby enriching an interaction.
However, a synesthetic approach does not only enhance a mental process. Frank Allen and Manuel Schwartz ascertained that “Impassioned emotional states have widespread physical effects” (Allan & Schwartz, 1940, p. 118). In 1940, they explored “The effect of stimulation of the senses of vision, hearing, taste and smell upon the sensibility of the organ of vision” and found evidence that “all sense organs are so interrelated that stimulation of any one of them influences all others either by enhancing or depressing their responsiveness” (Allan & Schwartz, 1940, p. 118). Since then, the evidence that synesthesia is a global phenomenon has expanded (Hänggi et al., 2011; Hupe et al., 2012 as cited in Mroczko-Wasowicz & Nikolic, 2014), “and so did the support for the arguments that synesthesia relates to high-level cognitive functions and abilities, including memory and creativity” (Rothen and Meier, 2010; Rothen et al., 2012; Mulvenna, 2013; Meier, 2013 as cited in Mroczko-Wasowicz & Nikolic, 2014, p.8).

In conclusion, it is expected that the enhancement of synesthetic qualities in an interaction leads to an increased mental and physical engagement and can serve as a mechanism to accelerate mental operations with cognitively demanding, abstract contents (Mroczko-Wasowicz & Nikolic, 2014). In this way, the interaction becomes more intuitive and takes the user experience to a higher level.
5. Related work - relevant examples

Synesthesia and cross-modal perception have been broadly studied in cognitive science and experimental psychology. However, design itself possesses cross-sensory perspectives. This chapter presents an overview of relevant design examples. The selected examples vary from artistic expressions to a more traditional HCI approach. All have influenced the resulting design project.

5.1 Lexus - Journey through the Senses

Philippe Nigro, Milan Design Week 2015

Lexus’ installation *Journey through the Senses*, exhibited during the Milan Design Week 2015, has been an inspiring piece of work. In this installation, the multi-sensory experience of driving a car is taken a step further. *Journey through the Senses* was awarded the MilanoDesignAward for the category Best Entertaining and embodies the brand’s emphasis on senses and its focus on a pleasurable, sensory-filled driving experience. The installation was composed of several rooms through which the visitor was guided. In every room, a new experience was created. Those experiences were inspired by moments felt when driving a Lexus car. In one room, the visitor could become part of the designer’s interpretation of the experience of driving through rain. This multi-sensory experience consisted of vision (a light projection on the wall reminiscent of raindrops running down a window) of sound (drops hitting a surface), and of touch (sparkling candy that created a feeling of rain on one’s tongue inside the body). This use of sensual modalities created a holistic experience for the visitor. In another room, the visitor received a bowl of warm soup while standing in the dark and looking down on a light projection showing planet earth. The familiar taste of broth, a component of many cultures’ cuisines, in combination with the dark space and the projection of earth, gave a feeling of warm hospitality. Philippe Nigro, the designer, used synesthetic design to create an intimate and emotional experience for the visitor. He translated his experience from one context into another through the use of associations. This installation reveals the affect that multi-sensory design can have on the perceptual experience and provides the initial motivation for the choice of topic explored in this thesis.

![Figure 6: components of the installation “Journey through the senses”](image-url)
5.2 Odor Emoticon, Olfacticon: An Olfactory Application that Conveys Emotions

Lingyun Sun; Wei Xiang; Shi Chen, Zhejiang University, 2014
Shiwei Cheng, Zhejiang University of Technology, 2014
V. Michael Bove, MIT, 2014

Olfacticons are an olfactory extension of commonly used graphical emoticons. Sun et al. explore the linkages being made between emotions and odors and place them in the context of modern communication systems. Sun et al. discovered that connections between odors and emotions were bases in 80% of the cases on the features of odors (Sun, Xiang, Chen, Cheng, & Bove, 2016). This is an indication of connections being made on a perceptual level, namely that the features of the odors evoke a particular feeling. On the other hand, these connections could also be associative and made on the basis of personal experience. The sweet odor called birthday cake was chosen to represent gratitude. A reason for this associative connection could be the fact that positive events are often celebrated with cake.

The experiments which provided ground for the development of the Olfacticons have influenced and guided the design process of this thesis.

5.3 The Sound of Touch

David Merrill and Hayes Raffle, MIT Media Laboratory, 2007

"The Sound of Touch", a spatial installation, consists of an instrument called the wand, and a texture kit. The wand enables the real-time recording and the physical stimulation of sound, and the playback by banging it against physical objects. The texture kit consists of a variety of physical objects with varying shapes and textures. "The purpose of the kit is to enable convenient experimentation stimulating a stored sample with a wide range of physical textures." (Merrill & Raffle, 2007, p. 1). Electronic sound synthesis and digital music are replacing the rich physical aspects of manipulating musical sound that are common with traditional instruments like blowing, bowing, striking, picking, plucking and fretting. With "The Sound
of Touch”, Merrill and Hayes bring back these naturally affordances into electronic music by cross-coupling properties of interaction with physical objects (Merrill & Raffle, 2007).

“The Sound of Touch” has served as an inspiration for the design project based on this thesis. The cross-coupling of the modalities of color and visual patterns and smell are the focus of “The Color of Smell” project. Furthermore, the explorative setting of “The Sound of Touch” has influenced the physical expression of “The Color of Smell”.

5.4 I/O Brush: Drawing with Everyday Objects as Ink
Kimiko Ryokai, Stefan Marti and Hiroshi Ishii, MIT Media Laboratory, 2004

The I/O Brush, in combination with The Sound of Touch, has served as the main inspiration and footing for the design project of this thesis.

The I/O brush is an interactive drawing tool that enables one to pick up colors and structures of objects and then draw with them on a smart surface. The I/O brush originally targets kindergarten age children and animates them to test the elements and principles of design. The brush permits the user to create a personal color-texture palette. Thereby, as desired by the designers, children are urged to explore their environment and ultimately develop new skills. The design concept is based on aspects linking traditional drawing and painting methods with modern technological possibilities. Traditional drawing tools, like the fountain pen, had a pick up and a release function. This no longer exists in most pens used nowadays, but is brought back by the I/O Brush which functions as an input and output device. In traditional painting practice, it was common for artists to search for colors and patterns in nature. This element of artistic discovery and environmental awareness is also being brought back with the I/O Brush.

The properties of the I/O Brush could be extended to other modalities. Ryokai et al. suggest further investigations into the idea of a synesthctic drawing tool (Ryokai, Marti, & Ishii, 2004). Such a drawing tool would be based on cross-sensory connections. The I/O Brush has, therefore, served as a direct inspiration for the "Smell-Brush" introduced in the design project resulting from this thesis.
Figure 9: The I/O Brush
6. Methods

In this chapter the methods used throughout the design process will be introduced.

6.1 Research Through Design

Research Through Design (RtD) is the chosen method guiding the design process described in this thesis.

William Gaver describes the RtD approach as a “design practice” whose ultimate goal can be seen in the designer’s manifestation of “possibilities and problems” through the creation of topical and theoretical design (Gaver, 2012, p. 937). “Design researchers often borrow conceptual perspectives from other disciplines and discuss their applicability for design” (Gaver, 2012, p. 938). Research conducted in the field of cognitive science and experimental psychology provides a ground for this thesis’ research and is ultimately placed in an interaction design context. Four main criteria need to be taken into consideration to place RtD in an interaction design context. First, the thorough and detailed documentation of the design process and research is considered to be an important criterion. Second, the research and the design have to “constitute a significant invention” (Zimmerman, Forlizzi, & Everson, 2007, p. 7). Third, a RtD should be of relevance for the design community and thus should offer a product or a vision on design which “transforms the world from its current state to a preferred state” (Zimmerman, Forlizzi, & Everson, 2007, p. 1). Fourth, the design process has to be documented in a manner that allows for future reproduction. Everson et al call this extensibility.

This thesis’ research was guided by the principles of RtD. This can be seen in the critical examination of the use of senses in design, the constant reframing of the problem, and the potential to build upon and expand the project in future research.

6.2 Co-Design

Co-design can be seen as a prototypical practice (Björgvinsson, 2008) in which design opportunities regarding future (computer) systems are explored in close collaboration with the people who are destined to use them (Schuler & Namioka, 1993). By including potential user into the design process, a human-centered design is facilitated. One premise for the successful conduction of this method is the willingness of people to participate in the creative process under the conditions provided by the design team (Sanders and Stappers 2008 as cited in Mitchell, Ross, May, Sims, & Parker, 2015). Workshops are a common co-designing practice. Usually a specific target group is invited to share ideas and build upon these shared ideas. In this context, Ellen Bravo stresses that the difference between making suggestions and making decisions needs to be clarified in order to prevent disaccord between the designer, the participant and the stakeholder involved (Bravo, 1993). Ideally, participants are provided with materials to physically express their ideas or to easily express them verbally.

Throughout this research process, co-design has been a valuable method to generate ideas and get new insights. Two workshops have been conducted. The workshops have bridged theory and practice.
6.3 Prototyping

“Prototypes provide the means for examining design problems and evaluating solution” (Houde & Hill, 1997, p. 1). The essence of a prototype is the representation of a design idea. Houde & Hill suggest a modal to differentiate the various aspects of a prototype to select focus on the different functions tested. The modal has three dimensions that are given equal weight and which are arranged in a triangle. These dimensions are the role, the look and feel, and the implementation. The role of the prototype tests and explores the function of the new design in a user’s life. The look & feel tests the sensory experience that will be provided to the future user. The implementation explores the technical issues posed by the prototype. This model helps one decide, before building the prototype, what design questions need to be answered. This provides a focus of exploration. In the design project resulting from this thesis, prototyping has functioned as a means to explore and explain different aspects of the design idea.

![Houde & Hill’s model for prototyping](image)

6.3.1 The Wizard of Oz

The Wizard of Oz technique has been a valuable method during the testing phase of the final prototype.

The Wizard of Oz prototyping or user-testing technique refers to the children’s story “The Wonderful Wizard of Oz”. The technique enables the exploration of interaction with low-fidelity prototypes. By manually imitating a not-yet-digitally-implemented function of the future design, the test subject is being tricked to believe the tested system is working independently. Here a line can be drawn to the children’s story, “So, the reality behind this great and terrible wizard was a timid little man who was so convincing in his ruse that everyone hand thought he was something that he was not” (Buxton, 2007, p. 237). The prototypes, similar to the timid little man in the story let the user think to be something that they actually are not (yet) (Buxton, 2007). In this way, prototypes can be tested in an early stage of the design process. According to the results, the prototype can be altered and further developed.
6.3.2 Rapid video prototyping

In this research the method of video prototyping has been crucial for the initial exploration of the design concepts.

Mackay et al. refer to the exploration of design ideas as video prototyping and to the generation of ideas through video as video brainstorming (Mackay, Ratzer, & Janecek, 2000). The use of video prototypes throughout the design process can facilitate mediation between design activities and “manage the tension between qualitative details and design abstractions” (Mackay, Ratzer, & Janecek, 2000, p. 72). Video prototyping is a helpful method to demonstrate and iterate design concepts in the explorative phase of the design process.
7. Design Project & Process

The design project upon which this thesis is based explores different aspects of cross-sensory connections in an interaction design context. In the conducted experiments, the cross-sensory connections function as a constant in various settings.

7.1 Smell-Training

Participation in a smell-training activity related to the research project "Nosewise": A video game platform for smell-based brain training, conducted in collaboration between Malmö University and Stockholm University, initiated the design process. During smell-training, a range of aromas belonging to the game Nez-du-vin have been successively smelled by the participants of the activity. Then, the participants had to guess the name of the aroma. Each participant talked about associations and memories evoked by the smell. Similar associations were made, often affected by the participants' previous experience, e.g. the memory of a specific candy available in the 90's in the Netherlands or a frequent vacation in the Alps during childhood. The descriptions of the aromas' features were also inspirational aspects for the progression of the design process of this thesis. The initial smell-training activity has developed into a weekly workshop.

![Figure 11: Smell-training workshop](image)

7.2 Brief Experiment

In a first brief experiment, people's reaction on the topic of synesthetic perception (cross-sensory connections) was tested.

The brief experiment had the aim to explore the effect of auditory cues upon associative abilities. The song "Brothers in Arms" by the band "Dire Straits" was presented to individuals. The song was chosen because it was found to be a classic and still enjoys popularity, but is not a recent hit and is, therefore, presumably not listened to on a daily basis. Furthermore, due to its 30-year popularity, it might trigger memories and associations stored in long-term memory.
The participants, individually, had to listen to the song and afterwards were asked to associate the song as a whole – melody and vocals – with a color, a temperature and a smell. The participant was exposed to auditory cues and was expected to use words as an answer, rather than being able to choose from a range of colors, smells or temperatures.

Participants reacted very differently to this task. A main difference could to be detected among participants who imagined an atmosphere around the song, and accordingly constructed associations of color, temperature and smell. Another group of participants created associative connections more instinctively by answering quite directly and without the creation of a story and atmosphere. After investigating the participant’s choice, however, the associations could be explained. It was notable that this group’s associations were merely built upon features of the respective sensory cue.

7.3 Experiment 1: Testing smell associations

The following experiment was built upon the findings of the previous experiment. It was interesting how participants of the experiment were describing attributes of the song’s melody and other associations. However, there was difficulty in smell association without olfactory cues available. The following experiment added smells for the participants to inhale.

Setting:
In a room, five smells were presented to each participant. The smell containers were closed with a perforated piece of paper and labeled with numbers. No further visual cues were available. The smells were separately presented to the participant. A total of nine participants took part.

Procedure:
In this first experiment, the reaction of the participants to smell was tested. The participant was given one of the smell containers and asked to smell it. Simultaneously, participants were asked four questions investigating different aspects. The first question concerned general associative connections. The second questions aimed at memories and emotion triggered by the smell cue. For the third question, the participant was asked to describe the attributes of the smell in words. The third question overlapped with the fourth question which concerned the cross-modal connection between color and smell. The last two questions entered the domain of synesthetic perception and cross-sensory connections on a perceptual level. The first two questions aimed more at connections at the conceptual level.

Aims:
The aim of this experiment was to acquaint the test subjects with smells and to make them consciously think about the smells as well as the effect the smells had on them. A first attempt was made to familiarize the test-subjects with smell as an activator for a synesthetic experience and have them talk about it.
Findings:

Test subjects were open to the experiment. Question one took longer to answer than the following questions. One possible reason for this could be the open-ended nature of this question. Another explanation could be that some time was needed to get used to the smell and to consciously process it. Question two, related to memories and emotions, seemed to be harder to answer. Question three, regarding the attributes of the smell, was found to be easier to answer. Often attributes were already named in question one. Remarkable was the ease with which the smells were linked to a color as well as the similarity of the color-smell linkage among the test subjects.

Interesting relations and similarities of perception between the participants were identified. In particular, the color-smell linkage was the same, or very similar, in several cases.
7.4 Iteration & Experiment 2: Testing cross-modal connections

Building on the findings of the first experiment, a second experiment was created. This experiment was intended to explore the cross-sensory connections made in combination with smell. Due to the previous investigation in sound-smell combinations and color-smell combination, these modalities were also being chosen for the second experiment. Within the color-smell combinations, one extra visual attribute, namely 2D shape, was included.

Setting:
This time, 17 different smells were presented to the participants. The smell containers were covered with a perforated piece of paper and spread out on a table. The containers were labeled with numbers. No further visual cues were available. The first task was directed towards the sound-smell connection. A total of nine participants took place in this experiment.

Procedure:
Once again, the song “Brothers in Arms” was played to the participants while they were smelling the selection of smells. Then the participants were asked to select one smell they associated with the song.

In a second task, three photos of abstract paintings were shown to the participants. The participants were asked to link one smell to each picture.

Aim:
The aim of this experiment was to animate the test-subjects to consciously and actively make cross-sensory connections, with smell being one modality involved. The reaction and experience of the participants regarding the chosen connections was documented, analyzed and evaluated to further the design process.

Figure 13: Second experiment: Participants linking smells to the song “Brother’s in Arms” (left), a pre-selection of smells linked to pictures of abstract art (right)
Findings:
One finding from the comments of participants was that 17 smells were too much and had an overwhelming effect. Participants found it hard to choose between such a large number of smells while listening to the song and suggested that a smaller selection of smells would have eased the linkage and made it more elaborate.

Interestingly, decisions were made reasonably quickly. The test subjects were sure of their choices. The second task was found to be more interesting and the linkage could be explained better. The main reason for the cross-sensory linkage between picture (visual cue) and smell was based on color and shape. Often the participants wanted to select several smells for one picture, as they connected a different smell to the shape than to the color. In the end, participants were able to select one smell as representative for the picture.

In the sound-smell linkage task, it was interesting the ease with which the test subjects made a connection in comparison to the first intervention. While the participants of the interventions were asked to think of a smell and link it to the song, in the second experiment a smell was available and the connection could be made without linguistic involvement. That underlines the unique characteristic of smell bypassing the linguistic center in the process of perception.

Evaluation:
Test subjects were open to both experiments and did not face major difficulties creating connection between the modalities of smell and color and shape (photos) and smell and the song as a whole (melody and vocals). The second task, however, seemed to be more interesting, as the participants were able to more elaborately explain their choices. Therefore, color/shape-smell connections were taken into the ideation in the next stage of the design process.
Figure 14: Connections being made in second task of experiment 2

There is something that hits you first, it’s complex and simple at the same time. It’s a mix of things. The disgusting cafeteria smell has all things that are not matching but still being mixed together, similar as in the picture.

Olive oil smell gives me a calm feeling. The picture also has a calm atmosphere, a lot of empty spaces. I also associate olive oil smell with the colors in the picture, I could look at that picture forever and also smell that smell forever. It’s not a strong smell but very pleasing.

Figure 15: Participant’s explanation for the chosen connection during experiment 2, task 2
7.5 Ideation

Based on the findings of the experiments, a first ideation round was conducted. The research throughout the literature review and the experiments dealt mainly with synesthetic perception and cross-sensory connection distributed throughout the common population. Thus, the goal of the design project became to increase awareness of the existence of these connections and make them tangible and graspable for non-synesthetes.

This phase of the project started off with brainstorming, bodystorming, fast sketching and combining findings. Four main concepts were developed, focused on the presentation of color/shape-smell connections. During ideation, attempts were made to integrate color/shape-smell connection in functional interactions, but were put aside due to time constraints. This will be further explained in the perspective section of this thesis.

7.5.1 Concept development & methods

Four concepts emerged from the ideation phase. All concepts aim at making cross-sensory connections visible and tangible. Thereby, each concept can be placed in a slightly different context and explores different interfaces on which to display the cross-sensory connection. The method of rapid video prototyping was used to visualize and explained the concepts.

7.6 Video Prototypes

Four video prototypes have been developed and can be deemed as explorations furthering the design process.

The videos can be found on Vimeo. Links are provided underneath the respective concept.
7.6.1 Concept 1 - The Color of Smell

The concept “The Color of Smell” refers to the related work presented above.

In “The Color of Smell” smells can be tagged with a cross-modal color-shape connection. When pouring one of the tagged smells on top of a smart table surface, the respective colors and shapes appear and, similar to smell, slowly disappear. “The Color of Smell” explores a way to paint with smell, using common cross-modal connections. The smell-painter can manipulate the painting by controlling the amount of smell.

![Figure 16: “The Color of Smell” video prototype](https://vimeo.com/168084870)

7.6.2 Concept 2 – The Smell Diary

“The Smell Diary” builds upon the Proust Phenomenon mentioned earlier. This unique quality of smell, that of figuratively transporting us to different places and taking us on a journey, is mentioned by David Howes in “The Aesthetics of Mixing the Senses”. The smell diaries are jars which can be filled with a smell which is specifically linked to a memory. This idea strongly builds upon associative connections triggered by smell. By linking the smell to a color and other aspects of this memory, as for example sound samples, a multi-modal diary can be created. This diary might not contain the same level of detailed descriptions as is possible to attain with written words, but instead preserves the memory in the form of an emotional ambiance.

![Figure 17: “The Smell Diary” video prototype](https://vimeo.com/168084906)
7.6.3 Concept 3 – Inside Out

“Inside Out” is built upon the idea of using a smart t-shirt as an interface on which to display color-shape mappings deduced from perceived smells. As soon as the wearer of the t-shirt smells something in his environment that arises from a color-shape association, the t-shirt reacts by changing color and pattern accordingly. This synesthetic individual and creative process happening alone in the mind is brought into the public sphere and functions, thereby, as a means of self-expression.

Figure 18: “Inside Out” video prototype

Vimeo link: https://vimeo.com/168084928

7.6.4 Concept 4 - CrosssDating

“CrosssDating” relates to the idea of online dating platforms like Tinder. In CrosssDating, the future date mates are matched via similar cross-sensory connections appearing in them. The aspiring date-mate links smells to an abstract picture (color-shape combinations), similar to that described in Experiment 2 (exploring cross-modal connections). As soon as another person creates the same combination, the two are matched and receive each other’s contact details. Experiment 2 has provided evidence that linkages between smell and an abstract picture are based on associative connections and cross-modal analogies. The accomplished associations derive from memories which occur through influences from the world around us. Cross-modal analogies happen on a perceptual level and might therefore be a clue as to the sensorial qualities we seek in a mate. Those two connections in combination reveal our identity and make us who we are. Therefore, this is thought to be a richer way of partner selection.

Figure 19: “CrosssDating” video prototype

Vimeo link: https://vimeo.com/168084946
7.6.5 Iteration on concepts

In a second iteration one of the concepts presented in the videoprototypes was chosen to be further enhanced. The choice concerned the potential of the concept with regard to the modes of interaction and its possible applications in a use-context.

“The Color of Smell” was chosen to be developed into a final prototype.

7.7 Workshops

To advance the concept of “The Color of Smell”, two workshops exploring different aspects were conducted. Based on the findings of the earlier experiments the color/shape-smell connections were defined in a first workshop by actively letting the participants express their synesthetic experience with different materials. A second workshop was conducted at later stage in the setting of the final, physical prototype. In this workshop the physical interaction with aspects of the prototype was explored. The participants had the chance to built an artifact of interaction with different materials and use this artifact in the setting of the prototype as a whole – an installation.

7.7.1 Workshop 1 - Color-Smell Mapping

In this first workshop the findings of the experiments were elaborated further.

Setting:
Participants were presented four smells (lily, melon, cedar tree and vanilla) preserved in essential oils which were chosen to grant a comparable intensity of the smells. No distinct visual cues were available. Workshop participants were asked to smell one smell at a time and choose one or more representative colors out of a preselected range of colored pens. Additionally, the participants were asked to draw patterns or shapes characterizing the smell.
Findings & evaluation:
The findings of the first experiments were supported by the results of the workshop. Participants’ tendency to select the same colors and shapes according to the smells at hand were significant. The smell of lily, for example, was predominantly linked to a light blue in combination with a patrol green. However color selection was limited and color choice could therefore have been slightly different. Anyways, it can be stated that the colors linked to the smell of lily are within the blue-green color range, commonly referred to as cold colors. Likewise a similar conformity could be detected in shape linkages. Indeed, shapes-mappings created according to the smell of lily were mainly wavy and fluent.

Interviews conducted after the color-smell mapping activity confirmed that the chosen connections were primarily based upon features of the smell. This hints to the occurrence of a cross-modal analogy as introduced in chapter 4. However, associative connections were made too. In fact, in several cases the smell of melon was associated with a specific chewing gum popular in the 90s. Colors and shapes were chosen accordingly. The color pink was chosen for the smell of melon, which might be misleading. Certainly the majority of participants mistook the smell of melon for strawberry smell which might explain the color pink with regard to associative connections.

Figure 21: A selection of color-smell mappings created in workshop 2

- melon
- lily
- vanilla
- cedar wood
7.7.2 Workshop 2 – Smell Brush & Interaction

A second workshop was conducted in the setting of the quasi-finished prototype. In this setting the smells and the respective color-mappings were already chosen. This workshop was aimed at exploring interaction modes with the prototype. The first aspect of the workshop was the question on how a smell-brush could look like and how it would serve the function of transporting a smell to canvas. The second aspect was the interaction with the system as a whole.

Smell-brush development:
The participants were presented a table on which materials of different sorts were displayed. At the same time a range of ideas for the look & feel of a smell-brush were suggested. Participants were asked to evaluate the existing smell-brushes and, if desired, to add something or develop a new brush from the materials at hand or two draw their ideas on a piece of paper.

Interaction with the physical prototype:
In a second step, participants were asked to use their smell-brush or one of the prepared ones and interact with it in a prearranged space consisting in a table with a range of smells and a box with a surface on which color-smell mappings were projected (The box was aiming on representing a multi touch table top). Participants were asked to transport the smells with the brushes to the table and paint with them. The aim of this workshop was to find out how participants react on the idea of transporting smell and painting with it. Special focus was set on the body gestures of the test subjects and their ideas on how smell in form of color and shape would stick to the canvas.
Figure 24: Workshop 2: Bodystorming - a motion picture

YouTube link:
https://www.youtube.com/watch?v=jiDvISlREoo
Findings & evaluation:
All participants urged to work with an air-flow as one function for the brush. Additionally, the participants desired to have a range of brushes at hand to be able to regulate and manipulate the distribution of the smells. One request for the brush was a pick up function to be able to change and mix smells after they had been placed onto the canvas. Due to time constraints participants did not build their own brush but preferred to draw and explain their visions of a smell brush. To bodystorm the activity of smell-painting the already prepared brushes were being used and manipulated in different ways, with regard to the expressed ideas of the participants on how a smell-brush should function. The interaction in space delivered interesting insights. The participants were active in moving from the table with the smells to the canvas with the projections. One participant started mixing smells as if mixing colors. His body language reminded of the activity of multitasking in a kitchen environment. Interesting was the desire of participants wanting to smell the smells on the canvas to test if their smell combinations were fitting. Another participant took an empty glass container and imitated the notion of picking up smell from the table and mixing them in the glass container. Finally, he applied them back on the table. Yet another participant questioned the use of a flat screen to display the color-mappings. He wanted his smell paintings to look similar to sandcastles and emerge from the table.

7.8 Final concept

The final concept "The Color of Smell" can be categorized as an expressive tool that enables to paint with smell. "The Color of Smell" is set up as a spatial installation that consists of a selection of smells, synthetic and natural, a smell-brush and a multitouch table top. A smell-brush enables to pick up smells and transport them to the table top above which the smell can be released and distributed. The painting canvas is a table of standing height easy to act on. The size of the table is big enough to explore smell painting in its variety, but small enough to be in one's reach. In workshop 2, while exploring the mediation between smell and brush most participants pictured the smell to be a substance that descents (this could be due to the fact that the smells were presented in form of liquids, essential oils). From this perspective, the table top was found to be a good medium to sustain the smells or rather their respective color-mappings.

The smell-brush captures smell and distributes thus being a tool mediating between the two modalities, the olfactory and the visual. Additionally, the smell brush enables to regulate the distribution of the smells. According to the brush manipulation the smells are spread on the table top in form of color-mappings. The brush manipulation has effect on the intensity of the visual output and the direction in which the smell is guided. "The Color of Smell" is a means to visualize cross-sensory connection that happen in all people. Workshop 1: Color-smell mapping has been a base for the color-mappings that were developed digitally for the final prototype. By visualizing the cross-sensory connection between color/shape and smell these connections are taken out of a person's mind and become tangible and graspable. Hence, the smell-painting represents a picture of the perception happening within one's mind. "The Color of Smell" does not distinguish strictly between the sensory and conceptual perception, cross-modal analogy and associative connection respectively, as explained in chapter 4.
The color/shape-smell mappings were created upon a combination of these two forms synesthetic perception as in accordance with the findings of workshop 1: Color-smell mapping. The video prototype contains a second scenario. In this scenario smell-painting is conducted through the synesthetic mapping of real objects. The smell painter can pick up any object and create the respective color-composition. Objects with distinctive smells are especially interesting regarding this scenario. Ryokai, Marti and Ishii conclude their research paper about the “I/O Brush” with a similar suggestion for a synesthetic drawing tool mapping the smell of real world visual properties (Ryokai, Marti, & Ishii, 2004).

The goal of this design project was to raise awareness of synesthetic perception occurring commonly throughout the population. By categorizing “The Color of Smell” as an expressive tool its function remains wide and can be interpreted by its user.

7.9 Final prototype

“The Color of Smell” is presented in form of a physical prototype and an animation portraying the look & feel. A short movie prototype explains the intended functionality.

*This link points to the final video prototype on Vimeo: [https://vimeo.com/171216965](https://vimeo.com/171216965)*

The Color/Shape-Smell Mapping

For testing purpose essential oils were used as a source for smell. The oils used in the Color-smell mapping workshop (1) served for the final color/shape mappings. These graphical mappings were combined in an animation. The synesthetic experiences that the participants of the experiments and the color-mapping workshop (1) reported, was crucial for the final visual representation of the smells.

Figure 25: Final color-smell mappings
The “Table”

The physical prototype consists of a wooden box with a semi-transparent top representing a multitouch table. Inside a projector is placed, projecting upwards the animation of color-smell mappings. A smaller table holding a collection of smells and smell brushes is placed in close distance to the imitated multitouch table. The prototype was tested with the “Wizard of Oz” technique, due to its technical constraints. When an aspiring smell painter approached the table with a brush holding one of the smells the animation was started, giving the impression that the color-mapping appeared simultaneously to the movement of the brush.

![Figure 26: Multitouch table prototype](image)

The “Smell-Brush”

Several smell-brush prototypes were used in the final installation prototype according to the desire of participants of workshop 2, to have a variety of different smell-brushes at their disposal. All smell-brushes presented had a pick-up & drop function and incorporated an airflow, either facilitated through a ventilator, a fan or a pipette-like function.

![Figure 27: Selection of Smell-Brush prototypes (left), final selection of Smell-Brush prototypes (right)](image)
7.9.1 Context

The final prototype explores primarily the look and feel domain with respect to the model presented by Houde & Hill. However, also the role that “The Color of Smell” might play in a user’s life was explored and tested in workshop 2: Smell-Brush & Interaction. “The Color of Smell” is an interactive art installation whose potential setting is in museums and galleries. The majority of participants found the idea of smell painting rather intimate and expressed the wish to be alone when conducting this activity. Nevertheless, the idea of communicating through smell-painting was found to be appealing and one participant stated: “I would like to share my personal creation”. “The Color of Smell” can thus be labeled a meditative, expressive tool.

In its current state “The Color of Smell” can find context in an interactive art environment. However, in the future its use might be extended to different contexts. Potential investigations could address the application of “The Color of Smell” in a collaborative setting. How would people react upon each other’s choices? What would those choices communicate? These are interesting questions for further research.
8. Reflection

In its current state “The Color of Smell” is still a prototype and accordingly a representation of a design idea which means it is a research project with an open end. With respect to the practice of RtD, “The Color of Smell” offers a foundation for re- Assessing existing design questions and generating new ones. At the same time, the research on which the “The Color of Smell” is based upon indicates the direction of further investigations thereby satisfying the request for extensibility as mentioned by Everson et al. By remaining accessible, the research has the potential to develop into a research program, as opposed to an individual study, and thus ultimately generate progress (Lakatos (1970) as cited in Koskinen, Binder, & Redström, 2008) in the field of synesthetic design. On the other hand, the not clearly refined context and the shortcoming of a specific target group can be criticized. A stronger positioning of the design in a specific context could have strengthened the concept.

Throughout the design process a range of different methods were used. Co-design has proven to be a crucial element within this research project and the experiments have provided essential insights upon which the concept was built. The involvement of users in workshops has confirmed assumptions made throughout the exploration phase and has even furthered the design elaboration. Furthermore the Wizard of Oz technique has been essential for testing the final prototype. The technique has enabled the study of the test subjects’ physical gestures when using the prototype. However, the test subjects were also limited by the animation which simulated a certain stroke on the table top. A working system would have provided the smell-painter with more gestural freedom.

Regardless, every step has delivered insights from people outside this research, which has proven valuable for the final prototype. The workshops were conducted towards the end of the design process so that further exploration of the findings could deliver interesting new design opportunities especially with regard to the smell-brush and the functions incorporated in the multitouch table. In general, the design idea “The Color of Smell” in its physical form and as a video prototype show potential for further studies.
9. Discussion & Conclusion

The initial experiments with smell and the first workshop have provided answers for research question n. 1: “How can smell strengthen the perceptual ability to create cross-sensory connections?”. The analysis of literature in the fields of neuroscience and cognitive psychology has supported the results and anchored them in a research context. The short answer to the first research question can thus be: Smell strengthens the perceptual ability to create cross-sensory connection, of different kinds, by activating perceptual and cognitive processes in the brain. This statement is elaborated in the section of the thesis dealing with the psychological and physiological properties of smell and in the main chapter about synesthetic design.

The second questions guiding the research, “How can a synesthetic approach to design be included in interactions?”, is mainly answered by the design process which demonstrates one possible approach of creating a cross-modal interaction including the olfactory and the visual sense. The correlation between olfaction and other modalities could be examined in future research according to the findings from the study. This could provide more generally applicable answers to this research question. One design decision was to work with common cross-sensory connections. This choice can be explained through the above stated wish of raising awareness of shared synesthetic experiences. However, experiments, workshops and user-testing have also shown that smell perception is highly individual. Therefore, individual synesthetic mappings could be a future extension to the concept presented, especially with regard to the component of self-expression.

The third research questions deals with the effect of synesthetic components on the interactive experience. This question was answered through the testing of the final prototype and throughout the co-design process. All participants reacted positively to the integration of cross-modal components in design. The inclusion of smell in interactions was perceived to be quite intimate. Participants thought this intimacy to be related to memories triggered by the smell and the attended emotion. In other words, by visually expressing the feeling evoked by smell, the activity of smell painting was perceived to be highly personal and introspective. By including a personal touch in an interaction the obtained experience is moved to another lever. Indeed, the interaction is tailored by the user who becomes himself part of the experience up to the point of being, in fact, the protagonist of the interaction.
10. Perspectives

“The Color of Smell” turned out to be an interactive art installation.

Originally however, one of the questions guiding this research enquired the use of cross-sensory connection to enrich a functional interaction. In this context, functional means the inclusion of control elements for a distinct manipulation of the product which to interact with. Formerly, the idea was to create a functional synesthetic interaction by applying common cross-modal connections. Especially concerning the concept of ideasthesia this perspective seemed appealing. In their investigation on semantic mechanisms Mroczko-Wasowicz and Nikolic mention the idea that a concept, in a generalized form, “may serve an extended function, not only to give a label to the stimulus, but also to prepare the person to interact with the conceptualized stimulus” (Mroczko-Wasowicz & Nikolic, 2014, p. 8). Since semantics may be a distributed property of the brain, also the motor cortex might be involved in processing the semantic information. “The motor-cortex plays an important role in the acquisition of action-related concepts” (Gallese and Lakoff, 2005 as cited in Mroczko-Wasowicz & Nikolic, 2014, p. 8) and is therefore “particularly important when a subject needs to prepare for a behavioral interaction with the object” (Mroczko-Wasowicz & Nikolic, 2014, p. 8). Due to these findings in human neuroscience, the drive to invest further in the idea of functional synesthetic interaction is apparent and could be subject of further studies.

In addition, smell as a component in cross-modal interactions, as proposed in “The Color of Smell”, has advantages with respect to other modalities. Due to its close physiological connection to the limbic system and long-term memory, smell has proven to be a suited medium for the formulation of cross-modal connections, in specific associative connections which regularly lead to conceptual perception (Haverkamp, 2013; Mroczko-Wasowicz & Nikolic, 2014). Long-term memory stores general knowledge which in turn provides a basis for more specific knowledge stored in working memory. This specific knowledge is important for the execution of functional interactions. These facts support the assumption that a synesthetic approach, including smell as modality, can benefit functional interactions and therefore further investigations in this direction are advocated.
References


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Table of figures


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