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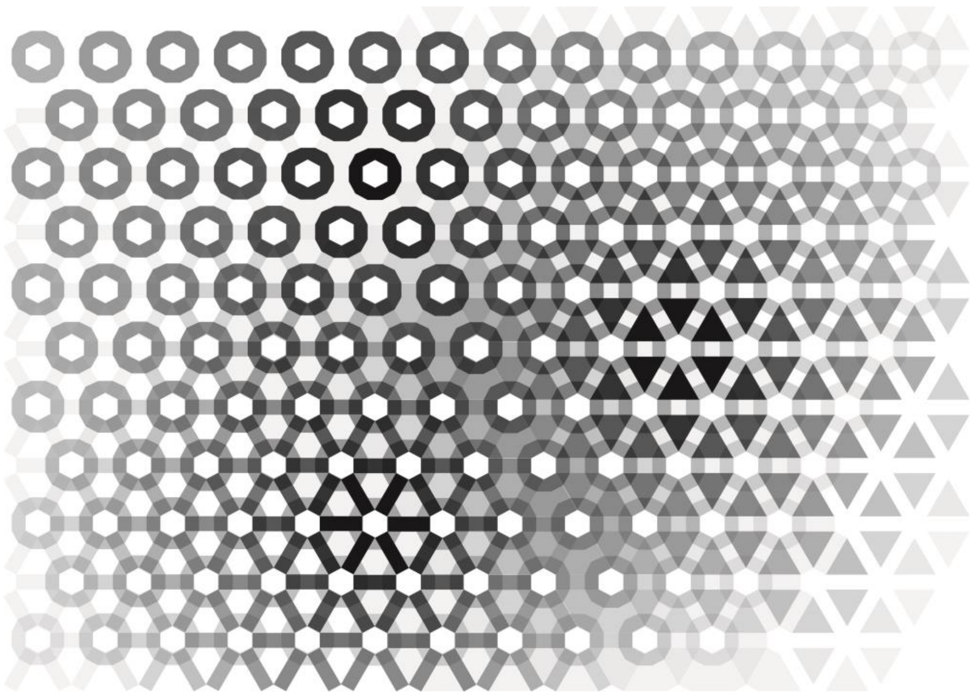

Between challenge and solution

STATUSCOPE – a tool for designing status communication in highly automated vehicles

Master of Science Thesis

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Gothenburg, Sweden, 2014

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Cover:
The geometrical tiling used as an abstract representation of the design space discussed in the thesis. Illustration by the author.

Gothenburg, Sweden, 2014

ABSTRACT

The task of designing human-machine interfaces for automated driving remains a largely unexplored area. The research on human factors in context of vehicle automation provides insights into a number of aspects that need to be considered. Specific requirements and recommendations can be found as well as proposals for design frameworks. Although extensive knowledge on automated systems exists, its implications for design are not always straightforward. This work thus bridge the gap between current research findings and the request for new design solutions by proposing a tool STATUSCOPE that allows to explore the design space of status communication in highly automated vehicles in a tangible and dynamic form.

By exploring the design space of status communication for automated driving via categories, aspects and their properties, the STATUSCOPE tool provides designers with a starting point to approach this challenge. The proposed aid can serve to generate new ideas, make conscious decisions about design as well as analyze existing concepts. It is to be used in a group or individually, and can be especially suitable for teams where designers need to mediate with experts of various fields. Both human-centered and technology-driven development is supported.

The design space represented in the STATUSCOPE has been identified by a structured literature review, with use of content analysis methods, and tested with industry experts in workshops. The format of this design support was created in an iterative process in which it has been continuously improved.

The benefit of the tool is that it delivers research findings in a format that can be readily used in design-oriented activities, thus transforming the complexity of the subject into a tangible and playful creativity support. This approach not only applies the concept of design space within the automotive domain, but also extends it to a hands-on tool facilitating interaction design.

Keywords: automated driving, vehicle automation, highly automated vehicles, design space, design tool, human-machine interaction, interaction design

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Gothenburg, June 2014
Agnieszka Szymaszek

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1. Introduction

Design from its definition implies envisioning yet non-existing artefacts, systems or realities (Jones 1992). In some areas this task can be particularly difficult because of novelty, uncertainty or complexity of the issue.

Interaction design for automated vehicles shares that characteristic. The technologies enabling automation of a driving task are still under development. Our knowledge of automated driving is based on tests performed on prototypes and simulators, as there are no commercially available cars like this yet. There are lots of questions regarding wider use of such vehicles, which need to be answered. For example, automated vehicles will involve several legal and liability issues (Schijndel-de Nooij et al. 2011). Finally, automation will add to the complexity of a vehicle, which as it has been already observed, increased greatly with computerization of in-vehicle systems (Walker et al. 2001).

At the same time, several car manufacturers announced their intention to introduce semi- to highly automated vehicles to road traffic within next decade (KPMG 2013, p. 7; Carroll 2013; Guillaume 2014). Furthermore, a large scale test on public roads was announced to take place in Gothenburg by the year 2017 (Volvo Cars Group 2013).

1.1 Problem Statement

Technological advances show that automated cars can become reality in near future, but there is number of non-technical issues that need to be addressed to realize these plans.

These issues were widely addressed from both theoretical and practical perspective. Several challenges and obstacles have been identified in course of EU founded projects dedicated to vehicle automation (Toffetti et al. 2009; Flemisch et al. 2011). Driver's ability to regain control over a vehicle after period of automated driving in case of emergency is regarded as one of the most serious problems (Flemisch et al. 2011; Beukel & Voort 2013). Also experiences from other industries, such as aviation, indicate that automation can induce certain types of human errors (Stanton & Marsden 1996; Saffarian, de Winter & Happee 2012). Furthermore, some conceptual models for automated driving have been created, such as H-metaphor and collaborative approach (Flemisch et al. 2003; Flemisch et al. 2008b). On the other hand, a lot of work was focused on developing specific, technology-driven solutions and test them in driving simulators or test cars (Merat & Jamson 2009; Flemisch et al. 2011).

However, the task of designing HMI for highly automated vehicles remains a largely undiscovered area. The motivation for my work is therefore to study how designers can approach that challenge using methods known in interaction design research and practice. The importance of this question becomes evident in light of rapid expanse of mobile technology that can be observed in recent years, as the "cars and driving provide abundant lessons for all forms of ubiquitous computing" (Walker et al. 2001, p.226). Thus vehicle automation can be seen as a frontier of new generation of technologies, so deeply embedded into everyday tasks, that they touch some fundamental questions and beliefs about our relationship with machines.

Up to date research in the area of interaction design for automated vehicles was focused on either theoretical issues or specific designs limited to certain technology or scenario of use. A lot of knowledge has been gathered on human factors related to automated driving, what resulted in number of design requirements and recommendations (Merat & Lee 2012). But it is not straightforward how designers can understand them, apply them in their work and effectively combine with other demands that need to be met (Davidsson & Alm 2009). It may be beneficial to render these important findings into a form that can be more readily employed in design-oriented activities. Therefore, the main purpose of my work is to contribute to filling the gap that is present between the already existing high level models and new low level solutions to be developed.

1.2 Research Question

The main hypothesis of this thesis is that design of human-machine interfaces for automated vehicles can be supported by exploring properties of interaction between the driver and the automated vehicle. It is hypothesized that this can be done by providing design aids that consist of dimensions to consider for a designer, such as interaction properties (e.g. input and output modalities, directness, temporal aspect) and range of their possible options. This approach allows to map a design space for the new task of interaction design for automated driving.

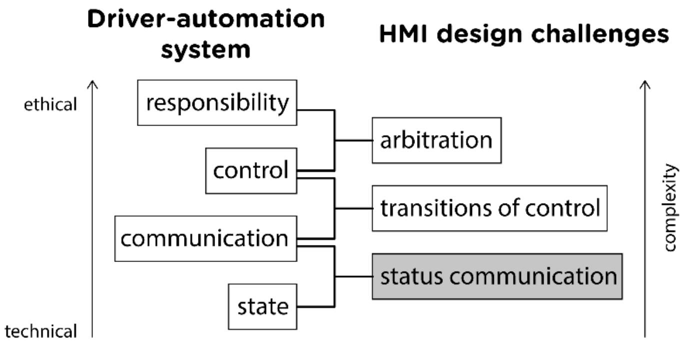

Figure 1. The role of status communication in relation to other HMI design challenges in automated driving.

The thesis goal is to define a design space for communicating status of automated vehicle that can be used as a decision support in development of new systems, as it has been demonstrated in case of other forms of novel interfaces (Rasmussen et al. 2012; Nørgaard et al. 2013). The problem of communicating status of the system is both crucial and well-studied feature required for automated driving systems, however not well supported. The status communication can be seen as a basis for developing more complex interactions, such as transitions of control and arbitration (see Fig. 1). In relation to them, problem of communicating status is relatively technical and objective, while with rising complexity of interaction the ethical value of design increases. Design for effective status communication can provide a solid foundation for discussing more advanced HMI challenges. Given this, the research question can be formulated as follows:

How can a design space be specified so that it:

(1) supports the design of interaction for automated driving, and in particular communicating the status of a highly automated vehicle,

(2) describes salient properties of interaction between the driver and the automated vehicle.

1.3 Scope

For the scope of this thesis, the research question has been centered on one aspect of interaction design for automated driving, namely communicating status of automated system. Therefore the design space described in this work is concerned with the above stated issue. However, this work is not to exclude closely related problems, such as transition of control and take-over situations, although they will not be addressed directly. It is believed that an effective communication of the system status can serve as a basis to develop solutions for example for transition of control and take-over situation. Furthermore, the work can be positioned according to the level of automation and driver involvement it aims to address (see Fig. 2).

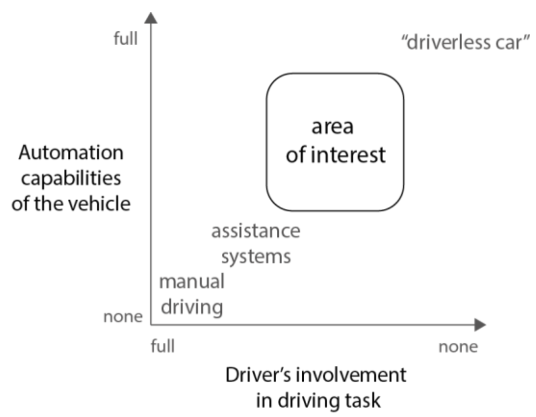

Figure 2. The scope of the thesis in relation to the level of automation technology and the role of driver in automated vehicle.

As can be seen in Fig. 2, the work considers vehicles with capabilities of highly automated driving, equipped with multiple automated systems supporting driver, that are planned to be introduced to road traffic within next decade. Therefore, the interfaces for already existing advanced driver assistance systems (ADAS) will be omitted. Also fully automated, so-called “driverless cars” lie outside the scope of the thesis, as it is assumed that a person remains responsible for the driving, even if the role of the driver is limited to monitoring the automated system.

The scope has been limited to the internal status communication, which is an exchange of information between the driver and the automation and excludes the external status communication. For automated driving the external status communication means displaying vehicle’s state to the road users outside of the vehicle, such as other drivers and intelligent vehicles, pedestrians or cyclists. It is an important and recognized problem (Schijndel-de Nooij et al. 2011, pp.98–99), however it is not going to be covered in this thesis.

In addition, the design space aims to support designers at the stage of concept development, similarly as this tool was employed in explorations of other new interaction techniques (Rasmussen et al. 2012; Döring, Sylvester & Schmidt 2013). The other common use of the design space is user interface evaluation and comparison (Kern & Schmidt 2009). However, this is out of the scope for this thesis, as needs to be excluded, because highly-automated in-vehicle interfaces are yet to exist for public use.

The scope of the design space includes interaction properties, which can be shaped by the designer and related to the elements of the user interface, while excluding factors that are not under influence of the designer (e.g. driver’s capabilities or system’s limitations). They may be implicitly referred to in the text as needed.

2. Background

The challenge of designing interaction for automated driving was early recognized thanks to previous experiences with introducing automation in other industries. Primarily studies performed in aviation allowed to formulate several human factors concerns about vehicle automation (Stanton & Young 2000). Researchers anticipated similar automation-related errors to appear in automated driving as these causing some fatal plane crashes (Young, Stanton & Harris, 2007). Although drawing on knowledge from aviation domain, it was also recognized that new design approaches need to be developed in case of road transportation (Young, Stanton & Harris, 2007).

Some general approaches to designing for automation has been referred to in automotive context. They deal with the fundamental questions on what can and should be automated as well as to what extent to automate it. Parasuraman, Sheridan and Wickens (2000) proposed a model that uses the stages of human cognition to guide such decisions. Another influential view see the role of automation in working together with humans, as a good team player would do, instead of trying to replace people or compensate for their limitations (Dekker & Woods 2002). Specifically applied to partially automated vehicles, Beukel and Voort (2013) developed a model that can guide designers in deciding on a proper level of support, with an approach that driver support should be suitable to a driving situation.

Similarly as in early days of personal computing, the researchers were looking towards metaphors as powerful concepts that were believed to help to understand automated vehicles for their first generation of users (Cooper, Reimann & Cronin 2007). This led to exploring a metaphor of an intelligent vehicle as a horse, so-called H-metaphor (Flemisch et al. 2003). Wider design audience could become familiar with the term thanks to Norman, who dedicated a part of his book on designing for future intelligent products to the H-metaphor (Norman 2007). The idea was further explored in the projects that focused on haptic interaction, devices and actuation, such as the H-mode project (Damböck et al. 2011). The studies on the H-metaphor informed design for automated driving with insights on natural an integrated interactions (Flemisch et al. 2008b).

Significant development of the research in the field has took place in a series of EU-funded projects that were gathering several partners across academia and industry. Among the projects that have been dedicated to different issues of vehicle automation, those which explicitly addressed problems related to interaction design are: HAVEit, CityMobil, interactIVe, and most recently the project adaptIVe. Overall, the research trend stressing the importance of interaction design and human-centered approach is raising in major EU projects, as the question of "how the interfaces and interaction with such a highly automated vehicle should be designed" remains open (Schieben et al. 2011, p.252).

The need to work on human factors and design "in parallel to technical development" has been recognized in the project Highly Automated Vehicles for Intelligent Transport (HAVEit) (Schieben et al. 2011). Within the HAVEit project several generic interaction schemes have been developed, applied across demonstration vehicles and evaluated, for example one-dimensional scale of automation or transitions layers (Flemisch et al. 2009). This work was of great importance for the thesis project as it explicitly addresses interaction design for automated driving and provides some design examples (Flemisch et al. 2011).

Further, the interactIVe project, which focused on accident avoidance, aimed to "to integrate the user-centred approach of designing and testing the most beneficial *information, warning, and intervention (IWI) strategies* for the HMI design" (Hesse et al. 2011, p.281). The outcome of the project of a main relevance for this thesis was a description of strategies to approach different problems in interaction design for automated driving. They were structured in a form of the list of 14 aspects to consider in the development of such systems (Hesse et al. 2011). Although created for the purpose of demonstrator vehicles within the interactIVe project, the strategies provide an important step towards supporting a design process. They can be seen as an attempt to present knowledge on human factors in automation as guidelines and recommendations for design, therefore stay in line with the research problem of this work.

In regard to the subject of the thesis, status communication is discussed among primary issues in the field. For instance "Optimal communication of an automated vehicle's status to the user" was identified as one of the major research needs at the Vehicle Automation workshop at Stanford (Fitch 2013). Similarly, "Communicate System Status" was defined as an aspect of design strategy towards automated driving within the interactIVe project (Hesse et al. 2011). These statements helped to position the problem of status communication in relation to other challenges in design for human-automated vehicle interaction (see also Fig 1.).

As the area of study at hand has its roots in the development of automated systems, the issue of designing for automated driving was mostly addressed from human factors and engineering perspective. A strong focus is put on human cognitive abilities and simulator tests as a method of study. There are however techniques that directly support design process in the vehicle automation context, for example the "theater system" that can serve for prototyping driving scenarios and interactions (Schieben et al. 2009).

3. Theory

This chapter is structured according to four domains of knowledge corresponding to main components of the topic at hand: automotive technology, human driver, interactions that take place between them, and the process of designing for these interactions.

The first section introduces technology-related aspects of the subject. It provides background information on automated systems in automotive context. The second section is dedicated to models of human, which can be used to explain how people function in a driving situation and therefore can serve as a basis for designing automated vehicles. The third section aims to present approaches to human interaction with automated systems relevant to the subject of the thesis. Finally, the last section introduces theoretical foundations of studies on the design process in particular and methods of supporting it.

3.1 Vehicle Automation

As the thesis deals with the interaction design applied to the new and developing domain of technology, firstly this area of application is introduced. The definition of vehicle automation is presented as well as the outline of the main issues and promises it holds for the future of road transportation.

3.1.1 What is Vehicle Automation?

Vehicle automation refers to operation of transportation units that does not require human input in order to perform some of the safety-critical control functions, such as following a selected route or maneuvering between other road users (National Highway Traffic Safety Administration 2013). The concept is not new and has been present in research as well as in popular culture for decades. Although today's road vehicle automation differs from futuristic visions, it was made possible thanks to considerable technological development and is pursued for several reasons.

In relation to these recent advancements, both terms automated and autonomous are in use. Also an expression autonomous driving is broadly utilized. Although very common, referring to automation in terms of the concept of autonomy was criticized as problematic and causing conceptual confusion. Some authors claim that artificial entities, such as automated vehicles does not have properties of autonomy as it is defined for human beings and use of this word creates false expectations of their relation to people (Stensson & Jansson 2013). Wider public can be most familiar with terms self-driving cars or driverless cars, which often appear in popular publications.

Attempts to create standardized definitions of vehicle automation have been made by governmental organizations both in Europe and North America. This kind of classification was created by authorities in Germany (Gasser 2013), and in the United States of America (NHTSA 2013), while the most recent taxonomy comes from an international automotive engineering organization (SAE International 2014).

Interestingly, authors of the report for the EU's SMART project draw conclusion that main challenges in introducing automation to commercial vehicles are not strictly technical, but ones related to the current trade-off between costs and reliability of the components required to build automated vehicles (Schijndel-de Nooij et al. 2011). Besides that, they point to several issues of integration, robustness and establishing common standards. Also, a convergence of sensing and connectivity technologies is presented as an important gap still to be filled, as well as the problems of improving accuracy of positioning and mapping, together with above mentioned international standardization (KPMG 2012).

3.1.2 Why Automate Driving?

Several expected benefits of handling the control over driving vehicles to machines are listed in the literature. Usually, authors underline advantages such as enhanced road traffic safety, by eliminating accidents caused by human error or allowing to detect dangerous situations, as well as greater comfort for a driver, who would enjoy lower workload (Merat & Lee 2012; NHTSA 2013). Therefore, vehicle automation can potentially contribute to reaching European policies about road safety, which aim for minimizing fatalities on roads and optimize use of resources (Beukel & Voort 2011).

Automated vehicles are expected to respond to demands of modern urban life, such as a need for efficient transportation systems in constantly growing metropolises. They have a potential to redefine scenarios of using road infrastructure in our cities (Schijndel-de Nooij et al. 2011). Also, they may help to manage and reduce environmental impact of heavy congestion, because the flow of vehicles can be optimized, or even create new quality of mobility for people with different disabilities (NHTSA 2013).

Moreover, that technology is seen as a driving force for new business opportunities and increased competitiveness for automotive industry in developed countries (Schijndel-de Nooij et al. 2011; NHTSA 2013). Last but not least, it provides excitement related to innovations that may allow cars to "do the driving for us" (NHTSA 2013, p.1).

3.1.3 Levels of Automation

In practice, when talking about vehicle automation it is common to refer to level of automation (LoA) of a certain system. Several approaches to distinguishing different levels of automation can be found in the literature, which vary in number of degrees and their names from definition to definition.

In the simplest and most common version, levels of automation are represented as continuum of control between human driver and automated system, where they form a gradual scale, or are defined between two axes, which are capabilities in longitudinal and lateral control (Flemisch et al. 2011). Alternatively automation is classified by means of functions and scenarios in which it is active for a given time (Gasser 2013). Some authors presented an attempt to define levels of automation based on relationship to two factors: automated support of a driving task and a traffic situation in which one is driving (Beukel & Voort 2011).

For practical reasons in this work has been adopted a scale presented by Flemish et al. (2011), that consist of five discrete levels of automation: manual driving, driver assisted, semi-automated, highly automated and fully automated. This scale has been chosen as it aims “to keep the mental model of the user about the assistance and automation as complex as necessary but as simple as possible” and therefore can be suitable for a period of technology adaptation (Flemisch et al. 2011, p.273).

3.1.4 Enabling Technologies

The advances in vehicle automation were made possible thanks to progresses in several research fields, such as artificial intelligence, robotics and machine learning, as well as development of hardware (sensors, radars, actuators) and software (probabilistic algorithms, signal processing, image processing). A report on state-of-the-art of automated driving technologies published in 2011 listed following technologies as building blocks for self-driving cars: high accuracy positioning systems (like GPS), long and short range radars, laser scanners, communication electronics, artificial vision systems, software and control algorithms (Schijndel-de Nooij et al. 2011).

Based on these technologies are Advanced Driver Assistance Systems (ADAS) that can be characterized by abilities to sense their surroundings, detect and recognize objects, which is achieved by fusion of numerous sensors (Schijndel-de Nooij et al. 2011). Examples of already commercially available automated systems are adaptive cruise control (ACC), active breaking, warning systems for lane-keeping, forward collision or blind spot, as well as assistance in breaking and parking (Schijndel-de Nooij et al. 2011). The growing number of ADAS functions is studied in field operational tests (Merat & Lee 2012) and efforts are made in order to establish validation methods for them (Beukel & Voort 2009; Broggi et al. 2013).

3.2 Models of Understanding Human in a Driving Situation

Extensive work has been done in investigating how humans perform complex and demanding tasks, such as manual or assisted driving of a vehicle. The motivation was mostly to understand errors that may occur on the way and to ensure people’s safety. Research in the field of human factors lead to several explanations of mental processes involved in driving, and cognitive ergonomics provided their possible implications in system design. The focus has been on mental and behavioral aspects, and theories was developed on the ground of cognitive science and neuropsychology.

3.2.1 Mental Processes

On the most general level, there has been efforts to model human information processing and decision making. Such models describe the operations performed in brain and are important for the subject of the thesis, as they constitute a major part of concepts and terminology used in the context of interaction design for automated vehicles.

The theory of Multiple Resource Model was proposed by Wickens and in author's intention can serve as a reference framework for design of systems requiring distribution of mental resources (Wickens 2008). It systemizes capabilities and limitations of human brain as "a set of three dichotomies of information processing": spatial and verbal code, visual and auditory modality, as well as stages of perception, cognition and responding, together with additional notion of focal and ambient vision (Wickens 2008). This model is helpful in conceptualizing the problem of multitasking and mental overload, which becomes more and more severe with growing number of functions available in vehicles.

Furthermore, the problem of attention workload was long studied by Kahneman, who developed a framework of information processing, defining two ways in which thoughts are formulated in human brain as System 1 (fast, emotional, subconscious and responsible for intuition) and as System 2 (slow, logical, conscious and responsible for reasoning) (Kahneman 2011). Among other theories that are cited in the context of automated driving is a model of driving situation represented as a series of control loops (Hollnagel, Nåbo & Lau 2003; Hollnagel 2006; Beukel & Voort 2009). Also, the problem of driver distraction is extensively studied in regard to in-vehicle interfaces (Regan, Lee &Young 2009; Regan, Hallett & Gordon 2011).

Closely related to models of information processing is the concept of situation awareness, which relates to being able to comprehend relevance and importance of information at a given moment and in relation to a performed task (Endsley, Bolte & Jones 2011). The term was originally used in context of automation in aviation industry, but it is relevant for road vehicle automation too (Parasuraman, Sheridan & Wickens 2008; Beukel & Voort 2013). Distributed cognition is another relevant psychological theory which states that knowledge of an individual is embedded in social and physical environment, constructed by culture (Hutchins 1995). Addressing issue of information overload, multimodality theory developed into an influential approach to interface design, as it studies relations between modalities with consequences for information presentation (Sarter 2006; Sarter 2013).

3.2.2 Discussion and Need for a Holistic Approach

Hitherto studies on human in driving situation focus almost exclusively on cognitive processes, therefore represent a person only partially. But there is much more about drivers to explore, such as their emotions and unconsciousness, what attracted an interest in science only recently. Therefore a more holistic approach to modelling a human driver would be needed. Beukel and Voort comes to simple, but powerful observation that "the development is most of the times based on what is technologically possible, not necessarily on what drivers are in need for" (Beukel & Voort 2011, p. 226). User experience can be seen as an emerging trend in automotive design (Walker et al. 2001; Gkouskos & Chen 2012). A better understanding of affective aspect of human as a driver is needed, but some useful distinctions can be borrowed from neuroscience, such as difference between emotions and feelings (LeDoux 1999).

3.3 Human-Automated Vehicle Interaction

From the interaction design perspective, the research problem presented in this thesis lies on the intersection of several areas of study. To avoid terminological confusion, there has to be explained some basic concepts and their understanding applied in this work.

Within automotive industry the term human-machine interfaces (HMI) is commonly used to refer to design of functional, performance and reliability aspects of the vehicle's interface. However, as cars becomes more and more equipped with the electronics, the automotive HMI becomes closely related to broader field of human-computer interaction (HCI), with which it shares theoretical foundations. An important difference is that automotive user interface design deals with safety-critical systems, while most of HCI applications are not (Kern 2011). Furthermore, a specialized area of human-automation interaction studies relationships, impact of the automation on the operators as well as provides guidelines for developers and designers (Hancock et al. 2013).

3.3.1 Natural Interaction

From the usability experts there has been a call for a natural interaction for human-automation interfaces. This postulate was expressed among others by Norman, who provided guidelines for design of automated artefacts (Norman 2007). In an effort to achieve this kind of intuitive interfaces, there has been proposed models of adaptive automation, in which the system can adjust to the changing conditions (Hancock et al. 2013; Calhoun et al. 2012; Sarter 2007; Feigh, Dorneich & Hayes 2012).

3.3.2 Current Metaphors and Frameworks for Interaction with Automated Vehicle

The H-metaphor was introduced as a powerful model for vehicle automation (Flemisch et al. 2003). An idea is based on use of metaphors for a new types of interfaces and on its successful implementation at early stage of personal computers adoption. It has been used to develop interface elements that map some of the horse riding interactions to an active and multimodal control device (Damböck et al. 2011).

The model of cooperative control is widely discussed in relation to automated driving and offers an alternative to an approach of switching authority either for driver or for automation (Young, Stanton, & Harris, 2007; Flemisch et al. 2008a; Flemisch et al. 2012). Also, the Assisted Driver Model is aimed to guide a design of partly automated vehicles, with emphasis on driver support functions and complementary division of control (Beukel & Voort 2009).

3.3.3 Challenges of Interaction Design for Vehicle Automation

The challenges faced by designers in relation to automated driving were widely covered in reports dedicated to the vehicle automation (Schijndel-de Nooij et al. 2011; KPMG 2012; Gasser 2013). They can be summarized with the statement that "the challenge for highly automated vehicles is to reduce a relatively high complexity of the automation into a manageable complexity for the human being" (Damböck et al. 2011, p.377). The authors underline a need for inner and outer compatibility, defined as matching between corresponding interior (mental) and exterior (physical) features of the man and the machine, that can be compared to the fit of "a power outlet and a power plug" (Flemisch et al. 2008a, p.9). The three main thematic groups for design challenges are the errors related to automation, the problem of transitions between manual and automated driving, as well as issues of appropriate trust in automated system.

Automation Induced Errors

Following experiences from other industries, where human errors related to automation were studied in detail, major problems that are expected to appear with introduction of automation to a driving task include (Toffetti et al. 2009; Saffarian, de Winter & Happee 2012):

- Loss of skill
- Problems with responding to system failures
- Reduced situation awareness
- Behavioral adaptation
- Erratic Mental Workload
- Overreliance
- Inadequate mental model of automation functioning

Transition of Control and Take-Over Situation

The transitions in control and authority between the driver and automation are believed to be the key problem for automated driving, as they constitute the moments when automated driving can be most vulnerable to dangerous human errors (Flemisch et al. 2012, p. 14). Several studies focused on problem of transitions between different automation levels and particular interest were given to drivers' reaction to emergency take-over situations (Merat & Jamson 2009; Toffetti et al. 2009; Schieben et al. 2011; Flemisch et al. 2012). As the background for this considerations can serve understanding of interdependencies between terms such as control, authority and responsibility in automated driving (Flemisch et al. 2012). Furthermore, a classification of transitions was presented in the HAVEit project (Schieben et al. 2011). Other authors suggested a systematic analysis of automation levels as a guide to development of appropriate transition of control (Beukel & Voort 2011).

Trust Calibration Issues

Another group of challenges to be addressed in interaction design for automated driving are mechanisms of developing trust into the system. The concept of trust has been studied in general within human-automation interaction field with focus on problems caused on under- or overreliance on the system (Lee & See 2004; Parasuraman, Sheridan & Wickens 2008; Merritt & Ilgen 2008). In the context of vehicle automation some recent studies investigated how drivers perform while presented with information on uncertainty of the automated system (Helldin et al. 2013; Beller, Heesen & Vollrath 2013). Other experiments aimed to measure influence of perceived intelligence of the system on the driver gaze patterns (Thill, Nilsson & Hemeren 2013) and impact of perceived vehicle's anthropomorphism on driver's expectations towards the system (Waytz, Heafner & Epley 2014).

3.4 Designing Interaction for Automated Vehicles

The design of human-machine interfaces for automated vehicles is an issue that has to be overcame to allow adoption of automated vehicles (Schijndel-de Nooij et al. 2011; Beukel & Voort 2011; KPMG 2012). However, when it comes to user interface design, the relevant resources to support design decisions for this specific task are quite scarce.

Nevertheless, as a notable example can serve interaction strategies developed in course of the interactIVe project and meant as guidelines or recommendations for HMI design of ADAS in respect to information, warning and intervention (Hesse et al. 2011). One of the concepts used to structure these strategies was a design space. Furthermore, the same term appears also in the context of haptic-multimodal couplings in automated driving (Flemisch et al. 2008c; Flemisch et al. 2010).

Design space is a concept that was previously employed several times in supporting design process in order to cope with complexity of novel interaction techniques. It can be understood as "all the possible design solutions that would work; that prospective users and other stakeholders would find meaningful" or "the territory of all possible solutions" (Westerlund 2009, p.35). Pioneering examples of using design space as a conceptual construct were very structured, but also rigid and rather impractical (Card & Mackinlay 1997). However, defining a design space can offer a framework to describe and develop interactions with new technologies, such as in case of studies on shape-changing and ephemeral user interfaces (Rasmussen et al. 2012; Nørgaard et al. 2013; Döring, Sylvester & Schmidt 2013). In an automotive context, it was employed as a tool for analysis of in-vehicle interfaces (Kern & Schmidt 2009).

In this work, the design space aimed to describe status communication between the driver and the automated vehicle for the purpose of user interface development. As the research problem was centered on the interaction itself, studying the properties of interaction served to define a design space. The properties of interactive artifact related to interaction has been defined by Lundgren (2011, p.112) as those which relate to "how the artifact interacts with the user" and "lets the user interact with it", "explicitly inscribed in the artifact" as well as "related to over-reaching design decisions". The notion of interaction-related properties guided the design space definition.

4. Methods and Planning

The following section describes theoretical foundations of the approach to the research problem and lists stages planned for the thesis work. It is aimed to demonstrate how methodology considerations informed my research approach and selection of methods.

4.1 Research Approach

The research problem presented in this thesis regards design process of future, safety critical interfaces for very technologically advanced systems. That determined the selection of approach and methods of realization for the project. The work addresses a process of designing a product – in this case a human-vehicle interface – not the product itself. This means that the outcomes are not meant to be design solutions, but a tool that helps to develop them. The design of such in-vehicle interfaces is primarily considered with safety issues, what makes differentiate them from products with the main goals in efficiency or entertainment. That implies special requirements at the design stage, as the possibility that a design cause error or failure has to be minimized. Lastly, vehicle automation technology is new and undergoes continuous development, therefore design process need to take under account issues such as high uncertainty, little real life experience, high cost of implementing solutions as well as user acceptance.

Keeping above in mind, the initial decision was to choose an approach to guide and direct thesis work. Following the nature of the research problem explained above, a design research approach has been adopted, which is understood as "systematic work to develop practice" (Hallnäs & Redström 2006, p.125). The term design research refers to combining design and research methodologies in order to build knowledge in discipline of design, but its specific meaning is a subject of discussion within academic community (Fallman 2008; Friedman 2003; Cross 1999).

Despite its complicated nature, the design research approach provided a solid structure to address the research problem of the thesis. Furthermore, it was aimed to balance theoretical and practical work within the project, so it stays in line with the purpose of the thesis and the outcomes are linked to actual design process. On the other hand, developing my own solutions for status communication in automated vehicles was excluded due to my focus on the design process rather than certain designs.

In particular, the design approach employed in this work was inspired by notions of design research methodology as presented by Blessing & Chakrabarti (2009). The methodology described by the authors served to define the general framework of the thesis. However, it is not implemented in its full scale, as it extends the scope of my thesis work. It has been chosen for a clear structure and as "*design research itself involves design*, namely the creation and evaluation of a model or theory of the desired situation and of the support" (Blessing & Chakrabarti 2009). The stages of design research methodology include research clarification, building an understanding of the problem, development of support and evaluation of support. This stages set the frame of the thesis work into different phrases described in the section Planning.

4.2 Methods of Supporting Design Process

Design space was selected as a support to be developed in course of the thesis, as it corresponded to the research problem character described above. It is a tool used in a design process, it helps to structure requirements for the design, map the new and unfamiliar problems, as well as can be used to generate and compare design ideas. To summarize, design space can assist decisions from an early stage of the concept development, before more resources are spent on their implementation.

Alternative support methods used in interaction design process could be numerous user research techniques. Their advantage is that they gather insights and requirements directly from stakeholders. An example can be requirement elicitation process that allows to construct understanding of the use system and transform this knowledge into design concepts (Engelbrektsson 2004). However, as automated driving is still highly hypothetical for users today, providing realistic conditions to perform such methods would be difficult. In terms of user research it is possible to draw some insights for the thesis from current studies and user tests of some automated systems implemented in commercially available cars (Merat & Lee 2012). Also, task analysis can be useful method in context of safety critical systems. However, again it has little relevance in case of this thesis, as it is "used mainly to investigate an existing situation, not to envision new systems or devices" (Rogers, Sharp & Preece 2011, p.231).

The new and original approach applied to the research questions in this thesis has caused that the methods specific for the different stages of work were systematically identified in course of the project. As determining methods that has been employed in the thesis constitute the part of the process, they were described and motivated in the chapter 5. The Process: Towards the STATUSCOPE tool, under the respective parts of the work where they were used.

4.3 Planning

The thesis project covered 20 weeks that has been divided in five phases described below (see Fig. 3). The project initiation stage dealt with the gathering of background information, organization of work and preparing for the later stages. It aimed to refine research problem and corresponded to research clarification in the design research methodology (Blessing & Chakrabarti 2009). The work consisted of a literature search as well as identifying relevant theories and methods.

4.3.1 Stage I: Defining the design space

The first stage, Defining the design space was analytical and refered to the part of the research question "describe salient properties of interaction between the driver and the automated vehicle". It aimed to gain an understanding of the research problem and propose its structured description. The goal was to define a design space for communication of status in highly automated vehicles, which constituted a deliverable for this phrase. The work involved methods for identifying a design space (Rasmussen et al. 2012; Nørgaard et al. 2013) and methods of studying interaction properties (Lundgren & Gkouskos 2013).

4.3.2 Stage II: Scheme of use

The second phase, Scheme of use was dedicated to synthesis and addressed the part of the research question "support design of interaction for automated driving". The aim was to describe use of the design space defined at the previous stage in a design process. This work had a goal to identify specific strategies or scenarios of how it may be applied in practice. Various forms of prototyping and testing were used in an iterative manner. The outcomes served to conduct evaluation of the support and a pilot evaluation was planned at this stage.

4.3.3 Stage III: Evaluation

The third stage, Evaluation served to assess the developed solution. Its main problem was to answer the question if the design space meets the goals set for it. The aim was to verify its potential as a support in design process and the goal was to present a usable outcome. The planned evaluation involved interviews or workshop with, depending on their availability, domain experts or interaction design students. Some methods that has been used were heuristic evaluation and design exploration.

Finally, the last stage of the project was dedicated to writing and editing the report with the aim to communicate process and results of the thesis.

Period	*Stage name*	*Milestones*
Weeks 1-4	**Project initiation: Literature review, methodology**	Week 4: Planning report
Weeks 5-8	**Stage 1: Defining the design space**	Week 8: Description of the proposed design space
Weeks 9-10	**Stage 2: Scheme of use**	Week 10: Presenting a scheme for use of the design space
Weeks 11-16	**Stage 3: Evaluation**	Week 16: Presenting results of evaluation
Weeks 17-20	**Report and Presentation**	Week 18: Hand-in report for presentation

Figure 3. The schedule of the project.

5. The Process: Towards the STATUSCOPE tool

The work on the project followed the three stages described in the Planning section with the first stage being analytical and the last stage providing a synthesis to the research problem. The design stage in the middle took form of an iterative process that partly overlapped with both phases of analysis and synthesis.

Through the whole process of working on the project I kept a notebook that served as a journal and in which I have collected questions, memos from literature review, agenda for supervision meetings, sketches and ideas on the subject as well as all project related notes (see Fig. 4). The notebook helped me to keep track of the progress in a natural, spontaneous and informal way, as well as it was taken to meetings, seminars and used comfortably on the side of design activities, independently from energy sources. The physicality of this format for continuous reporting made it portable and available for creative moments.

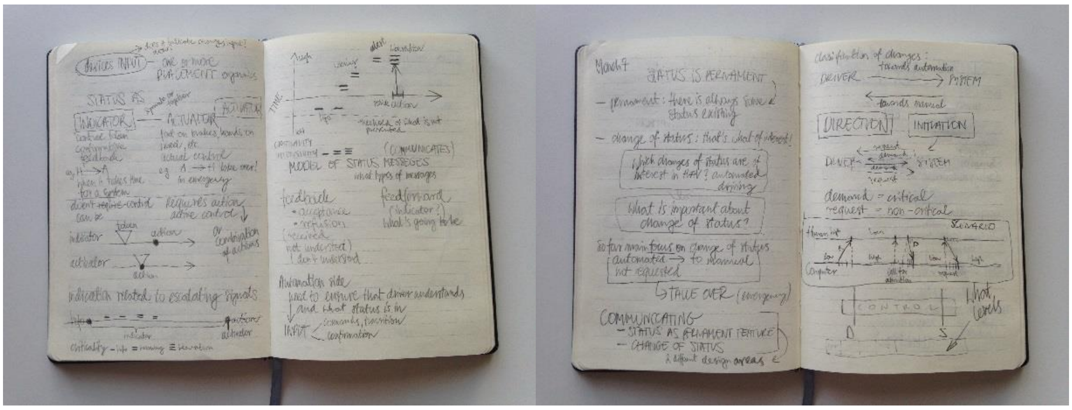

Figure 4. Examples of pages form the project's notebook.

5.1 Defining the Design Space

The process of defining design space presented a major research and methodological challenge in course of the project. There is no standard method for design space definition and previous authors addressed the problem from different perspectives (Card & Mackinlay 1997; Hassenzahl & Wessler 2000; Ballagas et al. 2008; Westerlund 2009; Findlater & Gajos 2009; Paternò, Santoro & Spano 2011). The concept of design space was used before in context of automotive user interface (Kern & Schmidt 2009) and in relation to interaction design for vehicle automation (Flemisch et al. 2008c; Flemisch et al. 2010; Hesse et al. 2011). Although these contributions have been very insightful and reassuring for the direction of my work, they did not offered a methodology that could be applied in case of the project. In the first case the design space was identified based on number of existing automotive user interfaces, which was not possible to apply due to the fact that automated vehicles are not available on the market (Kern & Schmidt 2009). In the papers dealing directly with vehicle automation, the design space was mentioned on a general level among other methods to “mentally structure the complexity of design and improve orientation in the design and engineering process” (Flemisch et al. 2008c).

For these reasons it was required to find a methodology suitable to answer the research questions of the project. Below I describe the process of developing the approach to design space definition applied in the thesis project. I was following the general outline set by three papers that I have identified as taking the approach closest to the one intended in the project (Rasmussen et al. 2012; Nørgaard et al. 2013; Döring, Sylvester & Schmidt 2013), and supported with the guidelines from literature review methodology based on grounded theory (Wolfswinkel et al. 2011).

From different approaches to defining a design space, I have chosen the one presented in the papers dedicated to shape-changing interfaces (Rasmussen et al. 2012; Nørgaard et al. 2013) and ephemeral user interfaces (Döring, Sylvester & Schmidt 2013). These publications were selected for several points matching intentions of my project. They study new, unexplored types of interfaces that has been enabled by advanced technologies, what is characteristic similar to automated vehicles. Furthermore, the papers are based on review of existing research and design examples in the domain of interest, which was the method I planned to follow. The goals stated in the papers in relation to design process match my goals: "providing an overview of the design possibilities", "contribute to a grammar that can help designers understand and articulate the qualities of using (...) as a means of interaction", "open design space", and leading to "outline open research questions"(Rasmussen et al. 2012; Nørgaard et al. 2013; Döring, Sylvester & Schmidt 2013). Lastly, the above mentioned works are design-oriented and one of them was tried out in practice for generating new concepts (Nørgaard et al. 2013). However, they differ from this project in the fact that the focus is on materials and physicality of the interfaces, not on the interaction itself. Nevertheless, the interfaces for automated vehicles can be seen as physical in the first place too, as they are determined by physical space of the car.

After analyzing the selected papers in terms of the process, the following three steps of defining a design space appeared to be used:

- Selection of the papers for a review based on criteria of relevance to the topic.
- Selection and analysis of the most important aspects of the interfaces.
- Selection and organizing main properties of these aspects, as well as types of choices that designers can make in relation to them.

The papers included only short information on the methodology used, which allowed to formulate this general outline, but have not described the process in detailed. Therefore, I have contacted the authors with the question about their process and received a reply from a researchers working on one of the papers that they did not followed any specific methodology, but rather applied bottom-up approach involving throughout reading and group discussions (personal correspondence with Kasper Anders Søren Hornbæk and Axel Sylvester). However, the initial idea for the work on particular stages based on the information form the authors and a general outline derived from the papers included:

- Papers selection: Defining roughly inclusion criteria for papers, then check papers against them and refine them as literature search will extend.
- Main aspects selection: Using a method of qualitative analysis, possibly based on grounded theory (Lazar, Feng & Hochheiser 2010), for its similarity with the process used by (Rasmussen et al. 2012; Nørgaard et al. 2013; Döring, Sylvester & Schmidt 2013): noting themes emerging during reading, developing them into concepts, grouping into categories, which can form main aspects of design space.
- Properties selection: Depending on properties that will be identified, arrange them on a scale or list their states, and arrange them in space to show their relationships.

As I aimed for more guidelines to structure and document my literature review, I have made more research on qualitative analysis methodologies to find the one that would match my goals and resources. The problem for the project was that in context of human-computer interaction, qualitative analysis is mostly regarded as method of processing data generated from user research, such as interviews, observations, recordings etc. (Lazar, Feng & Hochheiser 2010; Mayring 2000; Walsh et al. 2013). The described content analysis techniques are meant for teams of researchers dealing with raw data from user studies. This was not a case in my project, so that approach was not helpful in terms of selecting material and analysing texts for this work. I was rather looking for an application of a qualitative analysis to review of existing research, as that was my major source to study the domain of vehicle automation and corresponded to selected approach to defining a design space (Rasmussen 2012, Döring, Sylvester & Schmidt 2013).

Finally, the promising methodology was found in a paper describing literature review with use of grounded theory, in which the authors offer a complete framework covering stages from defining search criteria to presenting the results (Wolfswinkel et al. 2011). The method consists of five stages: Define, Search, Select, Analyze and Present. What I found particularly helpful about the method by Wolfswinkel et al. were some straightforward techniques to use at different stages in order to keep analysis organized and documented. I have decided to implement three of them. The first called codebook is a table with a list of concepts emerged from a text analysis together with their definitions. The second called concept matrix is a table documenting which concepts appear in which papers. The third one is a matrix of papers in which selected papers are listed together with the reason for their selection.

I believed that it was a relevant approach for the project, although it is meant for performing a literature review in research projects of a much bigger scale, so I needed to be reasonable in how much to implement and scale it down. On the other hand, to my knowledge no established methodology exists for carrying out studies as the one intended for the project, therefore there was a need to choose and adapt the most suitable methodology. Based on the main stages of the Wolfswinkel et al. method, the design space definition process was divided into phases of literature review, coding and structuring the results.

5.1.1 Literature review

The phase of the literature review played an important role in the selected approach to the design space definition, as it was providing material for the further analysis and therefore determining the scope of the final results. The work at this stage corresponded to the steps Define, Search and Select (Wolfswinkel et al. 2011) and resulted in the group of papers chosen for the further analysis.

Define

As it was proposed by the authors of the method, I have started with a "well-marked scope of the topic and having a set of research questions" to serve as a point of reference (Wolfswinkel et al. 2011). In accordance with the scope of the thesis, delimitations of literature search were defined as following:

- The aspect of highly automated interfaces: communicating status of automated system. Related problems, such as transition of control and take-over situations will not be addressed directly.
- Level of automation: focus on highly automated driving, omitting the interfaces for already existing advanced driver assistance systems (ADAS) and fully automated, so-called "driverless cars".
- Focus on passenger cars at the early adoption stage for highly automated vehicles.
- Design space aim: to support designers at the stage of concept development, not evaluation of existing designs.
- Design space content: interaction properties shaped by the designer: the factors that are not under influence of designer.

Then the criteria for inclusion of the papers into the literature review were specified, initially starting with three questions, that proved to be valid despite of later and more elaborate iterations:

- *Does the work mentions status communication?*
  As the main focus for the project, the status communication in highly automated vehicles was the first measure to define relevant publications.
- *Does the work include recommendations or guidelines for design?*
  As the outcome of the project was intended to support the design process, any design aid mentioned in the existing literature was believed to contribute to the project.
- *Does the work have other implications for design?*
  This question was intentionally left open and flexible, so it allows to incorporate the papers that may be relevant to the project in a way that I was able to envision

and because I could expect that the literature on the narrow sense of the subject can be scarce.

The simple criteria for exclusion were also formulated at this stage, narrowing the date of publication to the twentieth first century and limiting language of the text to English.

Search

The search terms and resources were listed and the search was performed within databases (primarly ACM Digital Library and Springer Link), various conference proceedings (e.g. AutomotiveUI) and journals (mainly Human Factors). The special focus was given to the publications related to the EU-funded projects dedicated to the human factors in vehicle automation. The papers presenting work of the projects HAVEit and interactIVe provided the majority of relevant results. However, the search strategies recommended by Wolfswinkel et al. turned out not to be feasible, as search terms needed to be adjusted every time to the searched source, either because they were too broad or because they were too specific to result in meaningful findings. For these reasons search documentation was not kept according to the methodology by Wolfswinkel et al. As the core of the literature was gathered at the preparation stage of the project, I have used it as a basis for forward and backward citation tracking. This process allowed to obtain the majority of the papers included in the review.

Select

Selection of the papers to be analysed was based on inclusion criteria and documented in the form of the matrix of papers (see Appendix 1), as this format of documentation was recommended by Wolfswinkel et al. The table lists the selected papers by year of publication, title, type of publication, a note explaining the reasons for including the paper and a checklist for matching the inclusion criteria.

There has been 22 publications selected for a detailed review. The limit on the number of papers was put in order keep it suitable for the scope of this project and available resources. For the comparison, the authors of the design space for shape-changing interfaces reviewed 44 papers (Rasmussen et al. 2012).

5.1.2 Coding

The analysis of the papers included in the review was performed following a procedure of grounded-theory method for literature review at the Analyze stage, that involves activities such as open coding, axial coding and selective coding intertwined in an iterative mode (Wolfswinkel et al. 2011).

The papers included in the review were read through and relevant fragments were highlighted with some notes made on the side. Based on the excerpts, I was trying to formulate a concept summarizing it and note it. While considering the possible concepts I was avoiding the terms used in the text itself, instead looking at more abstract words that carry the essence of the text under discussion. For some papers rich in contextual information I was also writing memos to record additional thoughts that were not suitable from coding, but may be used to construct categories or main themes. The final list of concepts in relation to the literature was documented in form of the matrix of concepts (see Appendix 2).

Coding documentation

For the purpose of documentation, a table listing codes was used, where concepts were recorded including their name, explanation and example excerpt from the literature to illustrate the concept. While naming the concepts it was avoided to use the same words as in the paper, rather to represent it in abstract terms. Explanations were rewritten or adjusted when more texts were analyzed.

The open coding produced a lot of results for the first couple of papers, but I had difficulties to proceed with that technique. Coding procedure proposed by Wolfswinkel et al. turned out to be too rigid for the scope of the project. The format of the table used for the codebook worked well when recording concepts emerging from a single paper, however it offered only limited possibility to express relations between concepts, what was a core task of axial and selective coding.

The different stages of coding were intertwined and merged as after reading part of the papers a critical mass of concepts begin to clarify. The codes were constantly changing, because they had to be adjusted in order to represent the concept described differently in different papers. For example grouping some concepts under other concept that appeared to be of the higher level required a lot of re-arrangements in the codebook table, which was cumbersome and difficult to manage. That let me to gradually abandon the codebook and look for more flexible ways to perform the analysis.

5.1.3 Structuring the design space: Card sorting technique

In order to express relationships between concepts, I have started to first sketch them in my notebook dedicated to the project. However, the arrangements at that stage were very fluid and sketches turned out to be overcomplicated. Therefore the first attempt to organize the concepts emerging from the coding took a form of card sorting. The individual concepts and its brief explanations up to one sentence were printed out on separate cards, so they can be placed in different combinations.

Cards were then arranged on the wall and served to dynamically test different grouping options (see Fig. 5). The concepts were not complete in terms of number and areas of design space they covered, but they represented the most significant ideas identified during coding. New concepts were added as they were emerging from the literature review. Overall, the “cards on the wall” technique proved to be flexible and efficient. It allowed to express uncertainty of relations between the concepts, which was prevalent at this stage of the analysis. Also, such a representation served as a reference point during the reading, as at any time I could have a look at the arrangement of existing concepts and relate a new thought to it. Finally, it was easy to add a concept without committing it to a certain place in the design space, simply by placing it on the side. The cards were presented to the advisors and they were used to stimulate the discussion during a supervision meeting.

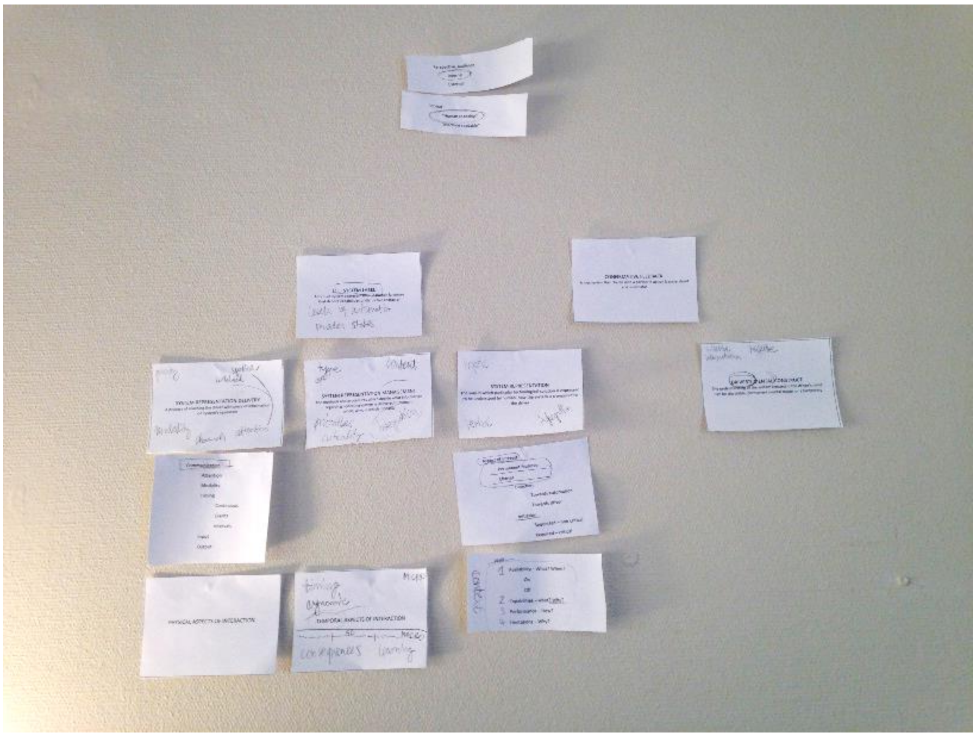

Figure 5. One of the card sorting iterations on the wall.

5.2 Scheme of Use

The second stage of the project served to develop a format for the presentation of the design space which will allow its practical application. The development was an iterative process in which initial ideas underwent couple of shifts and refinements. However, these transformations always served an underlying purpose of the project, which is supporting interaction design process. The purpose of the work could correspond to the Present step of methodology by Wolfswinkel et al., but there is a fundamental difference in terms of intended outcomes between the framework and the thesis project. At this stage the methodology meant for producing a literature review paper could not be applied to creating a design tool, as it is focused on theory building, not developing practice.

In the consequence, I had to adopt an individual approach, which was driven by negotiation of two forces: the content of the design space and user feedback. My work aimed to balance the tension between complexity of the conceptual tool and the requirements of people using it. I was working in iterations that consisted of three elements: recognizing a design issue, creating a solution that can address it, and confronting it with the users.

5.2.1 Iteration 1: Tables as a way to visualize the design space

The initial efforts were dedicated to the structure, hierarchy and arrangement of the concepts forming the design space. This work was partly performed in parallel with coding phase and card sorting. As the main groupings of concepts started to clarify, the related aspects were arranged under them. The problem was to represent that structure in a format that can be communicated to others.

In a first attempt, the concepts were grouped in three tables called accordingly: System Representation, System Representation Management and Status Communication Loop, with the last further divided to Automation Side and Driver Side. The System Representation was understood as a mental model of the automation created by the designer in the development process. System Representation Management was a general term to describe all rules and methods that are applied to System Representation. Finally, Status Communication Loop was covering cycles of delivery and response to status messages. The hierarchy of concepts falling under these groups was represented by divisions of columns in the tables (see Fig. 6).

SYSTEM REPRESENTATION					
Logic The underlying model of the system		**Function** Aims of system representation		**Form** Means of expression	
Sources System design Automation paradigms *Automated driving* *Driver support* *Adaptive automation* Design ideals *Harmonious interaction* *Intuitiveness/Natural interaction* *Compatibility* *Consistency* *Acceptance*	**Defining factors** Control and authority Levels of vehicle operation Stages of information processing Levels of driving task Type of driving situation Driving speed	**Safety related** Supporting situation awareness Avoiding automation errors Prevent mode confusion	**Non-safety related** Informing the driver Supporting user acceptance Providing good user experience Educating about automation	**Verbal** System labels *Levels of Automation* *Automation Modes*	**Audience** Internal – Driver and vehicle passengers External – Road users, other vehicles
Structure Continuous *Scale* Progressive, gradual *Levels, modes* Intermittent Integrated	**Dimensionality** One-dimensional (HAVEit) Two-dimensional Three-dimensional (VDA)			**Non-verbal** Visual *Abstract* *Pictorial* Haptic *Force feedback* *Actuation* Auditory *Vocal* *Acoustic*	

Figure 6. The first version of the design space representation.

Additionally, I was looking for a model that would explain relations between main categories and help to place them in relation to the design process. The inspiration came from a representation presented in the paper on design for balanced human-automation systems by Flemisch et. al (2011, p. 6). Based on that, I have divided the design process into three phases of pre-use (when the development takes place), actual usage (automated driving) and post-use (when the driver's mental model of automation is constructed and the system can be evaluated). That model allowed to locate thematic groups of System Representation and System Representation Management at the development side, while Status Communication Loop could be placed in usage as a way of delivering the previous two to the driver (see Fig. 7).

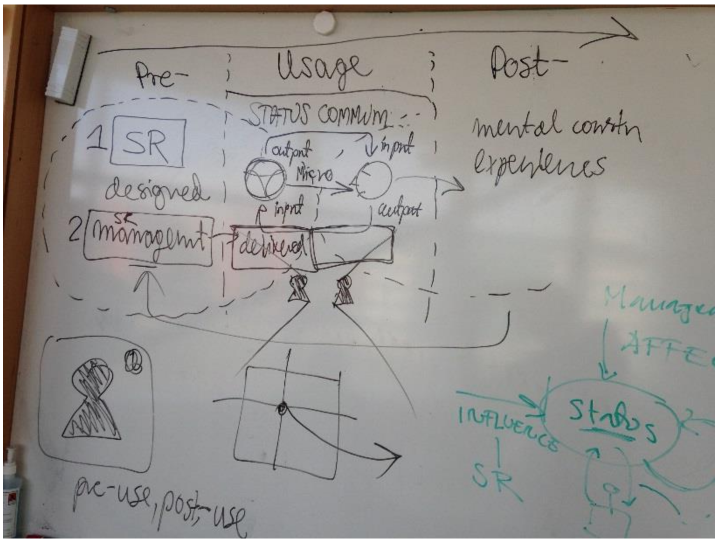

Figure 7. Sketch of initial ideas on the design space division form the process.

The division to the three groups presented in the tables, together with the model explaining their relations, were discussed with supervisors. That consultation revealed several problems with the structure, the presentation format and the language used. The main comment was that the wording should be simplified and the structure more focused and unified. A very useful suggestion was to try to arrange the concepts according to how they answer to the basic questions of What?, Why?, When?, Where?, How? and Who? in order to bring a clarity into the design space presentation.

5.2.2 Iteration 2: Simplified tables as the design space visualization

In the second iteration I followed with redesigning the tables. The problem at this stage was how to organize the information so it can be presented in a clear and concise form. That required to change the wording for the groups and clarify their meaning. I was looking for a reference in a well-established and practice-oriented interaction design literature.

An inspiration was found in a diagram showing main concerns in user experience design by Cooper, Reimann & Cronin (2007, p.xxxi). The three areas listed there are Form, Content and Behavior and they are explained as corresponding to different professions involved in development of digital products. That division informed an organization of concerns in the design space and provided names for its highest layer. Furthermore, following the Content and Form areas could have been easily mapped to the groups System

Representation and Status Communication Loop. However, the term Behavior have not covered all the remaining aspects, so wider term Context was used to denote all dynamic and situation-dependent concepts of the group System Representation Management. The three tables were reorganized accordingly to the new arrangement in a way that the columns corresponded to with the levels of the hierarchy. The levels of the design space were represented from the highest on the left to the lowest on the right (see Fig. 8).

CONTENT			
Category	**Aspect**	**Property**	
Sources	Automation paradigms	*Automated driving* *Driver support* *Adaptive automation*	
	Design ideals	*Harmonious interaction* *Intuitiveness/Natural interaction* *Compatibility* *Consistency* *Acceptance*	
	Defining factors	*Control and authority* *Levels of vehicle operation* *Stages of information processing* *Levels of driving task* *Type of driving situation* *Driving speed*	
Structure	Continuous Progressive, gradual Intermittent Integrated	*Scale* *Levels, modes*	
	Dimensionality	*One-dimensional* *Two-dimensional* *Three-dimensional*	
Format	Verbal - System labels	*Levels of Automation* *Automation Modes*	
	Non-verbal	*Visual*	*Abstract, Pictorial*
		Auditory	*Force feedback, Actuation*
		Haptic	*Vocal, Acoustic*
Subject	Permanent features	*Capabilities* *Limitations*	
	Status change	*Direction of change* *Initiation* *Scope*	

Figure 8. The second simplified version of the tables.

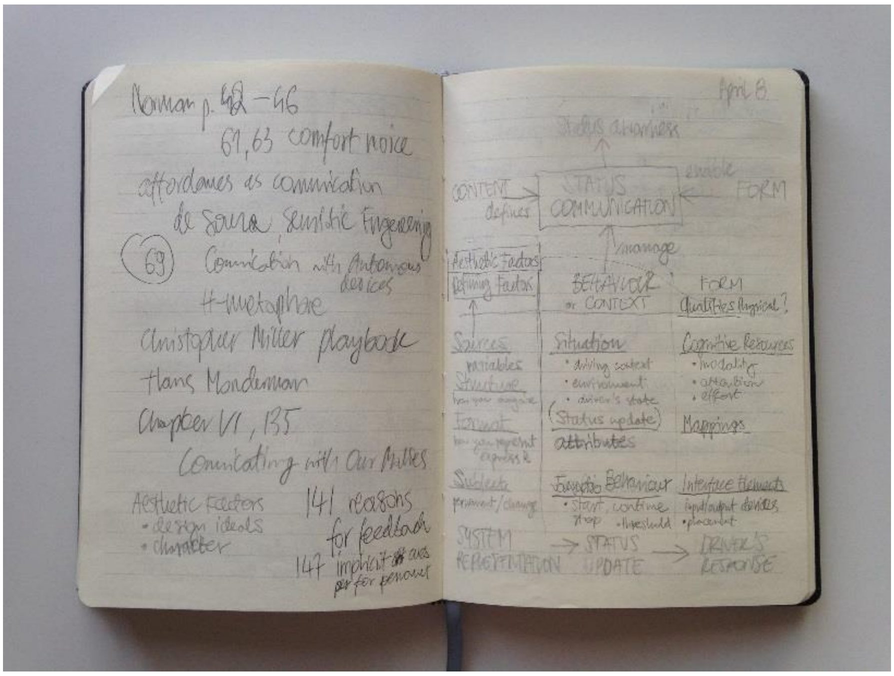

Figure 9. Schema illustrating relations of design space themes to the subject of status communication (page on the right).

Further inspired by the user experience diagram, I have tried to present relationships between the three areas and status communication. For that purpose, they have been arranged according to the questions they try to answer. The Content theme corresponds to questions What? and Why?, the Context theme to questions When?, Where?, and the Form theme to the question How?. I have sketched a simple schematic showing these relations, where the central subject of status communication was placed in the middle and the themes were located around it with arrows showing the questions with which they are concerned (see Fig. 9).

The new version was presented and discussed with a fellow interaction design student who had a previous experience of working on the project dedicated to automated driving. No formal test was performed, but the work was presented to the student and then discussed in an open conversation. The conversation took a form of an unstructured interview, where I was trying to ask follow up questions in response to the situation in order to gain an understanding of the problems that seem to appear.

The overall conclusion after the meeting was that the presentation format does not work for intended use of the design space. After analyzing the gathered observations and comments, I have formulated the needs for the design space representation:

- The structure of the design space should be mapped to some familiar representation or metaphor, so it supports an intuitive understanding of the main relationships within design space.
- The designer does not need to be presented with the whole complexity of the design space at once, but rather gradually.
- As the design space operates with lots of abstract terms, the format could possibly be more tangible.
- It was not clear for what the design space is meant to be used and how a designer can found it useful.
- It should be easier to manage it as a tool in terms of understanding, using and navigating through it.
- Use of more approachable language.
- Categories names and terms should be explained with short descriptions, examples or some illustration.
- The format should be more attractive, raising curiosity and keeping attention, as the current format was boring or making the person to get tired quickly.

However, there were also elements of the presentation in which I have noticed an improvement. The new labels for three main thematic groups of the design space were well understood just with a short explanation. Furthermore, it could be seen that the way to present they relation to status communication was very effective.

5.2.3 Iteration 3: Introducing design game concept

At this stage of the process I was convinced that a radical change of my design strategy is required. The presentation format for the design space developed to the point failed to meet the goals of the project, which was to serve as a support of the design process. Therefore the problem for this iteration was to find a new way to approach the issue. There was a clear need for a change, however it was not straightforward to see which direction the change should take. Not only there were many possible ways that can be followed, also the rationale for choosing a certain way had to be identified.

Keeping these considerations in mind, I have decided to base my further work on the input already gathered in the previous iteration. I have critically analyzed the feedback I have received and defined requirements for a new approach that would address the main problems:

- Understanding through form – embed the relations between design space elements into the presentation format
- Building on user's knowledge – use a metaphor, so people can relate the design space format to something familiar
- Reveal step by step – do not expose the whole complexity of the design space at once, allow to adjust level of detail of the presentation

There were also elements of the presentation that proved to bring it closer to the intended goals of the design space and therefore I have decided to keep working with then in this iteration. These included the names of the thematic groups Content, Context and Form and the schema representing their relation to the status communication. Then I proceed to sketching and design exploration taking as a starting point the main themes of the design space in relation to its subject. Three interesting ideas has been developed in that process.

The first concept that emerged was to use a metaphor of a tree for an information architecture of the design space, so to represent the hierarchy of layers in the design space. The tree metaphor have been applied in the following way:

- Roots: the numerous concepts form the aspects to consider, which in turn can be grouped in categories, which feed the main three themes
- Trunk: three main themes form a core of the design space, which is communication of status between the driver and automated system
- Crown: the goal and the outcome of communicating status is status awareness, which can lead to several other desired results, such as situation awareness, good collaboration between the driver and the automation, or well calibrated trust in automation.
- Foliage: status awareness contribute to numerous factors related to safety and comfort of driving as well as experiences that the driver has in automated vehicle
- The tree metaphor served as a conceptual tool and it was not meant to be used literally in the design space presentation.

The second idea was to separate the content of the design space from its organization. It was motivated by the fact that the big amount of information included in the presentation already proved to cause confusion for the users. Therefore it was expected that by splitting the information from the way it is organized can be beneficial. The first part could then serve as "a map" of the design space, while the second part would carry all the relevant information. Used in combination, both parts would allow to control amount of information and reach the relevant aspects of the design space.

Finally, the third thought was to develop the presentation format as a design game. The motivation to use a metaphor of a game in the context of the design space presentation was threefold: to make this design task playful, to establish a base for understanding by introducing a familiar metaphor, to help structure the presentation format to be uses as a group activity. The notion of a design game was believed to be particularly promising, as such method was previously used to support design process. Some examples of design games include group activities to facilitate user participation (Bødker & Buur 2002). Even a framework for designing exploratory games within participatory design was proposed (Brandt 2006). Other design games were created to be used in research on design methodology and for educational purposes (Habraken & Gross 1988). The review of design game examples helped me to realize more precisely the goals of the support I was designing for in terms of its audience and function. The tool to be developed for the thesis project was not addressed to users, but to designers, and was aimed to support design decisions, not to gather input.

In particular, I have focused on a board game as "a well-known facilitator of social interaction" (Bødker & Buur 2002, p.162). I believed that the collaborative aspect and team work can be supported through physical representation. Furthermore, I found inspiring an idea of translating a theory into a design tool by giving it physical form. It was implemented for example in the Tangible Interaction Frogger where the authors created a physical and dynamic representation of a tangible interaction framework (Chaboki et al. 2012).

The idea of a board game emerged when I was sketching the structure of the design space in form of a tree diagram and spontaneously I folded the edge of the paper to hide the aspects listed there, so I could have more focus on the higher levels. I continued to fold and unfold different layers and realized that this technique can be a realization of many requirements. That quick-and-dirty paper sketch was a first version of the board element of the final design tool (see Fig. 10). Following the game logic, I envisioned the cards that can hold information about the aspects of the design space. Lastly, as a part of the design game, it was thought about the form that users of the tool can use to document the outcomes of their work on the problem, which led to the development of a "sketch" element – a piece of paper on which design choices can be quickly noted.

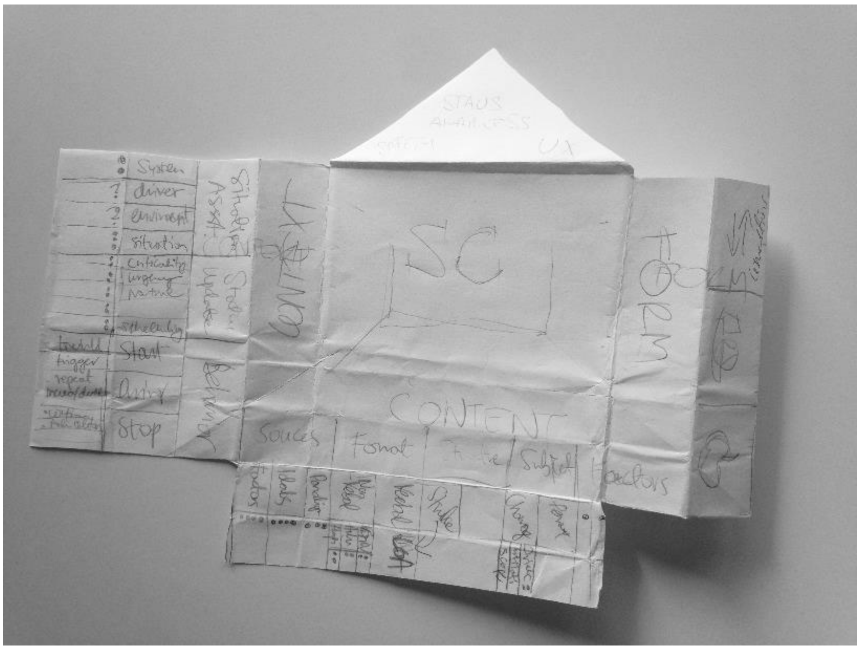

Figure 10. The first quick-and-dirty sketch of the board element.

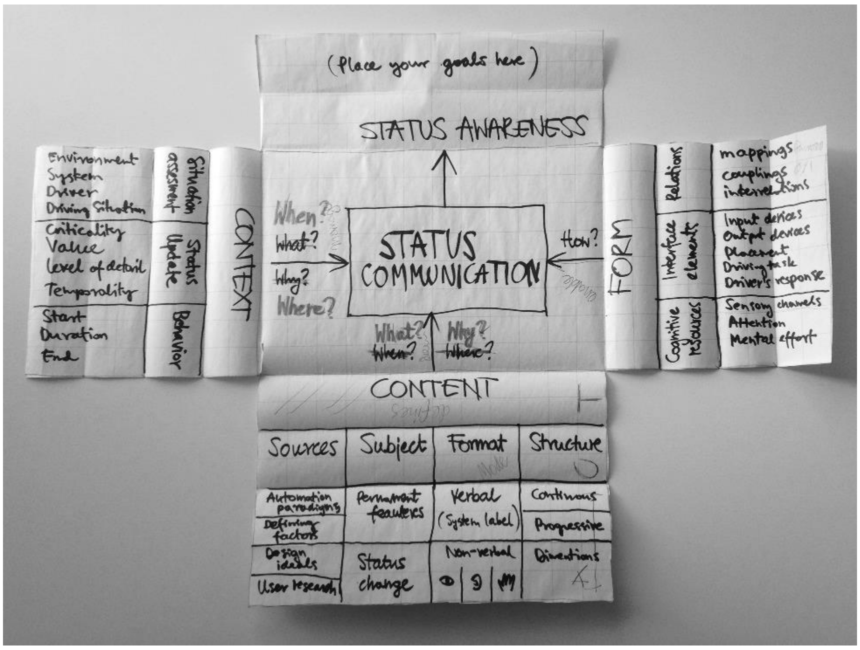

Figure 11. The second, full-scale paper prototype of the board.

The first full-scale paper prototype of the board and the "sketch" was created as a proof of concept and presented to the supervisors of the thesis (see Fig. 11). The concept was received very positively and gathered constructive feedback. To sum up, the new approach developed in this iteration responded to the requirements set for the design of the presentation format in all three areas:

- Understanding through form – the relations between design space elements has been represented on the board through their position in relation to the main subject, the structure is to be separated from its content:
    - The structure of the design space can be represented on the board.
    - The content (aspects belonging to the design space) can be represented as cards, one aspect per card, that carry all information about the aspect.
    - The board allows to locate an aspect in relation to the status communication.
    - The design choices based on cards are noted on a “sketch” paper.
- Building on user’s knowledge – the design game as a metaphor, as a board game format is familiar to majority of users, as well as cards.
- Reveal step by step – dynamic elements of the game would allow the board to be extendable or shrinkable depending on interest and need, card could be placed face up or in the stack do not expose the whole complexity of the design space at once, allow to adjust level of detail of the presentation.

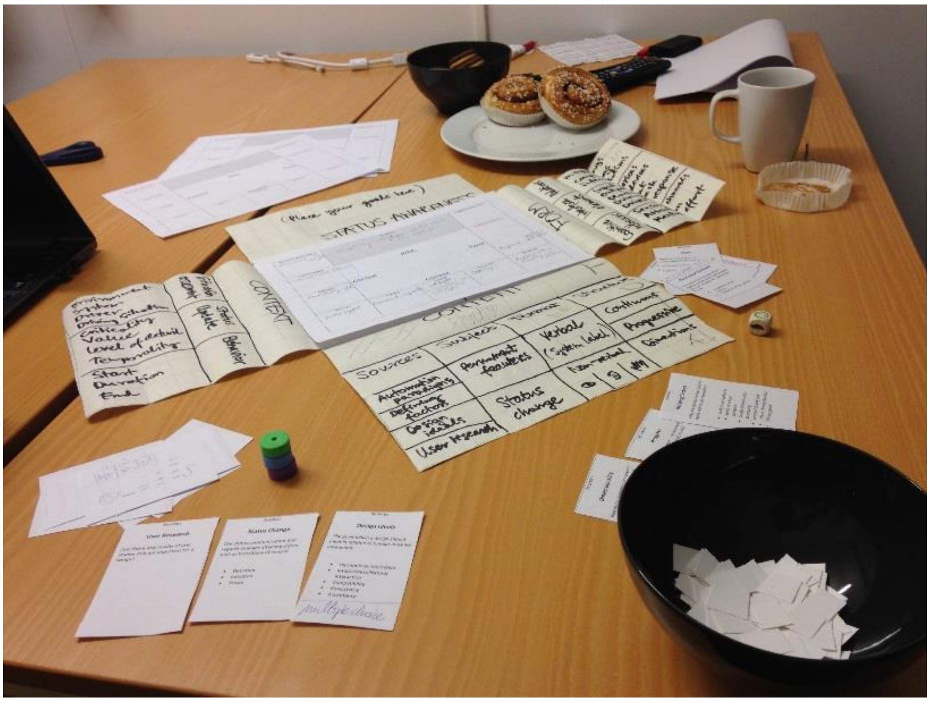

Figure 12. The second paper prototype completed with cards and “sketch” paper during gameplay prototyping.

5.2.4 Iteration 4: Creating a design game prototype

At this stage dedicated to the further development of the design game concept, the task was to give a form to the ideas and try them out. The second paper prototype consisted of the board element from the previous iteration, but was completed with cards holding information about aspects printed on paper (see Fig. 12). The cards were very rough in terms of their appearance and content, but they all included the title of the aspect and some options corresponding to it. The size of the tool was determined by the size of the “sketch” paper and set to be A4 format, so it is convenient to use it in a standard office environment. It was important to consider this aspect of the “sketch element”, because if the tool was going to be useful, it should be easy to integrate it with common working standards.

The preparation of cards required to include information covered in the design space in concise form. The properties and options were filtered and completed to the extent possible at that stage. In this way the development of the presentation format was helping to refine the content of the tool. However, the first version of cards lacked the aspects from the Form theme. The prototype was tested with an industrial designer currently working on projects within automotive industry, but without specific knowledge of vehicle automation. The problems observed during that session were mostly regarding the cards and provided good input for their design.

5.2.5 Iteration 5: Prototyping a gameplay for the design game

The important aspect of the game metaphor applied to the design was that the game implicate play. At first gamification appeared to be a suitable direction to follow. I have considered possible arrangements and discussed them with experts form the Interaction Design department, who have agreed to share their expertise in gameplay design. These independent conversations with three researchers were very informative and immersed me in considerations on nature of gamification and playfulness.

Thanks to a short literature review and consultations I have gained better understanding of the different ways in which playfulness can be manifested (Hunicke, LeBland & Zubek 2004; Lundgren, Bergström & Björk 2009; Lucero & Arrasvuori 2010; Arrasvuori et al. 2011; Knaving & Björk 2013). That allowed me to define more precisely the type of the play I was aiming for with the original concept. The playfulness intended in the design for the design space presentation could be defined as an experience opening up for creativity, inviting for exploration, generating unexpected insights.

I was further testing different gameplay dynamics aiming to achieve these factors with the tool I was developing (see Fig. 11). However, these attempts led me to realize that the game design would both exceed the scope of this thesis and my design skills. The game would need to be a consistent system which I did not have resources to develop in course of this project.

Therefore, I have become convinced that the scheme of use for the design space defined in the project should be described as a tool, rather than as a design game. Although the concept of a design game greatly contributed to the development of the project, its full realization would not match the scope of the work and its intended outcomes. I did not wanted to push game metaphor too far in my design by setting expectations towards certain experience when the design was not able to keep that promise. Rather, if the users discover aspects of playfulness the design tool can offer an element of surprise.

During this iteration there were two feedback sessions organized in order to test different ideas for gameplay with use of the design space representation. The participants were Master students in Interaction Design programme, including two people with no previous experience with vehicle automation, but a game design knowledge and one familiar to both topics. A very interesting, although technically difficult to realize suggestion came out from the participant was to consider where can be placed cards when they were used, and even to provide a sort of “pockets” in the board, where cards can be stored.

The input regarded a learning curve of the new tool. As it was easy overwhelm the user by offering too much information at once, there was a need to introduce participants to the cards and “funnel” their activities through the tool. Another observation was a need to illustrate a notion of status communication and explain how status communication differ between manual and automated driving. Overall, the test playing sessions proved that the goals of the project need to be reached in other way than through a board game metaphor.

5.2.6 Iteration 6: The emergence of a design tool

After considerations on the nature of the presentation format and designing it as a design tool, I could proceed to design of a more robust and refined prototype. The prototype was planned to be used in the evaluation workshops. At this stage the content of the design space was available and elements of its physical format were well defined. The design problem at this stage was creating a look and feel for the tool that would meet the threefold goals:

- Ease the use of the tool by making relationships between different elements of the tool recognizable without reading the text
- Support the understanding of the design space with visual cues, therefore lower the mental workload required for learning the tool
- Provide a visually attractive form for the tool to support interest in using it

The main two design tasks at this stage were to create:

- A graphic motif that can help to differentiate three main themes from each other on the cards, to be used on the back side of the cards
- Graphic elements that will visually link the categories with the aspect cards belonging to them, to be used across all the elements of the tool

In the graphic motif for the tool I was looking to convey ideas and relationships of the design space, in particular relationships between the main themes identified: Content, Context and Form. As these terms and relations between them are abstract, therefore the idea was to use geometric, non-representative graphic elements to represent them. Tessellation patterns offered several interesting options for that, as changing parameters of geometric forms can produce variety of configurations. They were relevant for this purpose, as they present how a surface can be divided and pattern created based on a logic rules and geometrical structure. The one that served as a backbone of the design is a 2-uniform tiling (Galebach n.d.), also described as (3.42 3.4.6.4)-tiling (Lenngren 2009, p.14).

Three figures that can be built on this grid are regular triangle, rectangle and dodecagon. Dodecagon was chosen to represent the Form theme, because it is constructed from both triangles and squares, similar like the Form is a combination of elements of the Content and the Context. The rectangles built from squares form a frame around triangle, what can symbolize the Context theme in a way that the Context encompass the Content.

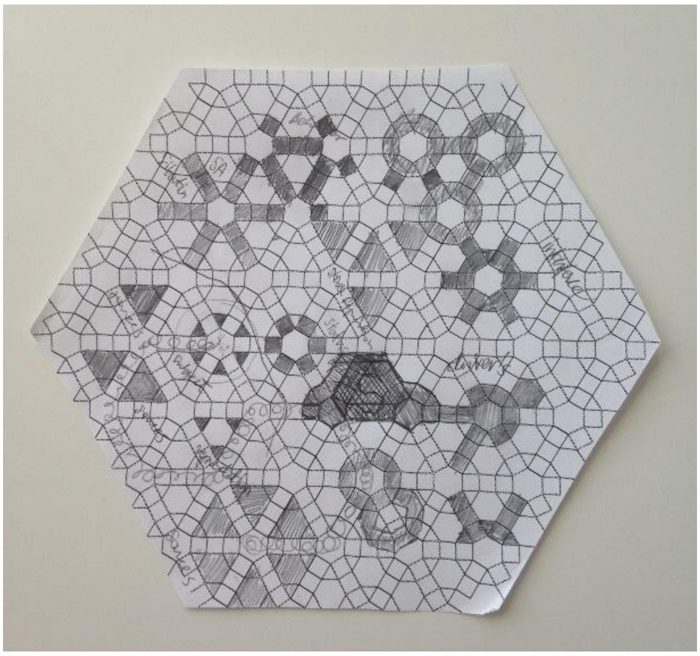

Figure 12. Sketch illustrating process of creating icons on the tiling grid.

Having the graphic motif based on a tessellation grid, the design for icons proceeded straightforward. In order to keep the look consistent, I decided to constrain the design for icons in a way that they have to be constructed on the tessellation grid by highlighting selected figures (see. Fig. 12). First I have sketched several forms for possible icons, keeping meaning of the categories in mind and trying to follow a rule that the categories belonging to the one theme should be represented with an icon built from shapes corresponding to that theme. For example, forms generated for the Content theme were variations of triangles, while the Context theme icons were based on squares only. In case of the Form theme, for which I decided to use combination of triangles and squares, I have seen possibility to compose more pictographic icons, so they can represent their categories in more concrete forms (e.g. Driver's Resources, Interface Elements).

Overall, the icons were not meant to illustrate the category, but to stand for it in a distinctive visual form. Therefore, at the next step I have tried to select forms that differ the most from each other, so they will not be easily confused. After choosing nine options that were satisfying all the above criteria, I have redrawn them in a digital vector-based format, so they can be readily used across the design.

The other concern at this stage of the process was to make the prototype more robust. Therefore, I decided to print the board and the cards on a thick, quality paper of high weight. The design was kept in black and white to intentionally lower the perceived fidelity of the tool. It was important that the workshop participants will not consider the prototype to be a finished product. Also, colors attract attention to the design and can evoke certain emotions. I believe that for the design tool it is preferred that the design is as neutral as possible, so it can fade in and the designer can focus on using the tool.

This advanced prototype was tested during the first workshop with domain experts. The response was positive towards the tool, but the content of the cards required detailed explanation. The main input was that there is a need to provide guidelines on how the tool can be used. It was not clear for the participants for what purpose the tool can be used. Furthermore, there has been observed a need to offer users stronger link between the design task and use of the cards.

5.2.7 Iteration 7: Developing use cases

At this stage, having the elements of the design space presentation at advanced level and drawing from the experiences of its evaluation, I was finally able to specify schemes of use for the tool. After the first workshop with domain experts it became evident that it was lacking a context for the participants. Despite the fact that there was limited possibility to learn about a design cycles at the organization in an available time, the participants managed to provide several insights on their process. The problem for this iteration was to complement the physical tool with a cognitive scaffolding aiding users in applying it in their work. The tradeoff between learnability (few clear and well defined, but limited scenarios) and exploration (numerous and flexible uses, but risking that the user will not realize their availability) was considered in the development of use cases. Finally, use cases identified based on observation during the first workshop were:

- Brainstorming for new ideas
- Checklist for an existing design concept
- Facilitating communication within a team

The description of the use cases can be found in the section 6.2.2 Use Cases under the Results chapter.

5.3 Evaluation

The subject of evaluation was a presentation format of the design space and its content. Two main methods of evaluating the work developed in course of the project were feedback sessions and workshops with industry experts. Due to the research problem focused on design process, primary user group involved in the assessment was designers and the methods used were opinion-based and heuristics. The goal of the tests were to determine if the tool has a potential to support design process in the intended ways.

5.3.1 Expert and peer evaluation

The first part of the evaluation involved feedback sessions with interaction design students, professional designer and experienced researchers. It was important for the project to confront the tool with the designers having broad range of experience, so it can be possible to determine which group can benefit from it the most and how the use can differ between different levels of expertise.

The focus of this part of evaluation was on contributing informed insights and reactions in response to the tool, as the use of the tool was tested in the workshops. The feedback sessions had an informal character and followed a schema that it started with a short presentation of the thesis project and the problem to discuss, which was then followed by user testing the prototype and an open discussion. Before the session there was an agenda prepared, including questions of interest in relation to the tested prototype.

The meetings took place mainly during the second stage of the project, which was development of the presentation format. Usually they marked the end of an iteration and the feedback gathered at the session served to formulate a design problems and requirements for the following iteration. Some of the most valuable comments and input was gathered through such consultations.

Timing	Methods	Subject related questions	
		Content Design Space	**Format Design Tool**
Before	Participant questionnaire		
During	User test Think aloud Feedback questionnaire	Comprehendability (span of the design space) Understandability (language) Knowledge questions Identification of problem areas	Ease of use
After	Interview Group discussion	Applicability Is the content relevant for design task?	Usefulness Applicability Is the tool useful as a design support?

Figure 13. The design of the workshop.

5.3.2 Workshops

The purpose of the workshop was to test the proposed design tool with a group of designers, who are its target audience, in terms of use that it can be in the design process of status communication for automated vehicles, in particular ease of use and comprehensibility. The test tried to answer the evaluation questions regarding the content and the format of the tool. The goal was to gather feedback on both aspects and be able to distinguish if the problem is related to the game, the design space or the combination of two. The workshops took form of a user test with simulating usage. However, the actual use of the tool by the participant was limited due to the learning curve required to become familiar with the subject and the novelty of both content and representation. The design of the evaluation in relation to timing, methods and aspects to be tested is presented in the table (see. Fig. 13).

Data collection methods

The evaluation of the design tool was performed using a combination of question- and observation-based qualitative methods including:

- Test use of the design tool
  The main activity of the workshop was a demonstration in which participants tried to use the design tool by themselves in a fictional design scenario. The focus was on a broad overview of the tool, not its use to solve a real life design task.
- Questionnaire, individual user perception
  The participants were asked to fill a simple feedback form including 3 questions about understanding and completeness of information as well as perceived usefulness of the tool. The forms were planned to be distributed during the workshop after main points of the demonstration, such as rules explanation, introducing the game board, using cards, using idea card and finally after completion of the game. This method turned out to be distractive for the flow of a workshop, and therefore was not continued during the second workshop.
- Group interview, discussion
  Towards the end of the workshop the participants were asked about their overall experience and comments on the tool. The focus of the questions was mostly on getting deeper understanding of detected problems and possible improvements.
- Think aloud, observation, video recording
  The participants were asked to share their thoughts while using the tool and the test session was documented with use of video recording for an analysis of how the physical elements of the game are used. The camera was fixed to register a table with the game, not the participants (see Fig. 14).

Objectives

The workshops aimed to answer the evaluation questions regarding the proposed design space and the form of its presentation. The goal was to gather feedback on both aspects and be able to distinguish if the problem is related to the game, the design space or the combination of two. The questions related to the format included:

- Is the proposed design tool understandable for a target audience, designers and professionals working with vehicle automation?
- Which elements of the tool are easy or difficult to comprehend and why?
- Does intended audience find the tool useful?

Opinions related to the content included:

- Is it regarded as complete and comprehensive in covering a design space for status communication in highly automated vehicles?
- Do participants agree with the selection, naming and classification of aspects covered in the design space?
- Are there any suggestions for improvement or alternative solution?

Participants

The workshop was primarily addressed to the designers, subject matter experts working in the automotive industry and directly involved in HMI design for highly automated vehicles. The participants have been selected based on two criteria: designer working in automotive and arability at the time of evaluation. During the workshop there were 2 or 1 external participant, as well as the project's industry advisor and the author, who was leading the activities. Before the workshop, the participants were asked to respond to the questionnaire, in which they provided information about the job title, background, knowledge in the area of HMI design for automated driving.

Mediating tools

The advanced paper prototype of the design game was used as a mediating tool. The prototype was aimed to realistically simulate use of the tool. It represented all elements necessary to carry out a session with use of the tool at the level that would not make an impression of a final product. The fidelity of the prototype aimed not to intimidate or prevent participants from contributing their feedback, by e.g. writing their comments on the cards or on the board. Some blank cards were prepared to be available for the participants during the workshop, so they can add their own suggestions on the aspects to consider in the design space.

Context and setup

For convenience of the participants the workshop took place at the company's offices, so in their usual professional environment. The evaluation was performed in conditions close to the participants' working context, but the test did not aim to be a real life use of the design tool. Before the workshop the participants received a welcome message with the agenda for the meeting, short presentation introducing the project and a questionnaire on their background and professional experience. The workshops was scheduled for a time slot of one and a half hour. Regarding the time plan, the actual user test was taking about 40 minutes. The first quarter was dedicated to welcome and setting up the tool and the camera. Then the introductory presentation was planned for about ten minutes, the user test itself was expected to take the remaining time, with the last quarter dedicated to the summary and discussion. However, during actual workshops the user test and the discussion were intertwined.

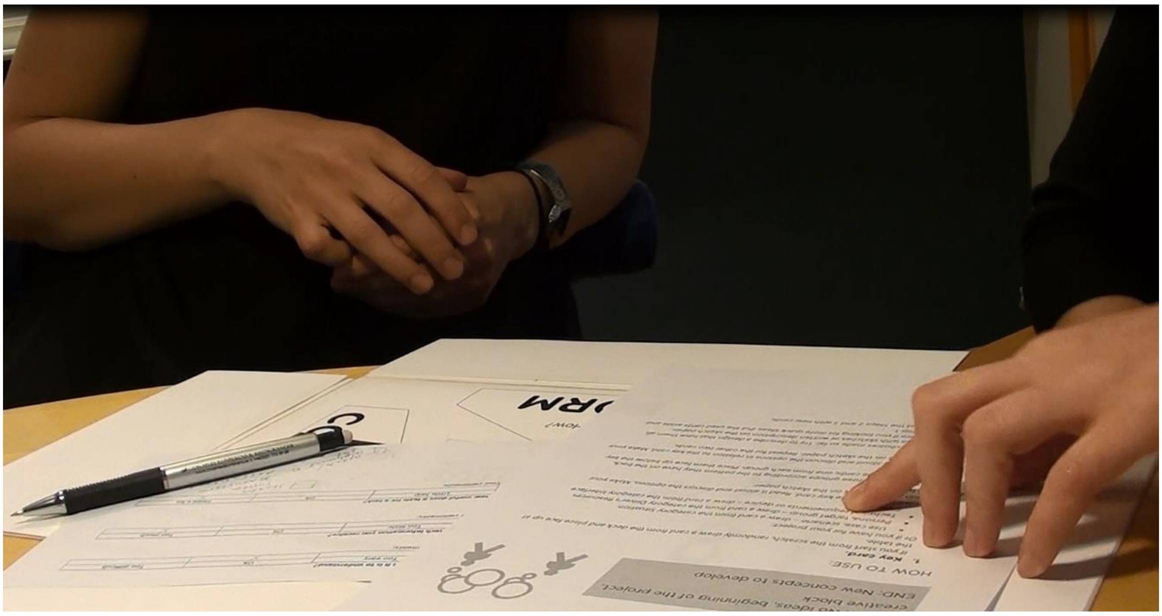

Figure 14. A screenshot from the footage took during the workshop.

6. Results

There are two main outcomes of the thesis corresponding to the two parts of the research question. The first part of the results describes interaction properties of status communication in highly automated vehicles, therefore constitutes the design space itself. The second part is a support for interaction design process in form of the design tool STATUSCOPE. Together both parts constitute an entity, in a way that the design space provides the content for the tool, which in turn is a presentation format to the design space.

6.1 Design Space for Status Communication in Highly Automated Vehicles

In this section the design space is introduced following a top-down approach, starting with the most general ideas and leading to the more specific concepts. Descriptions of elements that constitute the design space include definition of the concepts and explanation of how they are related to each other.

The design space is structured in the three layers: (1) THEMES, (2) CATEGORIES, (3) ASPECTS (see Fig. 15). This structure organizes the aspects in groups and support navigation through the design space.

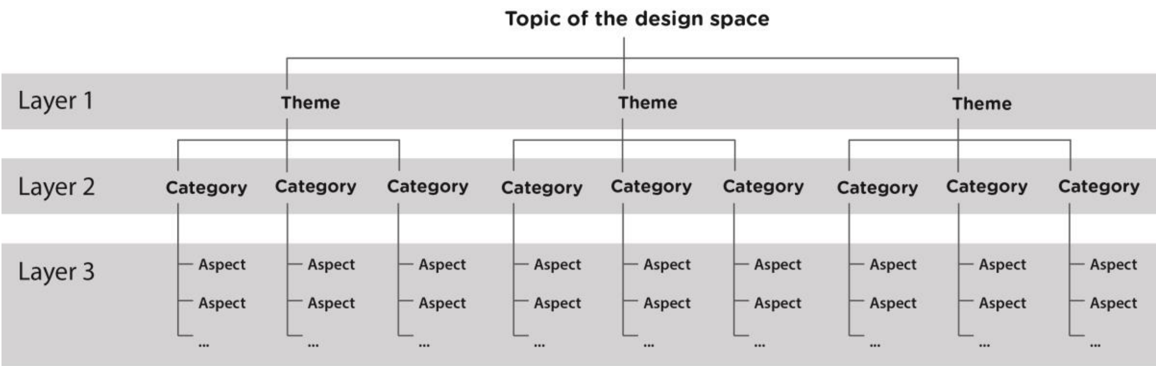

Figure 15. The organization of the design space into three layers.

The THEMES are the highest, most general groups. There are three main THEMES identified, each having three CATEGORIES belonging to it. The CATEGORIES are intermediate groups between THEMES and ASPECTS. The CATEGORIES group a number of ASPECTS that vary from three to five. For majority of ASPECTS there has been identified their PROPERTIES. The actual design decisions are taken at the level of ASPECT when chooses between PROPERTIES are made. The Fig. 16 presents the overview of the design space structure.

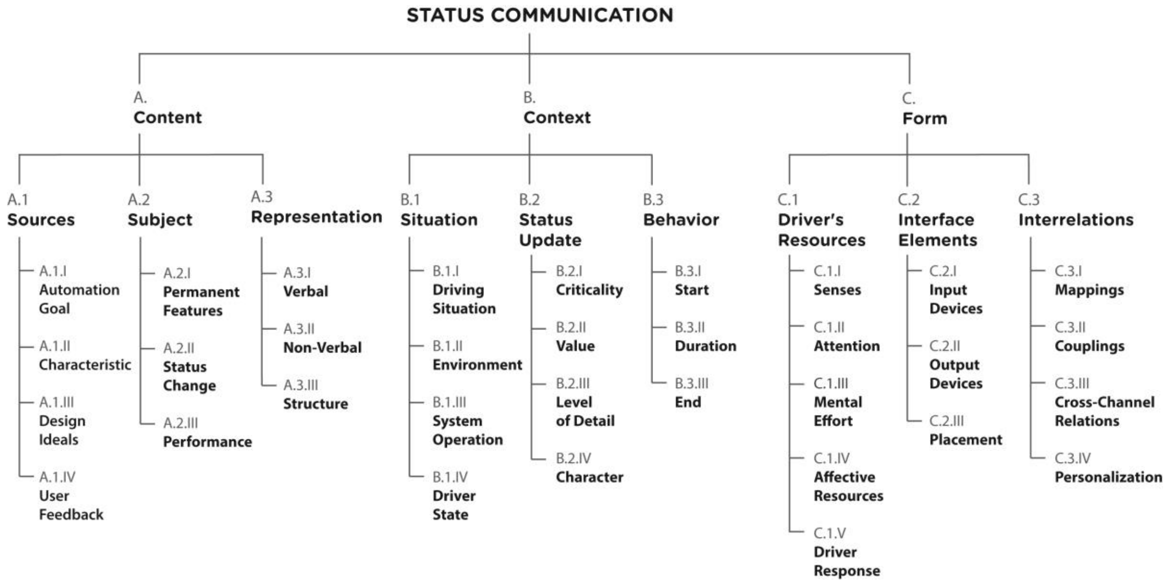

Figure 16. The diagram presenting the structure of the design space.

6.1.1 Status communication

The goal of the design space is to explore the concept of status communication in automated vehicles. What is meant by status communication in the context of this project can be seen in Fig. 17. It shows the automated driving as a triangle of interrelations between the driver, the vehicle and the automated system. The graphic representation was inspired by the diagram used in number of publications (Flemisch et al. 2008a; Flemisch et al. 2010). As the status communication is just one within many aspects of interaction between the agents in an automated system, for the purpose of the thesis the relations has been simplified to represent only those relevant for communicating the state. That serves explanatory functions and supports understanding of the design space. It also helps to illustrate how the status communication is different between automated and manual driving.

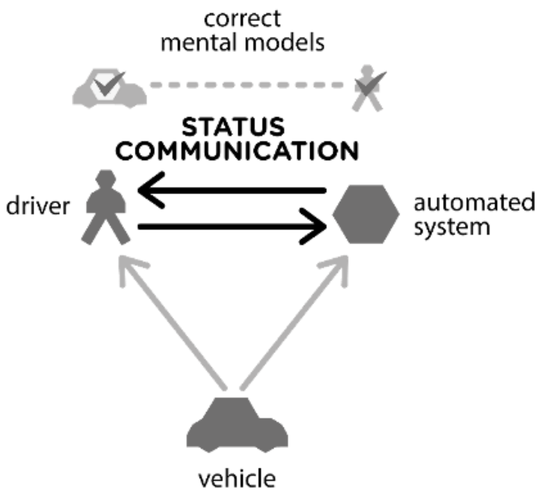

Figure 17. The model of status communication in the automated system.

In a broad sense, status communication within a system can be defined as an exchange of information between the agents during the process. When considering the context of driving, the system is consisting of a driver, a vehicle and an environment. In case of automated driving, an additional agent is introduced within the system, which is an automation. As the automation receives certain autonomy over a vehicle control it can be considered as another agent within the system, as it shares the authority with the human driver. The technology allowing the vehicle automation is incorporated all over a machine and inseparable from a vehicle, however the automated system as such is an abstract construct that helps us conceptualize such an agent. The degree to which the automation possesses control and authority over the vehicle in the certain system is expressed as level of automation.

With the automation as an agent within the driving system raises a new demand for status communication between the driver and the automated system. For a safe and comfortable driving both agents need to know who is in charge of the vehicle at the given moment. We can easily imagine how dangerous would be a situation in which the driver takes off her hands from a driving wheel being convinced that the vehicle will drive for itself while it is not the case. Or how annoying it could be to fight over a steering wheel with the automation. Therefore, it is crucial that both driver and automation stay updated about each other state.

The goal of status communication is a mutual awareness of the current status between the agents of the automated system. This awareness is a crucial issue for a safe automated driving, as an inconsistency of mental models of the situation can lead to problems with control (Flemisch et al. 2012, p.14). Status awareness differ from mode awareness in a sense that status awareness needs to be mutual. Mode awareness, a term well-established within human factors and automation domain, refers only to the status of automation as a human driver does not have modes in the same meaning as the system do.

There is a need to design status communication for automated driving similarly as there has been a need to develop status communication for manually operated vehicles. The challenge coming with automation is that technology itself is complex and intangible.

6.1.2 First layer: THEMES

The design space had been organized in three major THEMES: (A) Content, (B) Context, (C) Form, that correspond to the basic questions that the designer of status communication needs to answer. The questions of What? and Why? Fall under the theme Content. Further, the questions of When? and Where? are covered by the theme Context. Lastly, the question of How? is represented in the theme Form.

As the design space covers properties of interaction that the designer can manipulate or that come from design of the automated system, the question of an intended user lays beyond the design space. Therefore, the remaining question of Who?, which in this case relates to the intended audience or a target group, is incorporated in the design task or use case for which the design space is used. However, a human-centered approach is addressed in a design space in a way that the users are given an independent position, and are not included in the design space as a variable.

THEME A: Content

The Content theme answers the questions of what is included in the status communication and why it is communicated. This theme groups the aspects that can be derived from design of the automated system and the way it is expressed. The aspects gathered under theme Content constitute a core of the communication between the automated system and the driver. They can be distinguished from the Context, as they do not depend on the given conditions and from the Form, as they do not imply how information is delivered in physical space.

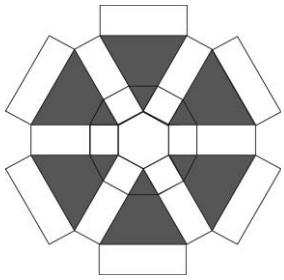

Fig 18. The symbolic representation of the theme Content.

The CATEGORIES that belong to the theme Content are:

- A.1. Sources – the basis of the status communication, what is inherited from the automated system design
- A.2. Subject – the main interest for design of status communication
- A.3. Representation – the format of expression in which the automated system is represented to the driver

The CATEGORIES are described in detail below in the section 6.1.3 CATEGORIES.

THEME B: Context

The Context theme covers the aspects responding to questions of when and where the status communication takes place. This includes all the context-dependent elements of the status communication, those which are affected by changes inside (e.g. automation mode) and outside (e.g. traffic) the automated driving system. The Context aspects can be seen as a specific realization of the Content at a given moment and under given conditions, but not attached to a specific Form. They deal with temporal (e.g. duration and order of information) and environmental (e.g. driving situation, road conditions) issues that need to be considered in order to keep the driver and the automation updated about their states.

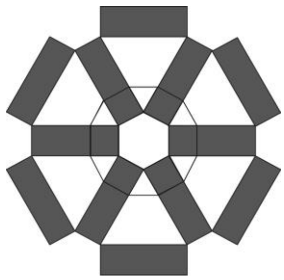

Fig 19 . The symbolic representation of the theme Context.

The CATEGORIES that belong to the theme Context are:

- B.1. Situation – internal and external conditions that affect the status update
- B.2. Status Update – a basic unit of information in status communication
- B.3. Behavior – the behavior of the status update in time

The CATEGORIES are described in detail below in the section 6.1.3 CATEGORIES.

THEME C: Form

The Form theme groups the aspects that specify how the status is communicated in a physical space and which resources are used for that communication. The aspects placed under this theme define input and output modalities (e.g. sensory channels, display devices), as well as the relations between input and output. They provide the material form to the Content and the Context of the status communication.

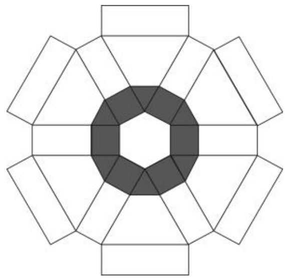

Fig 20. The symbolic representation of the theme Form.

The CATEGORIES that belong to the theme Form are:

- C.1. Driver's Resources – cognitive, emotional and bodily resources required in status communication
- C.2. Interface Elements – elements of the human-machine interface used for the status communication
- C.3. Interrelations – relations that exist between the driver's resources and the interface elements used for the status communication.

The CATEGORIES are described in detail below in the section 6.1.3 CATEGORIES.

6.1.3 Second layer: CATEGORIES

This section contains explanations of nine categories that were defined within the design space. The descriptions begin with the information about the position of the category in relation to the higher theme layer and the lower aspects layer. This is followed by the explanation of why the category belongs to a certain theme and why it contains certain aspects. Lastly, the relationships between aspects within the category are briefly described.

CATEGORY A.1. Sources

Position in the design space:
THEME A Content
Definition:
The Sources category refers to the underlying information that determine the content of status communication. The Sources constitute the basis of the status communication and what it inherits from the automated system design.

Fig 21. The icon of the category Sources.

Description:
There are four ASPECTS identified as the Sources of content for the status communication in automated driving:

- A.1.I. Automation Goal - a paradigm for the automated system design
- A.1.II. Characteristic - the factors used to define vehicle automation
- A.1.III. Design Ideals - the ideals or design goals that motivate the design of human-machine interaction
- A.1.IV. User Feedback - any relevant user studies that should be considered in the design

Automation Goal and Characteristic are typically inherited from the automated system design, as they are two most common aspects used in the literature and by authorities to describe vehicle automation. Design Ideals and User Feedback may not be addressed in case of every project, however they can serve to remind these aspects as possibilities to consider.

CATEGORY A.2. Subject

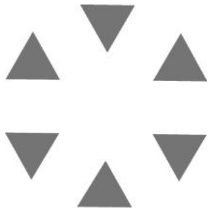

Fig 22. The icon of the category Subject.

Position in design space:
THEME A Content
Definition:
The Subject category specifies the main area of interest for design of status communication. The Subject marks a scope for which the design is aimed for, what is important as the requirements differ between areas of interest.
Description:
There are three ASPECTS identified as Subject for the status communication in automated driving:

- A.2.I. Permanent Features - implicit aspects of the system related to capabilities and limitations of the vehicle automation
- A.2.II. Status Change – any variation of the system or the driver status important for driving task
- A.2.III. Performance - the state of the vehicle automation in operation at a given moment

The all three aspects can be communicated together, but are not required to be. The aspect of Status Change received the major attention in the existing literature as it is the most safety-critical subject out of the three to be communicated. The communication of the Status Change is manifested in the Status Update. Up to date Permanent Features and Performance has been explored to the limited extent.

CATEGORY A.3. Representation

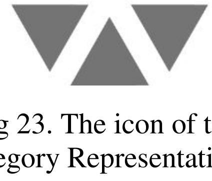

Fig 23. The icon of the category Representation.

Position in design space:
THEME A Content
Definition:
The Representation category describes how the automated system is represented to the driver as a content of status communication.

This aspect describes basic properties of representation in terms of format of its expression and organization.
Description:
There are three ASPECTS identified as format of the category Representation:

- A.3.I Verbal – the way in which word, numbers and symbols are used in the system representation
- A.3.II. Non-Verbal – the way in which the system representation is communicated without use of words, numbers and symbols
- A.3.III. Structure – the organization of the system representation

This category should not be confused with the theme Form, which describes representation of the system in terms of its physical properties. The format of expression and the way the system representation is organized affect the form which the Content can take. The Verbal and Non-Verbal Representation does not exclude each other and often can work in a complementary way. The Verbal Representation can use the terms appearing in the Characteristic. The aspect of Structure is important to consider for both formats of expression.

CATEGORY B.1. Situation

Fig 24. The icon of the category Situation.

Position in design space:
Theme B Context
Definition:
The Situation category covers different context-dependent aspects that affect the status communication, such as internal and external conditions of driving.
Description:
There four ASPECTS of conditions shaping the Situation has been identified:

- B.1.I. Driving Situation – the type of the driving task to be performed by the driver and the automated system
- B.1.II. Environment – the ability of the automated system to sense and assess safety based on information about the environment
- B.1.III. System Operation – the ability of the automated system to sense and assess safety of its own operation
- B.1.IV. Driver State – the ability of the automated system to sense and assess safety based on information about the driver

The use case for vehicle automation is usually defined by the Driving Situation in combination with different levels of safety for the Environment, the Driver's State and the System Operation. The System Operations aspect is linked with the Performance. The automation can have limited abilities to monitor Driver State in comparison to the driver's perception.

CATEGORY B.2. Status Update

Fig 25. The icon of the category Status Update.

Position in design space:
Theme B Context
Definition:
The category Status Update describes properties of a basic unit of status information communicated at a given moment. The status information consists of a piece of the Content that needs to be communicated in order to maintain status awareness.
Description:
The four ASPECTS describing the Status Update information are:

- B.2.I. Criticality – the level of the criticality of the status information for safety
- B.2.II. Value – the relation of the status information to the actual state of the system
- B.2.III. Level of Detail – the amount and precision of status information included in the update
- B.2.IV. Character – the position that the status update takes towards the driver

The Status Update is particularly interrelated with the Status Change, as ”any change in the system state has also to be reflected in the mental model of the actors, and if this update of the mental model fails, this inconsistency can lead to undesirable situations” (Flemisch et al. 2012, p.14). The aspects of the Status Update category determine requirements on how the status information should be delivered and therefore can have strong implications on the aspects from the Form theme.

CATEGORY B.3. Behavior

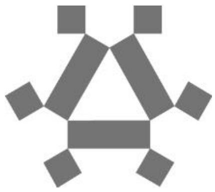

Fig 26. The icon of the category Behavior.

Position in design space:
Theme B Context
Definition:
The category Behavior defines the way in which the given piece of status information will behave in time, which is determined by the context-dependent aspects.
Description:
For the purpose of the simplicity, the Behavior of a status communication has been divided into three ASPECTS:

- B.3.I. Start – the conditions that the status information need to meet to be communicated
- B.3.II. Duration – the behavior of the status information over the time it is communicated
- B.3.III. End – the conditions that need to be meet for the status information to stop being communicated

The Start, Duration and End aspects apply to any Status Update that takes place in the status communication. Furthermore, adjusting parameters of the Start aspect can be used to filter the updates and the End aspect might ensure that the communication was successful.

CATEGORY C.1. Driver’s Resources

Fig 27. The icon of the category Driver’s Resources.

Position in design space:
Theme C Form
Definition:
The category Driver’s Resources groups all types of the bodily, cognitive and emotional resources that can be used in sending or delivering the status communication.
Description:
The five ASPECTS grouped under this category list the ways in which the status information reaches the driver physically and is mentally processed:

- C.1.I. Senses – the sensory channels required for the status communication
- C.1.II. Attention – the type and amount of attention required for the status communication
- C.1.III. Mental Effort – the type and level of mental effort required for the status communication
- C.1.IV. Affective Resources – the emotional and reflective states aimed to be evoked with the status communication
- C.1.V. Driver’s Response – the parts of driver’s body required to respond to the status communication

The Form of the status communication is partly defined by which of the driver’s physical resources serve as channels of input and output. The consideration of the driver’s mental resources contributes greatly to the Status Updates being successful. All the aspects of Driver’s Resources should be addressed in the design, especially when designing for a safe, holistic and truly embodied experience, however they need to be considered and applied with caution.

CATEGORY C.2. Interface Elements

Fig 28. The icon of the category Interface Elements.

Position in design space:
Theme C Form
Definition:
The Interface Elements category covers all the in-vehicle resources that can be used for the status communication. It groups aspects that allow the status communication on the side of the automated system to take a physical shape. The category is based on the previous work on design space of automotive user interfaces (Kern 2011, p.44).
Description:
The three ASPECTS falling under this category were identified:

- C.2.I. Input Devices – the interface elements used for an input in the status communication
- C.2.II. Output Devices – the interface elements used for an output in the status communication

- C.2.III. Placement – a physical location of the input and output devices used for status communication

The Interface Elements deals with giving a physical form to the system representation. The aspects from this category are related with the Driver's Resources in a way that the Input Devices need to be consulted with Driver's Response and Driver State, while the Output Devices are corresponding to Senses.

CATEGORY C.3. Interrelations

Position in design space:
Theme C Form
Definition:
The category Interrelations refers to relations that exist between physical and mental resources involved in the status communication. The relations between these resources take form of the combinations between input and output channels.

Fig 29. The icon of the category Interrelations.

Description:
The four ASPECTS can be identified to describe the Interrelations:

- C.3.I. Mappings – the relations between the status update and modalities used to communicate it to the driver
- C.3.II. Couplings – the relations between input and output channels used to communicate a status update
- C.3.III. Cross-Channel Relations – the configuration of modalities used to communicate a status update
- C.3.IV. Personalization – the consideration of needs and preferences of individual drivers

The aspects from this group refer to the most advanced, meta-issues in design of the status communication and address multimodality in the interface design on different levels of design decisions (Sarter 2006).

6.1.4 Third layer: ASPECTS

In this section there are presented explanations of the 33 aspects identified within the design space. Every name of an aspect is followed by the information to which theme and category it belongs to, so it can be placed in relation to the design space. The aspects' descriptions include their definition, properties and range of identified options for design decisions. The motivations to include given aspect under certain category is presented above, under the section 6.1.3 CATEGORIES.

ASPECT A.1.I. Automation Goal

Position in the design space:
THEME A Content, CATEGORY A.1. Sources

Definition:
The Automation Goal can be defined as an underlying vision of human-machine interaction that drives design and development of vehicle automation. This aspect sets a paradigm for the automated system design.
Description:
Three main approaches can be found in the literature based on the degree to which driving is automated:

- Fully automated driving
- Driver support
- Adaptive automation

Fully automated driving is an automation paradigm aiming for a system that, according to the definition by German Federal Highway Research Institute (BASt), does not require supervision of a human driver (Gasser 2013, p.10). In the other definition, full automation means that "safe operation rests solely on the automated vehicle system" (NHTSA2013, p.5). An example of such approach is a self-driving car developed by Google (Fagnant & Kockelman 2013).

Driver support is an alternative approach to vehicle automation that postulates partial automation as both more realistic to implement than full automation and more human-centred. It also aims to be guided by the drivers' needs and resigns from applying all possible technological advancements (Beukel & Voort 2011).

Adaptive automation is a concept of "having machines adapt to the cognitive and physical demands of users in a momentary and dynamic manner" (Hancock et al. 2013, p.10) and is concerned with the question of timing as much as with selection of functions and degree of their automation (Calhoun et al. 2012, p.413). It has been discussed as an attempt towards human-centered automation (Kaber & Endsley 2003; Hancock et al. 2013) and as a way to "reduce the driver's workload by filtering the presentation of information according to situational requirements" (Saffarian, de Winter & Happee 2012).

ASPECT A.1.II. Characteristic

Position in the design space:
THEME A Content, CATEGORY A.1. Sources
Definition:
The Characteristic covers factors user to formulate the definition of automated system to be used in status communication. This aspect deals with the way in which system representation is formulated.
Description:
Researchers and authorities use various factors to define vehicle automation, some of these dimensions found in the literature include:

- Control and authority (Flemisch et al. 2012)
- Levels of vehicle operation (e.g. longitudinal, lateral control) (Gasser 2013)
- Stages of information processing (Parasuraman, Sheridan & Wickens 2000)

- Levels of driving task (Beukel & Voort 2011)
- Type of driving situation (Beukel & Voort 2011)
- Driving speed (Verband der Automobilindustrie 2014)

There can be one or many factors employed in the definition of the automation states. From the interaction design perspective there is a trade-off between simplicity and accuracy of representation. For the purpose of regulations there are three or more factors used to define level of automation (Gasser 2013; VDA 2014), but in the interface design this can be reduced to one dimension (Flemisch et al. 2011, p.273).

ASPECT A.1.III. Design Ideals

Position in the design space:
THEME A Content, CATEGORY A.1. Sources
Definition:
The Design Ideals are goals that motivate the design of human-machine interaction in context of automated driving. They are often postulated in the literature and can serve as a reference for design decisions. Such ideals are important as they help to formulate goals for the design and requirements for a solution.
Description:
Some examples of the goals that are set for interaction design in automated driving found in the literature include:

- Intuitiveness (Damböck et al. 2011, p.377)
- Natural interaction (Norman 2007, pp.57–80)
- Compatibility (Flemisch et al. 2008a; Hesse et al. 2011)
- Driver acceptance (Beukel & Voort 2011, p.233)

The above list is open, as there can be other, more specific goals that may need to be considered in the given design task.

ASPECT A.1.IV. User Feedback

Position in the design space:
THEME A Content, CATEGORY A.1. Sources
Definition:
The User Feedback consist of any relevant studies or input from users that should to be considered in the design. This aspect encompass all that can be learnt from testing a design with the drivers.
Description:
The main sources of the User feedback are in case of vehicle automation:

- Simulation study, for example (Merat & Jamson 2009; Toffetti et al. 2009; Schieben et al. 2011)
- Test track (Hesse et al. 2013)
- Demonstration (Broggi et al. 2013)
- Real life use (data from use of existing ADAS functions)

The most common source of user feedback found in the literature review is simulator study due to the fact that several tests cover experiments regarding safety-critical scenarios, such as automation failure and therefore cannot put participants at risk.

ASPECT A.2.I. Permanent Features

Position in the design space:
THEME A Content, CATEGORY A.2. Subject
Definition:
The Permanent Features covers implicit communication about persistent aspects of the system independent from a given situation (Norman 2007, pp.61–66), such as its ability for automated driving and the boundaries of its operation. Understanding of system capabilities and limits by the driver is seen as one of main elements contributing to safe operation of automated vehicles (Abbink, Mulder & Boer 2012; Saffarian, de Winter & Happee 2012).
Description:
Implicit status communication may address the automated system in terms of:

- Capabilities, e.g. communication of an ability for automated driving: "automation capabilities of a specific vehicle" (Flemisch et al. 2008a, p.3)
- Limitations, e.g. continuous communication of availability if conditions for operation of a sub-system change frequently (Hesse et al. 2011, p.286)

As an example of the permanent feature communication can serve a simulator test of an ACC system performed within HAVEit, in which the participant was reported to be able to understand availability of the system based on indication of the sensor data (Schieben et al. 2011, p.262).

ASPECT A.2.II. Status Change

Position in the design space:
THEME A Content, CATEGORY A.2. Subject
Definition:
The Status Change defines all types of variations affecting the system status, which may be caused by change in abilities or intentions of the driver or of the system. In literature they are discussed mostly as transitions of control, either by switching between manual and automated driving or change in active level of automation.
Description:
Three basic properties can be used to classify changes in the system status (Schieben et al. 2011, pp.252–253):

- Direction (from the driver to the automation or from the automation to the driver)
- Initiation (by the driver or by the automation)
- Scope (suggested change or required change)

The changes affecting status were given a lot of attention in the literature, as they are regarded as moments in automated driving most prone to confusion (Flemisch et al. 2012, p. 14). Using the properties listed above, the take-over situation can be described as a required change in control over the vehicle directed from the automation to the driver and initiated by the automation. If the automated system is designed in a way it decides itself on the level of its operation, the communication of the status is crucial to avoid errors associated with loss of the awareness (Abbink, Mulder & Boer 2012). However, the status change does not have to be necessarily in regard to the control. The subject of change can be for example an intent or an ability of the system, which adjustment in accordance to the situation is communicated as feedback or feedforward (Koo et al. 2014).

ASPECT A.2.III. Performance

Position in the design space:
THEME A Content, CATEGORY A.2. Subject
Definition:
The Performance aspect covers communication of how well the automated system is performing at a given moment of its operation.
Description:
Communicating the performance of the system during automated driving on the regular basis is believed to be possibly provide an alternative to using warnings and alerts (Helldin et al. 2013). However, this aspect of status communication has been explored to the limited extent. In the existing literature a communication of the system performance is discussed as displaying uncertainty of the system (Helldin et al. 2013; Beller, Heesen & Vollrath 2013). Examples of different uncertainty visualization include a use of the face symbol with an emotional expression (Beller, Heesen & Vollrath 2013) and graphical representation of a bar illustrating the system ability (Helldin et al. 2013). The other properties related to the system performance except uncertainty can be also communicated, such as automation parameters, reliability and ability (Helldin 2014). Also, it was suggested that the uncertainty visualization can be mutual, with both the automation and the driver presenting their uncertainty level (Helldin et al. 2013, p.205).

ASPECT A.3.I. Verbal Representation

Position in the design space:
THEME A Content, CATEGORY A.3. Representation
Definition:
The Verbal Representation aspect can be defined as the way in which the automated system is communicated with the use of words, numbers or symbols.
Description:
All the information about the system status, which is meant to be delivered to the driver in a textual format falls under this aspect. The common examples of verbal representations of the automated system include labels used to denote:

- levels of automations
- the system modes
- massages

For example the designs of generic displays developed for HAVEit demonstrator vehicles used labels to represent available levels of automation on the scale (Flemisch et al. 2011). Also, warning messages are usually communicated as text (Koo et al. 2014). It is worth to note that as the representation of the system, use of textual format of the status communication needs to match driver's mental model, which is likely to differ from implementation models used in the development process (Cooper, Reimann & Cronin 2007, pp.27-32).

ASPECT A.3.II. Non-Verbal Representation

Position in the design space:
THEME A Content, CATEGORY A.3. Representation
Definition:
The Non-Verbal Representation aspect can be defined as the way in which the automated system is communicated without using words, numbers or symbols, but with use of other communication channels than verbal.
Description:
The Non-Verbal Representation of the automated system may be expressed in a format addressing different modalities:

- Visual (abstract, pictorial)
  An example of abstract visual representation can be the automation scale or bars indicating the automation performance (Helldin et al. 2013). Pictorial representation is often used in form of icons, e.g. depicting cars (Flemisch et al. 2012).
- Auditory (vocal, acoustic)
  Although auditory messages have been used mostly for warnings, they can have a potential to serve status communication as well. The effects of vocal versus acoustic information has been studied in context of take-over situation (Merat & Jamson 2009).
- Haptic (force feedback, actuation)
  An example of a haptic system representation can be a design using a grip force to communicate the level of automation (Damböck et al. 2011, p.380).

In the literature visual, auditory and haptic channels are typically used in combination to communicate with the driver and often together with textual labels and messages.

ASPECT A.3.III. Structure

Position in the design space:
THEME A Content, CATEGORY A.3. Representation
Definition:
The Structure aspect refers to how the system representation is organized.
Description:
The two properties that can be used to describe the Structure aspect of the system representation are its:

- Integrity – defines if the system is represented to the driver as an entity or as a group of sub-divided systems
- Continuity – defines if the representation of the system is continuous, e.g. scale or divided into discrete states, such as levels, modes

An interesting approach to continuity of the system representation is “fluid transition” (Schieben 2011, p.255). Haptic interfaces may allow for fluent transitions through the whole spectrum of automation scale (Damböck et al. 2011) or integrated, modeless integration (Griffiths & Gillespie 2005). Also in terms of structure of the system representation it should be noted that the focus of design for status communication should be on the driver’s mental models and not on actual technical model of its operation (Cooper, Reimann & Cronin 2007, pp. 27-32).

ASPECT B.1.I. Driving Situation

Position in the design space:
THEME B Context, CATEGORY B.1. Situation
Definition:
The Driving Situation aspect refers to the type of the traffic conditions in which automated riving is to be performed and the design of status communication is aimed for.
Description:
The three properties which were identified to describe the Driving Situation for automated driving are:

- Speed, such as low or high speed
- Road type e.g. parking lot, urban road, highway
- Familiarity, e.g. unknown, known, familiar

The speed in which the automated system is capable to operate is one of the factors that has been used for defining the automation use cases (VDA 2014). Driving situations can be classified according to environmental and driver’s individual differences, which corresponds to the road type and familiarity properties, according to Beukel & Voort (2011, p.229).

ASPECT B.1.II. Environment

Position in the design space:
THEME B Context, CATEGORY B.1. Situation
Definition:
The Environment aspect defines for which states of environmental conditions the design of status communication is aimed for.
Description:
The Environment aspect can be described by the ability of the automated system to sense and assess safety based on information about surrounding conditions, such as traffic or weather. For the purpose of simplicity the Environment aspect has been classified by the property of safety on the three step scale:

- Safe

- Risk
- Danger

For example within the interactIVe project some accident scenarios were analyzed, such as rear-end collisions which would involve detection of traffic situation around the automated vehicle (Hesse et al. 2011). These scenarios could be described as risk or danger environmental conditions.

ASPECT B.1.III. System Operation

Position in the design space:
THEME B Context, CATEGORY B.1. Situation
Definition:
The System Operation aspect defines for which states of the automation the design of status communication is aimed for.
Description:
The System Operation aspect can be described by the ability of the system to recognize the state of its own operation. For the purpose of simplicity the System Operation aspect has been classified by the property of safety on the three step scale:

- Normal
- Risk
- Failure

Many of the studies within the field focus on situations of failure or a risk of failure and the need of control take-over by the driver (Merat & Jamson 2009), however the transitions in normal driving has been investigated too (Schieben et al. 2011). If the System Operation is decided to be communicated to the driver it may be interlinked with the Performance aspect.

ASPECT B.1.IV. Driver State

Position in the design space:
THEME B Context, CATEGORY B.1. Situation
Definition:
The Driver State aspect defines for which driver’s states the design of status communication is aimed for.
Description:
The Driver State aspect can be described by the ability of the system to recognize the state of the driver, such as drowsiness or distraction. For the purpose of simplicity the System Driver State has been classified by the property of safety on the three step scale:

- Safe – normal driver state
- Risk – states such as distraction or drowsiness, which may affect driver performance
- Danger – non-responsive driver

An example of monitoring the driver state by the automation system can be found in the HAVEit project in form of the Driver State Assessment component (Flemisch et al. 2011).

ASPECT B.2.I. Criticality

Position in the design space:
THEME B Context, CATEGORY B.2. Status Update
Definition:
The Criticality aspect of the Status Update describes if the given status information is critical for the safety of the driver or not, as the design for automated driving is safety-critical.
Description:
The Driver State aspect can be described in a simple terms by stating if the given status communication is:

- Critical
- Non-critical

This distinction is important for the design as different measures and requirements has to be considered to communicate the safety-critical information. For example some states of the system that may lead to an accident, such as a deficit of control between the driver and the automation requires "extra safeguards" in the design to ensure that they are effectively communicated (Flemisch et al. 2012, p. 15).

ASPECT B.2.II. Value

Position in the design space:
THEME B Context, CATEGORY B.2. Status Update
Definition:
The Value aspect of the Status Update describes a relation of the status communication to the state of the system, and it defines if the given status information corresponds to actual change of vehicle state or to its past or future state.
Description:
The Value aspect can be defined as (Flemisch et al. 2012):

- Real value – corresponds to actual state of the system
- Nominal value – represents past or future state of the system

Some authors underline importance of communicating both actual and future states of the vehicle as well as the system's intentions (Damböck et al. 2011; Flemisch et al. 2012; Koo et al. 2014). This can include both feedback and feedforward, with the feedforward playing an important role in preparing the driver to take action if required and building trust in the automation. The role of such a nominal status communication is discussed in the context of the shared control automation and "team player" approach (Davidson & Alm 2009).

ASPECT B.2.III. Level of Detail

Position in the design space:
THEME B Context, CATEGORY B.2. Status Update
Definition:

The Level of Detail aspect of the Status Update refers to amount and precision of the status information included in the status communication.

Description:

The Level of Detail aspect can be classified according to the amount of the information delivered in the status communication:

- Minimum
- Optimal
- Maximum

The implications of different levels of accuracy in the status information are not fully understood yet, but the driver's responses to them have been investigated for example in a simulator study (Koo et al. 2014). An additional property to define the Level of Detail aspect can be possibility to reduce or expand the information being communicated.

ASPECT B.2.IV. Character

Position in the design space:

THEME B Context, CATEGORY B.2. Status Update

Definition:

The Character aspect of the Status Update refers to the position that the status update takes in relation of the driver.

Description:

The Character aspect can be described in terms used in relation to user interfaces and originally suggested by Reeves and Nass (Lundgren 2011, p.116):

- Submissive – the status update presents no call to action
- Suggestive – the status update proposes an action as a possible option
- Dominant – the status update calls for action

The character of the status information can be illustrated by the example of the interaction scheme "Transition layers", in which status changes initiated by the automation are classified as proposed or enforced (Schieben et al. 2011, p.254).

ASPECT B.3.I. Start

Position in the design space:

THEME B Context, CATEGORY B.3. Behavior

Definition:

The Start aspect of the status communication defines the conditions that the status information need to meet in order to start being communicated.

Description:

The two main properties that have been identified to characterize the Start aspect are:

- Threshold criteria – describes the conditions that need to be satisfied so the status information is allowed to be communicated, for example urgency can be a decisive factor
- Initiation – defines if the status information is triggered by the driver, by the system or can be started by both agents within the system

Status communication needs to be selective, so it does not overload the driver and "an intelligent interaction & information architecture needs to determine which state should be communicated when and in which way" (Hesse at al. 2011, p. 286). The threshold criteria such as urgency can be linked to the Criticality aspect and interdependent with the Status Change aspect. An example of a high level threshold criteria can be "The communication of the system status depends on the status confusion risk" (Hesse et al. 2011, p.286).

ASPECT B.3.II. Duration

Position in the design space:
THEME B Context, CATEGORY B.3. Behavior
Definition:
The Duration aspect of the status communication defines how a given status update should behave over the time it is communicated.
Description:
The three main properties that have been identified to characterize the Duration aspect are:

- Ordering – the ranking of the status information e.g by priority or by applying a certain filter
- Persistence – static or sequential lasting of the status information
- Intensity – dynamics of the status information such as increase, stable or decrease

An example of application of the intensity property can be the "Escalation/de-escalation" interaction scheme (Schieben et al. 2011, p.255). Also, it can be manifested in the sequence of interaction, when the status update may evolve in time and in relation to situation, what is used in the context of warnings (Hesse et al. 2011, p.287).

ASPECT B.3.III. End

Position in the design space:
THEME B Context, CATEGORY B.3. Behavior
Definition:
The End aspect of the status communication defines what conditions has to be meet for the information to stop being communicated.
Description:
The three main properties that have been identified to characterize the End aspect are:

- Effect – defines if registering an effect of the given status update is required to stop communicating it, e.g. succeed or failed
- Confirmative feedback – describes if the effect is communicated to the driver
- Stopped – defines if the status information is ended by the driver, by the system or can be stopped by both agents within the system

An example of ensuring that transition was successful and confirmative feedback can be a strategy of "Interlocked transitions", which provides an explicit feedback to the driver (Flemisch et al. 2011, p.274; Schieben et al. 2011, p.255)

ASPECT C.1.I. Senses

Position in the design space:
THEME C Form, CATEGORY C.1. Driver's Resources
Definition:
The Senses aspect refers to the sensory channels that are required for the status communication.
Description:
The three main sensory channels that were studied in context of automated driving, followed by some properties that can be used in the design, are:

- Vision (contrast, color, lightness, shape, Gestalt laws, change)
- Hearing (pitch, volume, timbre)
- Touch (frequency, strength, sensation)

Some research questions regarding use of appropriate sensory channels in the system's communication with the driver were posted in the interactIVe project as (Hesse et al. 2011, p. 287). The Senses aspect is linked to the aspects of Verbal and Non-Verbal Representation in a way that sensory channels are addressed depending on the format of the system representation. Also, the Senses aspect can be seen as corresponding on the human side to the Input Devices aspect on the automation side of a communication loop.

ASPECT C.1.II. Attention

Position in the design space:
THEME C Form, CATEGORY C.1. Driver's Resources
Definition:
The Attention aspect refers to the type and amount of attention required for the status communication.
Description:
In the context of automated driving the Attention aspect can be characterized for the status communication by two general types:

- Focal attention
- Peripheral attention

It has to be noted that automated driving may allow the driver's attention to be directed to other activities than driving. En example of a peripheral display can be a LED light strip running aroung the cabin of passenger car and used to guide driver's attention to the direction from which a safety threat has be detected by the automated system (Pfromm, Cieler & Bruder 2013). Another study investigated implications of occupying the driver's attention with secondary task on automated driving performance (Merat et al. 2012).

ASPECT C.1.III. Mental Effort

Position in the design space:
THEME C Form, CATEGORY C.1. Driver's Resources
Definition:

The Mental Effort aspect refers to the type and level of cognitive resources required from the driver for the status communication.

Description:

Some of the dimensions that can be found in the literature to characterize the Mental Effort aspect in the context of automated driving include:

- Workload – describes a demand of cognitive resources that are involved in the status communication
- Information processing stage – e.g. the system 1 or the system 2 in the Kahneman's model (2011)
- Surprise factor – describes if the status communication is expected or unexpected by the driver, what can affect the workload (Toffetti et al. 2009).

Optimizing the mental workload in automated driving scenarios is seen as one of the interaction design strategies for automated vehicles (Hesse et al. 2011) and one of the design guidelines for human-automation interaction (Abbink, Mulder & Boer 2012)). Some simulator studies investigated issues of cognitive demand in driver-automation interfaces in relation to secondary task (Griffiths & Gillespie 2005; Merat et al. 2012).

ASPECT C.1.IV. Affective Resources

Position in the design space:

THEME C Form, CATEGORY C.1. Driver's Resources

Definition:

The Affective Resources aspect refers to the emotional and reflective states aimed to be evoked with the status communication and aims to address user experience design for automated driving.

Description:

Some of the emotional states identified in the literature include:

- Trust (Hesse et al. 2011; Verberne, Ham & Midden 2012; Waytz, Heafner & Epley 2014)
- Acceptance (Beukel & Voort 2011; Verberne, Ham & Midden 2012)
- Enjoyment (Walker, Stanton & Young 2001)
- Other options may include a design for addressing negative emotions (Ho & Spence 2013)

The state of research on design of affective interfaces in automotive context in general has been presented by Ho & Spence (2013) and design methods to incorporate driver's experience in the interface design process were proposed by Gkouskos (2014). The trust and acceptance factors were discussed in the context of visualization of the system performance (Beller, Heesen & Vollrath 2013).

ASPECT C.1.V. Driver's Response

Position in the design space:

THEME C Form, CATEGORY C.1. Driver's Resources

Definition:

The Driver’s Response aspect refers to the parts of driver’s body required to respond to the status communication.

Description:

The Driver’s Response aspect has been inspired by a notion of the body parts interacting with the interface elements (Kern & Schmidt 2009). The parts of the body that may be involved in the status communication are:

- Head (face, eyes, voice)
- Hands (left/ right/ both)
- Feets (left/ right/ both)

Also, the Driver’s Response aspect can be seen as corresponding on the human side to the Output Devices aspect on the automation side of a communication loop.

ASPECT C.2.I. Input Devices

Position in the design space:

THEME C Form, CATEGORY C.2 Interface Elements

Definition:

The Input Devices are interface elements used for an input in the status communication.

Description:

The examples of interface elements that can be used for receiving input from the driver, similar to manual driving (Kern & Schmidt 2009):

- buttons, knobs, stalk control
- touchscreen
- multifunctional controller
- microphone
- camera
- sensors

Decisions on the Input Devices aspect constitute “perception” system of the automation (Flemisch et al. 2008a, pp.10–11). There can be expected new input devices designed for automated driving, for instance using hands-on sensors (Flemisch et al. 2011), as they may help to establish mutual communication between the driver and the automation.

ASPECT C.2.II. Output Devices

Position in the design space:

THEME C Form, CATEGORY C.2 Interface Elements

Definition:

The Output Devices are interface elements used for an output in the status communication.

Description:

The examples of interface elements that can be used for delivering status updated, similar to manual driving (Kern & Schmidt 2009):

- indicator lamp
- digital display

- head-up display
- speakers
- vibrating steering wheel
- vibrating pedals

There have been new output devices and displays designed for automated driving. As an example can serve a LED light strip placed all around interior of a cabin developed in the project PRORETA 3 to warn the driver on the surrounding traffic situation (Pfromm, Cieler & Bruder 2013). Also a haptic side stick solution was created and tested as the device used both for input and output (Damböck et al. 2011).

ASPECT C.2.III. Placement

Position in the design space:
THEME C Form, CATEGORY C.2 Interface Elements
Definition:
The Placement corresponds to a physical location of the input and output devices used for the status communication.
Description:
The two properties used to describe position of the interface element in a physical space of vehicle interior has been based on the framework developed for user interfaces for manual driving cars (Kern & Schmidt 2009):

- Driving Task Area:
  Primary, Secondary, Tertiary
- Vehicle Interior
  Central: windshield, dashboard, steering wheel, central stack, pedals
  Periphery: Seat, side, floor, roof

ASPECT C.2.I. Mappings

Position in the design space:
THEME C Form, CATEGORY C.3. Interrelations
Definition:
The Mappings aspect refers to the relations between the status update and modalities used to communicate it to the driver.
Description:
The Mappings aspect corresponds to "the creation of natural mappings between modalities and the information and tasks to be presented" in design of multimodal interfaces (Sarter 2006, p.440). This aspect can be described by a number of ways a given status update is designed to be communicated:

- One way
- Multiple ways

The choice of modality channel suitable for a use case was posted as a research question in context of the interaction design strategies for automated driving (Hesse et al. 2011). It is worth to note that the role of the designer is to assess if use of multiple modalities is necessary and appropriate for the status communication (Sarter 2006).

ASPECT C.3.II. Couplings

Position in the design space:
THEME C Form, CATEGORY C.3. Interrelations
Definition:
The Couplings aspect refers to the relations between input and output channels used to communicate a status update.
Description:
The Couplings aspect defines if it is possible for the driver to receive and respond to the status update via the same interface element. Therefore this aspect can be characterized in terms of the directness of interaction as:

- Direct
- Indirect

The direct link between output and input of the status communication has been explored in particular for haptic sensory channel, both in theoretical and practical studies (Griffiths & Gillespie 2005; Flemisch et al. 2010; Damböck et al. 2011; Abbink, Mulder & Boer 2012). An example of an indirect interaction can be any interface in which the driver receives a visual or auditory status update, which requires a haptic response (Schieben et al. 2011).

ASPECT C.3.III. Cross-Channel Relations

Position in the design space:
THEME C Form, CATEGORY C.3. Interrelations
Definition:
The Cross-Channel Relations aspect refers to the configuration of modalities used to communicate a status update.
Description:
The Cross-Channel Relations aspect corresponds to "consideration of the resulting spatial and temporal combination and synchronization" of the channels involved in design of multimodal interfaces (Sarter 2006, p.442). This aspect applies when the design allows multiple relations of output and input modalities, such as:

- Separate – the different modalities are not interlinked in the design of status communication
- Parallel – the different modalities are intentionally interlinked in the design of status communication, but appear at the same time or one after the other
- Combined – the different modalities are interlinked in the design of status communication

The combination of modalities was posted as a research question in context of the interaction design strategies for automated driving (Hesse et al. 2011). Crossmodal links in relation to the driver's cognitive resources are discussed by Sarter (2006) and Ho & Spence (2008).

ASPECT C.3.IV. Personalization

Position in the design space:
THEME C Form, CATEGORY C.3. Interrelations

Definition:

The Personalization aspect refers to the degree in which the design allows to accommodate differences between individual drivers.

Description:

The Personalization aspect corresponds to the need for multimodal interfaces "to be flexible and take into consideration possible changes in the needs and abilities of the user, his/her tasks and workload, and the environment that (s)he is operating in" (Sarter 2006, p.442). This aspect can be considered in terms of:

- Method of interaction – defines if the design allows a primary and secondary method
- Accessibility – defines if the design addresses individual disabilities, e.g. in case of elderly drivers
- Expertise – defines if the design addresses individual knowledge and skills In terms of multimodality it is recommended that interfaces are flexible, however it is not clear if they should be adjusted by the system or by the driver
- Customization – defines if the design addresses individual preferences of the driver

The adaptivity and adaptability was posted as an aspect of the interaction design strategies for automated driving (Hesse et al. 2011). It is worth to note that it is not clear if flexibility of the interface should be controlled by the automation or the driver (Sarter 2006).

6.2 STATUSCOPE – A Design Tool

The design tool developed in this thesis work was given a name STATUSCOPE, so it can be recognizable and easier referred to. The name STATUSCOPE was selected as it is believed to convey some cues about the character of the tool and its intended use:

- Status can be defined as "the situation at a particular time during a process" (Oxford Dictionaries, 2014) and status communication is the subject of the thesis.
- -scope (from Greek *skopein* 'look at') is "denoting an instrument for observing, viewing or examining" (Oxford Dictionaries, 2014), therefore

  The STATUSCOPE can be defined as a tool for viewing and examining the problem of status communication in automated vehicles.

The logo of the STATUSCOPE tool has been designed to visualize relations between the main themes of the design space (Fig. 30). It is built on a grid of an n-uniform tiling (Galebach n.d.) and composed from three forms: triangles, rectangles and dodecagon.

The triangles correspond to the Content theme as they fill the biggest areas in the grid. This shows how the Content is providing a core set of information for the status communication. The rectangles denote the Context theme as they form a net surrounding the triangles. Similarly, the Context frames the Content with external and situation dependent aspects. Finally, a dodecagon is associated with the Form theme, as its shape is made of both from triangles and squares. That represents how the Form of the status communication gives shape to the specific combination of elements from the Content and the Context themes. Such a visualization is aimed to subtly support the understanding of the design space.

Figure 30. The logo of the STATUSCOPE.

6.2.1 Elements of the design tool

The STATUSCOPE tool consist of three elements: the board, the cards and the "sketch" paper. The paper prototype of the tool has been developed in course of the project. The elements constitute a set in which they have their unique functions, however they can be used separately as well.

The design of the tool employs tangibility of the paper prototype in multiple ways. First, it uses physicality to externalize a complex conceptual structure of the design space. Second, it utilize spatial relations between elements to convey implicit relations between layers of the design space. Thirdly, it draws on familiarity of the form to encode affordances of the tool's elements. Lastly, it supports use of the tool in a social context.

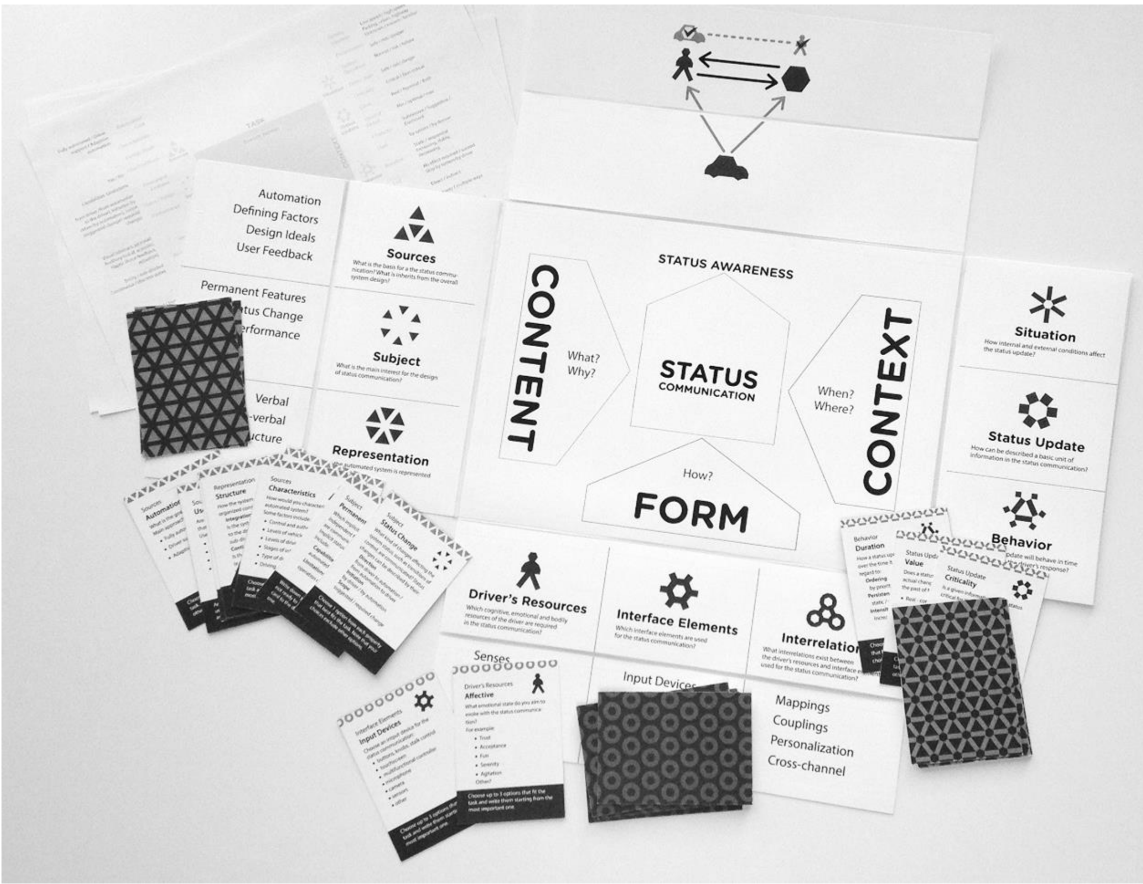

Figure 31. All the elements of the STATUSCOPE design tool.

Board

The board is the main element of the STATUSCOPE tool. It represents the structure of the design space of status communication in automated driving. The board is aimed to enable exploration of the aspects to consider in the design and supports navigation between them. The form of the board was designed to make use of tangible properties in order to convey the structure of the design space. For instance, the spatial dimension of the board allows to map the hierarchy of layers to their distance from the center.

It consist of the rectangular central piece and the four double-folded extensions that can be closed or opened independently and form both mountain and valley folds (see Fig. 32). The closed board has a size of a standard A4 office paper for the convenience in transportation.

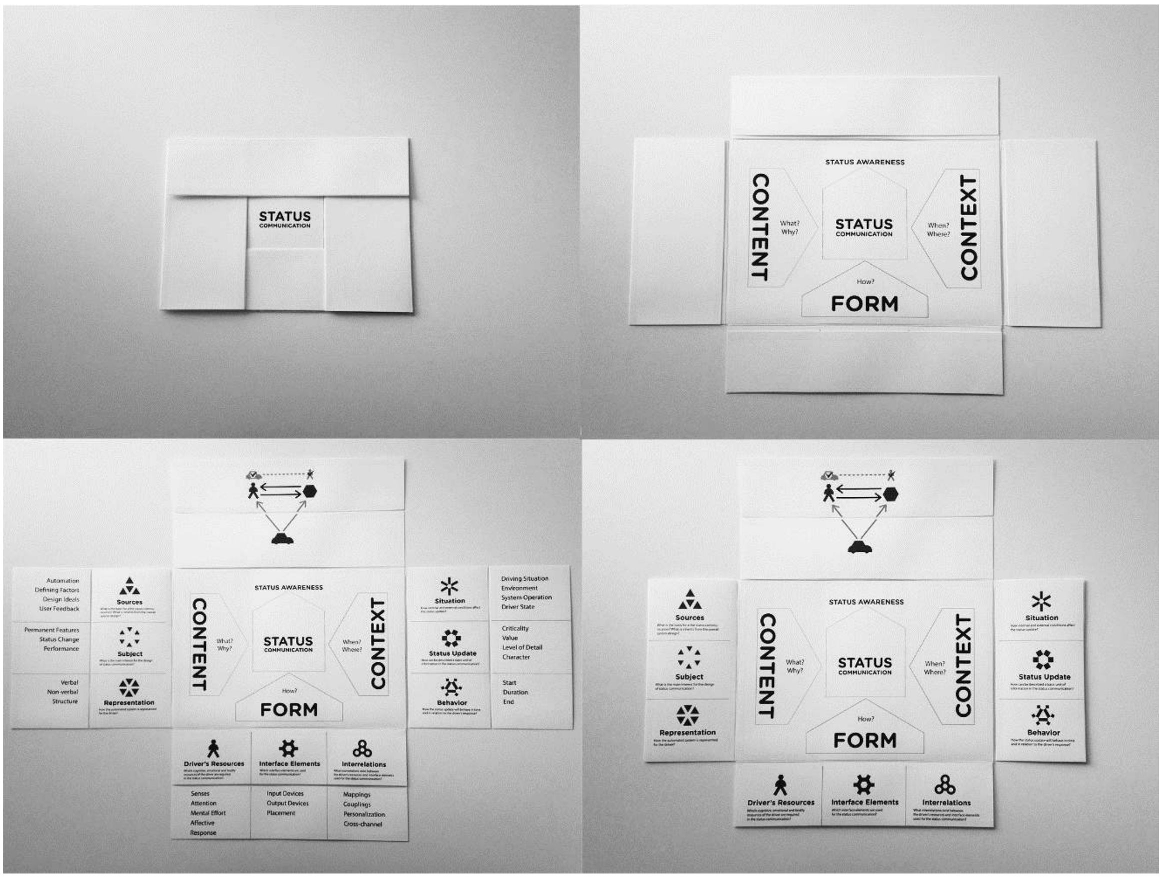

Figure 32. The four stages of unfolding the board (clockwise): (1) the closed board, (2) the first layer of the design space visible, (3) the second layer including categories, (4) the fully open board showing the third layer including all aspects.

Cards

The cards are the second element of the STATUSCOPE tool and is complementary to the board. They serve to present detailed information on the aspects identified within the design space. Their function in the tool is to allow designers to discover a range of topics to consider in the design.

The layout of a card (Fig. 33) consist of (from the top to the bottom):

- a pattern along the top edge indicating the theme
- an icon in the top right corner representing the category

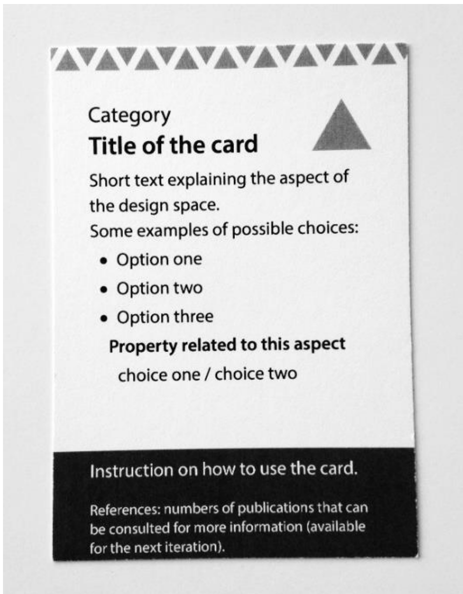

Figure 33. The design for a card layout.

- a main area providing information on the aspect of the design space, its title, an explanation and possible options for design decisions
- a bar in the bottom is dedicated to instructions of use
- on the back side of a card a pattern corresponding to the theme of the desing space (see Fig. 34).

Figure 34. The examples of cards form three decks corresponding to three main themes of the design space. The groups can be distinguished by the pattern on the back of the card (from left to right): the Content, the Context, the Form theme.

Sketch

The “sketch” paper is the third element of the STATUSCOPE tool (Fig. 35). It provides a space to document design choices made on basis of the cards. The sketch recreates the structure of the design space with the listing of possibilities for design decisions. The aim of this element is to offer a tangible outcome of using the tool to the designer.

The sketch can have multiple functions: it can be presented, discussed, used as a reference point or preserved as a process documentation. Also, it can work separately from the board and cards. The template is easily replicable as many copies may be used while using the tool.

The name of this element was decided to refer to sketchiness of ideas that may be generated while using the tool. The design is fade out by purpose, so the notes can stand out over the printed text. The sketch has a standard, A4 office paper format for easy reproduction.

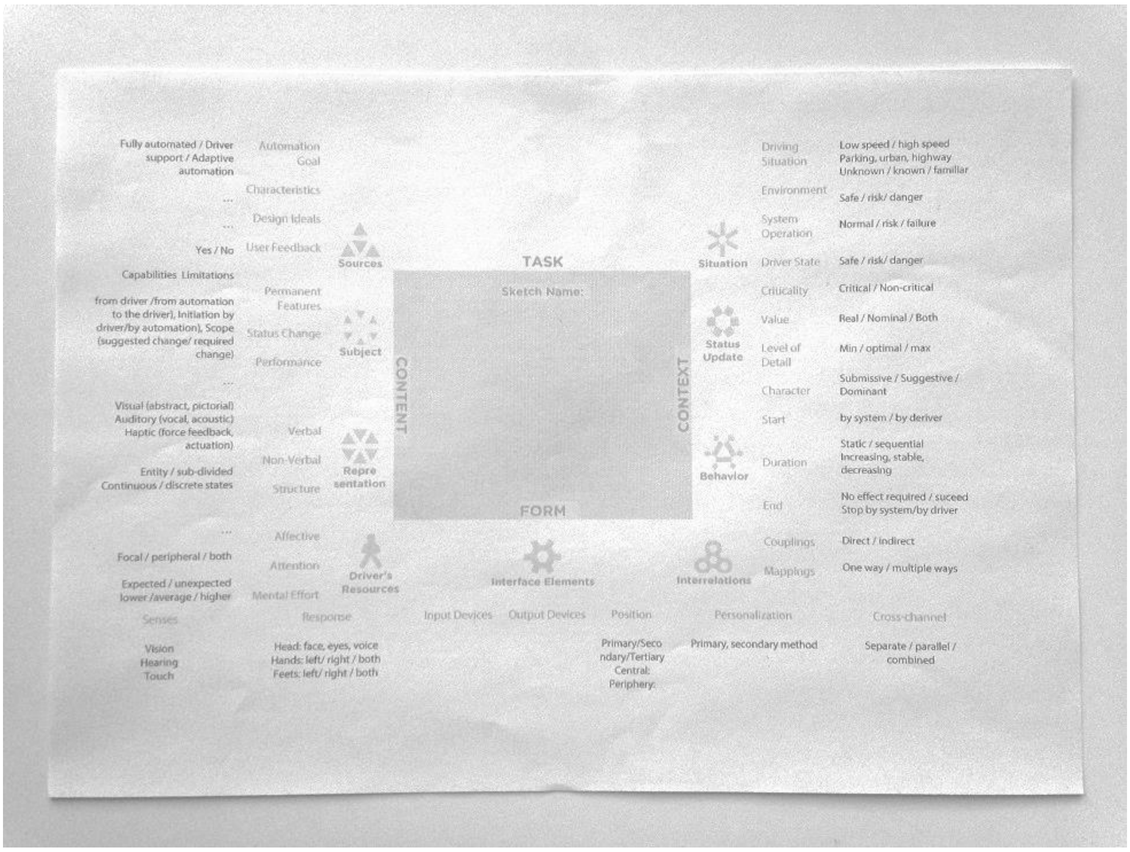

Figure 35. The design of the “sketch” element.

6.2.2 Use Cases

The overall scheme for using the STATUSCOPE tool can be described as going from thoughts to a sketch:

1. **Choose** a design task you want to work with.
2. **Explore** the design space through the board.
3. **Discover** the range of aspects to consider with cards.
4. **Decide** on your idea and fill your sketch.
5. **Move on:** take your sketch with you to present, discuss, iterate, compare, document…

In general, the tool can help to overcome creative blocks, which can occur when dealing with designs of such a complexity as in case of vehicle automation. The tool is intended to be used in both human-centered design process and technology-driven development. The two approaches can be applied by prioritizing some of the categories over others. For instance, in case of human-centered design the starting point can be following categories:

- Driver's Resources
- Sources
- Situation (if the focus is on use cases)
- Interrelations (if the focus is on multimodality)

Accordingly, for the technology-driven development it would be recommended to start with categories:

- Interface Elements
- Subject
- Representation
- Status Update

However, the strong need to prepare more specific scenarios guiding use of the design tool was recognized during its development process. The three use cases were identified based on the input gathered during the first workshop and created to demonstrate how the tool can be used at different stages of a design process. As mentioned above, the process of using the STATUSCOPE tool can be described with the metaphor of sketching. Consequently, the three use cases, which are described below in detail, can be related to the three functions of sketching described by Löwgren and Stolterman (2007, pp.28-29) (see Fig. 36).

Use case name	**Brainstorming for new ideas**	**Checklist for a design concept**	**Communication facilitation**
Function of sketching (Löwgren & Stolterman 2007)	Forming ideas	Communicating with self	Communicating with others
At the start	No ideas, beginning of a project, creative block	A ready concept or a finished design	Little or no understanding of the design problem among partners
At the end	New concepts to be further developed	Overview of the idea, with gaps within a design and opportunities to improve	A common ground for a further collaboration

Figure 36. The overview of the three use cases for the STATUSCOPE tool.

Brainstorming

The Brainstorming use case is intended for an initial phrase of a design process. It is aimed for teams and designers working individually when starting up with open or general ideas. This use case should be suitable for people new to vehicle automation and for experienced teams at initial phrase of the project.

The purpose of brainstorming with the STATUSCOPE tool is to "stimulate creative thinking, opening up new possibilities and combination of ideas" (Löwgren & Stolterman 2007), as well as:

- to structure the concept development process
- to deepen understanding of the problem
- to rapidly represent different ideas

Outcomes:
The outcomes of using the tool for brainstorming are ideas that can be further developed, inspiration coming from fresh ideas and overcoming a creative block. Also, it may lead to the re-framing of the design task, as exploring the design space allows to find questions to be answered or ones that the designer was not aware that need to be answered.

Limitations:
A limitation of this scenario is that the designer may not be ready to answer most all the questions regarding the design, and as a consequence the use of the tool and the concepts at this stage remains very open. In that case, the user does not need to focus on a given aspect and can proceed to the next one. It may be good to place such a card visible on the side, as it can be used later, when the concept will clarify.

Tips:
The focus in the brainstorming should be on quantity over quality: the more sketches the better. There is no need to spend too long time on a single "sketch" paper, at this stage there is no commitment to any idea. The aim of this use case is to create surprising and inspiring combinations of design properties. The most promising sketches can be tested with some quick-and-dirty prototyping technique.

Example:
A described use case was employed in one of the workshops. The task chosen by participants was the design for driver's acceptance in take-over situation. It required only three cards considered in that session to gain a new insight in the task. According to the task, the A.1.III. Design Ideal aspect could have been filled immediately with the driver acceptance. The next aspect considered was A.2.II. Non-Verbal Representation. This aspect required some thought, but participants decided that at least visual channel will be used, possibly more, but to be specified later. The last card was the aspect B.3.I. Start, which

resulted in a discussion and the conclusion that this aspect depends on who initiated a take-over, therefore in fact there should be two design concepts corresponding to the situation. This demonstrated how the use of the tool can stimulate re-framing and formulation of a design problem.

Checklist

The Checklist use case allows to examine the strong and weak points of a concept. It is meant to be used with an existing design concept as a starting point to work with, to develop it, check for its completeness, analyze or compare with other ideas. It is suitable for designers working individually or in small teams and the can mot useful for teams at advanced stages of a design process when the requirements are well defined. In practical terms it is a rather time consuming and detailed use case.

The purpose of using the tool as a checklist is in externalizing ideas. That allows to reflect on them, point to the aspects that need more attention and discover possibilities of further improvement, in other words "revealing obstacles and openings" (Löwgren & Stolterman 2007).

Outcomes:
The use of STATUSCOPE as a checklist for the design can result in several outcomes:

- see strong and weak points of the concept
- find opportunities to improve
- find potential problems or conflicts
- gain a fresh look on the design

Limitations:
It is possible that the analyzed concept does not fully fit within the design space, e.g. a card misses a specific property to describe your design or to cover some aspect of it. The design space is not a closed and finished set and it is meant as the starting point to stimulate thinking, but it should not limit the designer. If such a problematic property has been found, an option or an aspect not covered in the design space, the designer is free to add it on a sketch.

Tip:
When all the options that have been already decided are map out, one random aspect can be selected and a design decision made for it can be changed to another option. It can be valuable to think about how such a change affects the rest of the concept: what still makes sense, what does not, is there is anything new that emerged and can be used in the concept? This step can be repeated with other aspects.

Example:
An analysis of an existing design with the STATUSCOPE tool was performed in order to be presented as an example during the workshop. The design selected for the analysis was

the prototype of the in-vehicle interface for highly automated vehicle called Audi James 2025 (YouTube, 2014). The video demonstration was used in the analysis and the results were noted on the sketch paper (see Fig. 37).

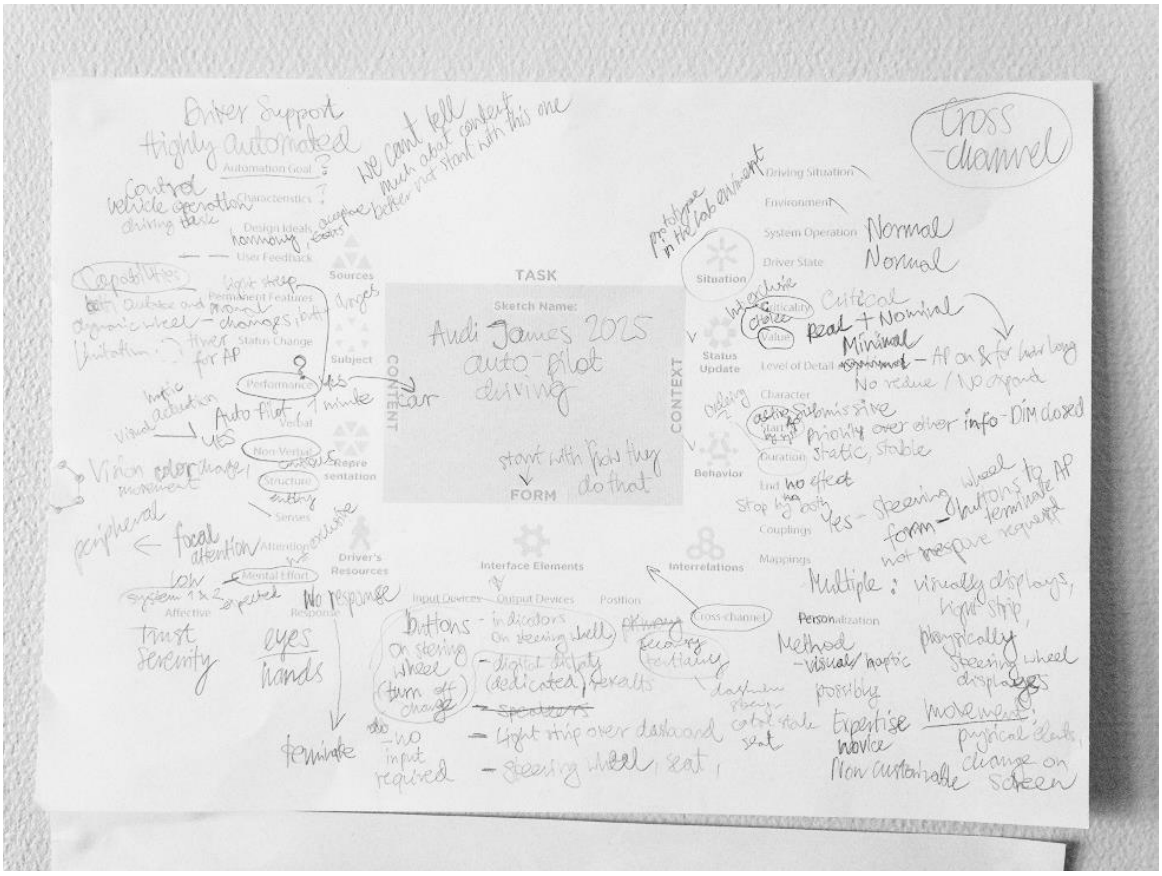

Figure 37. The sketch with results of using the STATUSCOPE tool for an analysis of an existing design.

Communication

The Communication facilitation use case can be used when there is a need to build a common ground with collaborators, to gather requirements or specify areas of competence for different groups or experts. The tool can support argumentation for design decisions and provide a tangible form to the design rationale. It is suitable for designers working with interdisciplinary teams and teams that need to clarify their areas of competence within a specific design project. The support of communication with use of the tool is possible on many layers:

- Within a design team
- With colleagues not familiar to vehicle automation
- With colleagues not familiar to issues of interaction design

As there can be various degree of maturity of user experience knowledge and practice within an organization, the tool can both help to mitigate these differences and rise the overall level of user experience maturity by exposing people to design related issues. Its potential to be used in a team work was observed in a workshop. An idea of gathering requirements from colleagues outside design team was mentioned.

Outcomes:
The outcomes of using the STATUSCOPE tool to facilitate communication can be:

- providing a consistent mental model of the design concept so all team members,
- input and critique gathered thanks to using the tool as a starting point for discussion,
- expression of questions or concerns about design.

Limitations:
The aspects of the design space may be interpreted differently depending on the knowledge of vehicle automation. It is important that all participants understand what is the status communication in automated vehicle and how is different from status communication for manual driving.

Tip:
It should be remembered that the same terms may be understood differently by people coming from different backgrounds. When the tool is used in group it may be good from time to time to check with others that everyone have a common understanding. Any misunderstanding or discussion can be seen as an opportunity to ask why others think the way they do. These kind of discussion can be very valuable for the project, as they provide information about different positions and approaches to the problem.

7. Discussion

The thesis project is discussed in this chapter first in relation to the results and then with focus on the process. The last two sections are dedicated to the issues of the generalizability of the results as well as to the short description of the perspectives for the future work.

7.1 Result Discussion

7.1.1 Design Space

The biggest strength and at the same time limitation of the design space, is that it is based on the previous research. In a consequence of the selected design space definition method the interaction properties that are not covered in the papers are also not represented in the design space. It has to be noted that the design space does not constitute a closed set of the interaction properties, neither has it attempted to map all the possible dimensions. Therefore, it should be seen as a rendering of the research findings in the domain of design for automated driving.

For the same reason, the identified design space can be considered as sensitive to getting out-of-date as the research in the field advances in a fast pace. However, the content of the tool is expected to be universal, because it attempts to extract the most basic, generic concepts for the human-automated vehicle interaction from the studies presented in the reviewed papers. The general structure of the design space should be lasting, as it is based on the well-established framework used across domains and design disciplines (Cooper, Reimann & Cronin 2007). Nevertheless, the options related to certain aspects of the design space are likely to change with time and would need to be updated in order to reflect the progress in the research.

For example, in the up-to-date literature mainly three modalities has been studied: visual, auditory and haptic. As they appear in the reviewed papers, they found their representation in the design space. However, as it was pointed out by an expert during the workshop, kinetic or proprioception channels were not mentioned in the design space, while they can be an important source for perception of driving situation, for instance by feeling acceleration or subtle changes of directions. Both of these channels present a very promising research area for status communication in highly automated vehicles, but very little attention has been dedicated to the kinetics in the previous research in context of automated driving.

Also, the example of kinetics demonstrates a clear advantage of the defining design space, which is recognition of the areas neglected in the research and openings for new research directions. One of such directions is definitely a place of the individual user within the design for automated driving. The question of Who? within the design space has been recognized in feedback session as the aspect underrepresented in the design space.

In fact, the aspects related to the driver are covered extensively in the design space, but an individual view on the user experience is represented only to the limited extent under the Personalization aspect. It can be stated that the human-centered design approach is deeply incorporated into the tool, as a task or a purpose for which the design tool is used can address human needs & goals and serve as a reference point for all the design decisions.

The design space was partially developed in parallel with its presentation format, therefore they are closely interrelated. The search for the appropriate form for a design tool guided the development of the design space structure. On the other hand, the content of the design space, such as use of terms and selections of the properties to include on cards were determined by the design of the design tool.

7.1.2 The Design Tool STATUSCOPE

The tangibility of the tool was very well received by the users. Especially the board attracted an interest of the designers and provided positive reactions. It was appreciated that the elements of the tool can be touched and manipulated. However, the amount of new information and the content of the cards caused difficulties in comprehending the design space. It has to be noted that the STATUSCOPE tool is not limited in its potential use in design process to the use cases presented in the thesis.

In regard of the format, separating the content of the design space from its structure was one of the main design choices made. The advantage of that solution is that information can be revealed as needed and it makes it easier to find location of the certain information in the design space. The drawback of this separation is that it can be difficult to grasp all the available information at once or explore all the content. In the consequence, the user of the tool may not be aware of the range of possible aspects to consider.

The primary audience of the tool has been decided to be designers new to the subject of automated riving, as they may be in the most need of such a tool. The trade-off of designing for novice and experienced designers has been considered in the process of the tool development. For novices the requirements are an accessible language and guidelines on the use of the tool, whereas the experts may prefer the academic terminology for its precision and familiarity. Also flexibility can be an important factor as expert users may be more likely to adapt the tool to their purposes.

As the prototype of the tool is realized in paper, some pros and cons of that solution can be discussed. The physical board and cards can get lost or damaged with use. Moreover it can be relatively hard to update the board. Hoverer, the benefits of the tangible format in the case of the STATUSCOPE far exceed potential drawbacks.

7.1.4 Looking through the keyhole: Challenge of Designing for Communication of Intelligent Agents

The study on the thesis subject lead to the conclusion that in design for status communication with vehicle automation there is an issue that can be described as the "keyhole view". The driver experiences the system only through given status updates, while the system is regarding an individual through the general model of a human, which by no means can describe a complexity of an individual person. In the consequence, the driver may develop partial and incomplete mental model of the automation, and the automation may fail to meet the driver's needs. Such a mutual misconceptions are the reason behind issues in interaction with automated systems, which happen "if the human does not understand the automation (in terms of capabilities, boundaries of operation, current functionality, goals, and LoA); or if the automation (and the engineer that made it) does not understand the human, (in terms of capabilities, goals, and inputs to the vehicle)", according to Abbink, Mulder & Boer (2012, p.26-27).

However, generalization is an unfortunate necessity in design. Although it has unwanted consequences (resulting in e.g. frustration, unintended use), it is inevitable part of the current design practice, in which products are designed for groups of users or use cases, not for individual people (possibly personal design is not desirable in automotive industry, as vehicles should be able to be driven by more than one person). Above all, making generalizations is not a wrong thing per se, to the contrary it is a wonderful capability of human minds that allows abstract thinking. The problem lays in a specific type of reductionism that adjusts the generalizations to what is possible or feasible with the current technology. Therefore the aim can be stated as not to avoid generalizations, but to make them carefully and being aware of reasons for decisions regarding them.

A consequence of the "keyhole view" problem is a meta-design issue, which is making the driver aware of the design itself. The system is perceived by the driver through its representation. This representation is delivered to the driver piece by piece in a form of status updates. That process is dynamic, distributed over time and affected by combination of several factors that cannot be fully envisioned by the designer. Therefore, the two main challenges of designing for status communication is to:

(1) Provide appropriate representations of the system and of the driver.

It has to be acknowledged in the design process that the driver interacts with the system representation, not the automated system itself, and similarly the automated system takes actions based on a model of the driver's behavior.

(2) Enable consistent communication of these representations.

This can be done by creating communication loops and avoiding bottlenecks, so the information and feedback can effectively flow between the driver and the automated system.

Some interesting strategies that may be used in order to address the problem of the system representation postulate increasing visibility of its underlying structure in terms of translucency (Lundström et al. 2012) and transparency (Helldin 2014) of the interface design. In automotive context, the concept of translucency has been applied in study on visualization of electric vehicles driving range, as a case of design for new and unfamiliar technology (Lundström et al. 2012). From the interaction design perspective, electric vehicles share with automated vehicles a need to develop new representations appropriate for the status communication with their respective technologies. Therefore it seems that the translucency approach, which aims "to treat the user interface as more than a set of levers that help manipulate the vehicle, but also as an explanatory guide for the (unfamiliar) technology and its limitations" may be very relevant for automated driving (Lundström et al. 2012, p.202).

Also some methods of applying transparency into interface design for automated systems has been proposed, including examples aimed for vehicle automation, such as "ability bar" or uncertainty visualization supporting communication in collaborative vehicle automation approach (Helldin 2014). More studies on psychological effect of providing the driver with the explanation of the reason behind state or action of the automated system would be required (Koo et al. 2014).

Above mentioned approaches can have a potential for the status communication as the automation could become a better "team player" by revealing to the user part of its operation. However, it still remains uncertain if that is desirable direction to follow from driver's perspective, who may already feel overloaded with information available during driving.

7.2 Process Discussion

As the thesis project is dedicated to developing a support for design of novel interfaces, similarly the work on it had to deal with working out methods and approaches. The process was original and required a number of decisions that shaped the final results. That generated some interesting observations and reflections, which are presented below.

7.2.1 Defining the design space

For the process of defining the design space I was looking for a method that can be well documented in order to make the process transparent. But it proved to be that definition of a design space is mostly subjective work, involving a lot of interpretation and depending on a research perspective. My attempts to keep the process as much objective as possible are described in the chapter 6.1. It is important to note that this has been qualitative work and because of its nature the element of interpretation is appreciated (Lazar, Feng & Hochheiser 2010). Despite trying to reduce the black box effect to a minimum while defining the design space, I need to admit that the major part of the results comes from my own processing of the information, not form applying a certain procedure. Therefore, the definition of a design space within this project was a process that cannot be fully documented.

In general, the guidelines included in the methodology by Wolfswinkel et. al (2011) were very helpful. However, at the level of recommended steps they were too rigid for the scope of this project, as the documentation effort would be exceeding the actual work on design space. Therefore, I have adopted a goal-centred view over proposed by authors process-centred approach and tried to keep the documentation reasonable, but focus on the identifying the design space.

Card Sorting Technique

It is worth to note that the codebook in form of the table in a text document proved to be too rigid and cumbersome technique. I have developed my own technique of representing the codes emerging from reading, which was card sorting on the wall. I found it superior over the table format proposed by Wolfswinkel et. al. (2011), as it:

- Provides a way to externalize both the concepts and the relationships between them. The codebook technique was missing the space to include relations between concepts. Card sorting can be more suitable for dynamic cognitive processes that take place in the design space definition and cannot be clearly divided to different stages of coding. This remains in line with the methodology employed in the project, who state that coding needs to be "performed in an intertwined fashion, going back and forth between papers, excerpts, concepts, categories and sub-categories" (Wolfswinkel et al. 2011, p.51).
- Is easy to update, rearrange and keep track of the different versions. By simply taking a photo of the cards' arrangement it is possible to preserve it before making any changes. The problem with the codebook was browsing through several versions of the table, which lacked an overview of the updates being made.
- Does not require a researcher to switch between coding and documentation, as it is possible to refer to cards without disturbing the reading and analysis. That makes card sorting more integrated in the coding process.

The trade-off with use of that technique is between flexibility and documentation. Its main weakness is that it provides little material for the coding documentation, as the cards have a limited space for information on references and rewriting excerpts from the text as examples is impractical. In consequence the outcomes of this technique were little help in the report writing, in contrast to the codebook as described by the adapted literature review framework. Therefore it can be used rather to complement, not to replace the coding documentation. Nevertheless, in the course of this project the card sorting technique was very well suited and can be recommended to support process of structuring a design space.

Similarly, I was trying to keep the concept matrix, a table linking the codes to the papers from which they originate (Wolfswinkel et al. 2011), however it also proved to be unrealistic during the analysis process. The concepts were constantly evaluating and the format of the table in a text document were not able to accommodate such flexibility. Lastly, the stages of literature analysis described as axial and selective coding (Wolfswinkel et al. 2011) were merged with scheme of use phase, so the distinction between the two stages become blurred.

7.2.2 Scheme of Use

This stage of the project was marked by difficult beginnings. The initial design space included extensive list of aspects to consider and hierarchy of several layers. It was challenging to represent it at first. However, the work on scheme of use greatly contributed to formulating the final design space. The form of the representation helped to clarify concepts and relationships between them as it was developing as well as to articulate them. In summary, the work on presentation format helped to polish the content of the design space.

Cards were a difficult element to design, but it was the "sketch" element that underwent most changes. In total four versions of the design for "sketch" paper were made. The apparent trade-off was in this case between more freedom for the user and simplicity on the one hand versus more guidance offered to the user, but also increased visual complexity on the other.

The shifts of concepts that occurred in course of the work allow me to draw an insight on their role for the design process. Such changes can be seen as detours from the main track of the project that consume valuable time and resources. However, they are hard to avoid in case of projects that cannot be based on well-established practices. Instead of being feared, they can be approached as opportunities, which can enrich final results in unexpected ways. The realization that the work goes off the planned track is crucial to define what the design is not about and articulate its own identity.

7.2.3 Evaluation

Workshops provided immense input, confirmed a need to develop scenarios of use and that the tool requires some training to be used. It was observed that the first contact with the content of the design space can be overwhelming.

While conducting the workshops, explanatory part was taking more time than expected and was transforming into discussion about the content. The plan to fill the sketch paper fully failed in both sessions, but it was observed that in some cases a combination of just couple of aspects provided an interesting insight. The activity was based on the previously prepared scenarios, which aimed to realistically represent different fictional design tasks that the tool can be used to support.

The scenario for a user test was adapted after the first workshop. An example to analyze was added, so it removed an element of the decision and leave more time for actual use of the tool. The feedback questionnaires distributed at different stages of the workshop have not worked well, as filling them was interrupting a flow and causing moments of silence. Therefore it was reduced in the second workshop to one questionnaire at the end of the session.

Terms used in the tool were new and participants often expressed that they are not sure if they understand them well. However, the explanations given in their own words were demonstrating good understanding of the term or a correct intuition. The design space touches on many disputable topics in the field, therefore some cards were controversial for selection of their options or lack of others. It was very positive to observe that the tool was stimulating thoughts and reflections on the design space.

7.3 Generalizability

The presented design space may be found useful with other automotive technologies. Research in interaction design for electric cars indicates a need for status communication, which can be seen as an important element of relieving range anxiety (Lundström et al. 2012). Similarly, the connectivity in vehicles may require status communication and design of adaptive infotainment systems can benefit from considering the status communication.

As it can be expected that all above mentioned technologies will be implemented together in future vehicles, it would be reasonable to consider them in a holistic way. Perhaps the status communication is more crucial in case of electromobility and connectivity, than infotainment system, as they may be related to the safety and comfort. Nevertheless, infotainment features are likely to be dependable on connectivity or affected by state of available electric power. Furthermore, adapting the tool to other intelligent vehicle technologies is possible. For example the aspect Automation Goal can be replaced with Connectivity Goal to express the main paradigms in implementing connected vehicle.

The design space is applicable to different types of vehicles, e.g. cars, trucks, buses or industrial machines as long as the status communication between the operator and the automated system within a vehicle is considered. As stated in the scope of the project, the focus of the project was on personal transportation. The changes that are likely to be required to adapt the tool to other driving contexts are mainly in categories of Interface Elements and Situation. In case of Interface Elements, it is because the devices and their arrangement in the cabin may vary depending on the purpose of the vehicle.

The limitation of the thesis is that the design space applies to the status communication inside a vehicle. So it is not meant to be used for status communication with external agents: other vehicles, human road users or infrastructure. This limitation corresponds to the state-of-the-art in the research, which is largely focused in design for the driver.

The format of a tool is believed to be applicable to many processes in interaction design. Main structure consisting of a board, cards and a sketch can be useful to create other design tools for different topics or representation of other design spaces. However the presented design of the paper prototype is specific for the tool itself in terms of number of sides and folds in the board and its division, graphic theme and icons as well as content of a tool.

7.4 Future work

The further work on the project would need to consider facilitating learning process of the tool and developing a workshop format that will allow participants effectively become familiar with the design space and comfortable with using the tool. Moreover, testing the tool in the context of a real life project would be crucial in order to study if it adds the value to the design concepts developed with its support.

Also, a need for more work on integration of the tool into the culture of a certain organization has been evident. Because the audience of the tool is rather narrow and very specialized, it can be desirable to craft its features to optimally fit the design process in a given organization. The adaptation can involve scenarios and use cases, rather than the design space itself. That would allow the potential of the tool to be realized at different stages of the project and in combination with other established methods, such as use cases, personas, simulator studies or brainstorming techniques.

Artefact vs. activity oriented approach

My approach towards the project was centered on the problem of the thesis project and the artefact that was expected to be developed as its result. The analysis, the development of the design space and then its presentation format were in focus through the process. I have experienced difficulties in developing a fully functional scenarios of use and that proved to be the most challenging part of the work. The evaluation led to the conclusion that the future work would benefit from more activity-oriented instead of artefact-oriented approach. Involving designers earlier in the process and learning about the processes implemented within their organizations could be essential for creating use cases for the tool. Although, it was not realistic within the setting of the thesis project, it could have been very beneficial in the future work on the design tool.

8. Conclusion

This thesis highlighted the current gap between the challenge of interaction design for automated driving and the solution required to introduce this technology to the road traffic.

There are important research findings that can be used to design status communication in highly automated vehicles, however there has been identified the lack of an appropriate format to represent them. Therefore, the research questions presented in this thesis addressed a need to support interaction design process in the automated driving domain. For that purpose the work focused on the concept of design space describing salient properties of interaction between the driver and the automated vehicle.

The proposed solution took form of a design tool STATUSCOPE, showing the possibility of transforming research findings into a tangible format that can be integrated into design activities. The tool represents the design space for communicating status of highly automated vehicles in a physical and dynamic way enabling its playful exploration.

The STATUSCOPE provides designers with a structured approach to develop solutions for a novel and complex design challenge. In the process of defining the design space and creating the tool, new methods were applied and adopted to the context of automated driving. That allowed the results to offer an advantage both in terms of the content of the tool and the form in which it is delivered.

Moreover, in the process of defining the design space, the two aspects were highlighted and judged to be of outmost importance when designing status communication:

- Providing appropriate representations of the system and of the driver
- Enabling consistent communication of these representations between the agents

The work presented in this thesis can be seen as the first steppingstone and need further evaluation and development in a future work. For instance, it would be of interest to investigate use of the tool in projects within different automotive manufacturers in order to optimize its applicability and flexibility.

The application of the results in other domains is a separate aspect to be tested. For instance, such alternative areas may include design for status communication in electric vehicles, but also design challenges related to automation and ubiquitous computing in other contexts than automotive.

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10. Appendices

List of appendices:

Appendix 1: Papers included in the literature review
Appendix 2: Matrix of concepts

Appendix 1: Papers included in the literature review

Nr	Year	Author(s)	Title	Published in	Reason(s) for selection	Status	Design example	Design Implications
1	2011	Hesse, T. et. al	Towards user-centred development of integrated information, warning, and intervention strategies for multiple ADAS in the EU project interactIVe	C. Stephanidis (ed.). *Universal Access in Human-Computer Interaction. Context Diversity*. Springer-Verlag	Explicitly addresses system status communication (p. 285-286) and HMI design for vehicles of various level of automation. Presents list of strategy aspects to guide design. Mentions design space as a method to structure the problem. interactIVe project	x	-	x
2	2012	Flemisch, F., Heesen, M., Hesse, T., Kelsch, J., Schieben, A., & Beller, J.	Towards a dynamic balance between humans and automation: authority, ability, responsibility and control in shared and cooperative control situations	*Cognition, Technology & Work*, *14*(1), 3–18.	Focus on changes of status, described by authors as transitions of control (p. 14). Conceptual framework for analysis and design of transitions in highly automated driving. Cooperative control with goal of “a dynamic but stable balance between human and automation” (p. 3). Example of display design from HAVEit project.	x	x	x
3	2008	Flemisch, F., Kelsch, J., & Löper, C.	Automation spectrum, inner/outer compatibility and other potentially useful human factors concepts for assistance and automation	D. de Waard, F. O. Flemisch, B. Lorenz, H. Oberheid, & K. A. Brookhuis (eds.). *Human Factors for assistance and automation*. Shaker Publishing.	Addresses status communication as automation awareness (p. 6), discusses issues to achieve it through design, focus on compatibility as a concept for automation design.	x	-	x
4	2011	Flemisch, F., Schieben, A., Schoemig, N., Strauss, M., Lueke, S., & Heyden, A.	Design of human computer interfaces for highly automated vehicles in the eu-project HAVEit.	C. Stephanidis (ed.). *Universal Access in Human-computer Interaction. Context Diversity*. Springer-Verlag.	Presents generic design for HAV including interface elements designed for status communication, like Automation Monitor and Scale (p. 274-277). Examples of displays design from HAVEit project.	x	x	x

Nr	Year	Author(s)	Title	Published in	Reason(s) for selection	Status	Design example	Design Implications
5	2011	Damböck, D., Kienle, M., Bengler, K., & Bubb, H.	The H-metaphor as an example for cooperative vehicle driving.	J. A. Jacko (ed.). *Human-Computer Interaction*. Springer-Verlag	Status communication is mentioned as a requirement and a measure to keep the driver in a loop (p. 376, 379). Focus on active haptic control device, tested against a button to switch LoA. Use of metaphor in design process. Design and testing of a side stick (p. 381).	x	x	x
6	2011	Schieben, A. Temme, G. Köster, F. Flemisch, F	How to interact with a highly automated vehicle – Generic interaction design schemes and test results of an usability assessment	D. de Waard et al., eds. *Human Centred Automation*. Shaker Publishing	Discusses issues related to status communication and presents some generic schemes for design and a design solution (p. 255). Focus on transitions between LoA. Example of display design from HAVEit project.	x	x	x
7	2010	Flemisch, F., Heesen, M., Kelsch, J., Schindler, J., Preusche, C., & Dittrich, J.	Shared and cooperative movement control of intelligent technical systems: Sketch of the design space of haptic-multimodal coupling between operator, co-automation, base system and environment	*11th IFAC/IFIP/IFORS/IEA Symposium on Analysis, Design, and Evaluation of Human-Machine Systems,* 31 August - 3 September, 2010, Valenciennes	Presents a design support in form of design space of haptic and non-haptic couplings, with one example of HAV, focus on haptic-multimodal couplings "as a base for shared control", status not mentioned explicitly. Example form HAVEit project.	-	x	x
8	2008	Flemisch, F., Kelsch, J., Löper, C., Schieben, A., Schindler, J., & Heesen, M.	Cooperative control and active interfaces for vehicle assistance and automation	*FISITA World Automotive Congress (2008).*	Does not explicitly mention status, but discusses driver-automation communication. Presents active interfaces and benefits of haptic interaction. Example of a prototype with side stick from H-Mode project.	x	x	x
9	2009	Merat, N., & Jamson, A. H	How do drivers behave in a highly automated car?	*Proceedings of the Fifth International Driving Symposium on Human Factor in Driver Assessment,*	Simulator test of a different warning solutions in critical situations, context of situation awareness in "dual-mode" driving, status communication mentioned only briefly in prototype description (p. 516), results have implication for design of warnings.	-	x	x

Nr	Year	Author(s)	Title	Published in	Reason(s) for selection	Status	Design example	Design Implications
				Training and Vehicle Design, Montana, USA.	Example of interface design from CityMobil project is not discussed.			
10	2013	Helldin, T., Falkman, G., Riveiro, M., & Davidsson, S.	Presenting system uncertainty in automotive UIs for supporting trust calibration in autonomous driving.	*Proceedings of the 5th International Conference AutomotiveUI '13*.	Addressing status communication as "promising alternative to providing warnings" (p.211). Evidence for uncertainty visualization resulting with drivers better prepared for take-over. Example of design displaying uncertainty of the system, tested in simulator, in collaboration with Volvo.	x	x	x
11	2013	Beller, J., Heesen, M., & Vollrath, M.	Improving the Driver-Automation Interaction: An Approach Using Automation Uncertainty.	*Human Factors,* 55(6).	Automation status mentioned in reference to system uncertainty display and driver's trust in automation (p. 1132, 1132). Based on simulator study with use of emoticon.	x	x	x
12	2006	Sarter, N.	Multimodal information presentation: Design guidance and research challenges.	*International Journal of Industrial Ergonomics,* 36(5).	Status communication is not mentioned directly, but the paper discusses communication channels, includes number of guidelines for multimodal information presentation and in this context refers to in-vehicle interfaces.	-	-	x
13	2009	Toffetti, A., Wilschut, E. S., Martens, M. H., Schieben, A., Rambaldini, A., Merat, N., & Flemisch, F.	CityMobil - Human Factor Issues Regarding Highly Automated Vehicles on eLane.	*Transportation Research Record: Journal of the Transportation Research Board,* No. 2110.	Summarize human factors challenges for HAV design, presents a prototype of audio interface (testing vocal and acoustic) developed within CityMobil project.	-	x	-
14	2012	Saffarian, M., de Winter, J. C. F., & Happee, R.	Automated Driving: Human-Factors Issues and Design Solutions.	*Proceedings of the Human Factors and Ergonomics Society*	Presents main human factors in HAV design and briefly describes potential solutions, lists some of functions that information displays can have in relation to automation.	-	-	x

Nr	Year	Author(s)	Title	Published in	Reason(s) for selection	Status	Design example	Design Implications
				Annual Meeting, 56(1).				
15	2012	Merat, N., & Lee, J. D.	Preface to the Special Section on Human Factors and Automation in Vehicles	*Human Factors*, 54(5).	Includes number of recommendations for designers of highly automated vehicles in relation to status communication.	-	-	x
16	2007	Norman, D.	*The Design of Future Things*	Basic Books, New York.	Underlines need of design for communication with automated devices (p. 57), implicit communication and affordances an tools leading to natural interaction (p. 61-63), challenge of bidirectional human-machine communication (p. 69). Motivation for status communication design (p. 135).	x	-	x
17	2011	Beukel, A. P. Van Den, & Voort, M. C. Van Der	Human-Centered Challenges and Contribution for the Implementation of Automated Driving.	G. Meyer & J. Valldorf (eds.), *Advanced Microsystems for Automotive Applications 2011*. Springer-Verlag.	Presents the Assisted Driver Model providing a framework to address human-related challenges of vehicle automation, includes recommendations for level of automation depending on situation. Mention status communication in relation to monitoring task (p. 230), does not present designs.	x	-	x
18	2001	Walker, G. H., Stanton, N. a., & Young, M. S.	Where Is Computing Driving Cars?	*International Journal of Human-Computer Interaction*, 13(2).	Status communication in relation to status awareness, negative effects of decoupling between actual and perceived system status (p. 209).	x	-	x
19	2009	Davidsson, S., & Alm, H.	Applying the" Team Player" Approach on Car Design.	D. Harris (ed.), *Engineering Psychology and Cognitive Ergonomics*. Springer-Verlag.	Includes expert opinions and thoughts on driver-automation communication in a team player model, e.g. what information should be presented Clear implications for design on generic level, no design example	x	-	x
20	2012	Merat, N., Jamson, A.H.,	Highly Automated Driving, Secondary	*Human Factors*, 54(5).	Simulator study on driver's situation awareness in relation to workload and attention, comparing	-	-	x

Nr	Year	Author(s)	Title	Published in	Reason(s) for selection	Status	Design example	Design Implications
		Lai, F.C.H., & Carsten, O.	Task Performance, and Driver State.		manual and automated driving, results providing design implications.			
21	2005	Griffiths, P.G. & Gillespie, R.B.	Sharing Control Between Humans and Automation Using Haptic Interface: Primary and Secondary Task Performance Benefits.	*Human Factors*, 47(3).	Does not mention status explicitly, but discusses communication between driver and automation as "efficient cooperation requires the communication of goal and intent" (p. 575). Example of haptic interface.	x	x	x
22	2012	Abbink, D., Mulder, M., & Boer, E.R.	Haptic shared control: smoothly shifting control authority?	*Cognition, Technology & Work,* 14(1).	Points to continuous communication as a requirement, discusses design guidelines for human-automation interaction and provides descriptions of case studies.	x	x	x

Appendix 2: Matrix of concepts

Legend: The numbers in the first column from the left correspond to the papers included in the literature review (see Appendix 1).

Nr of paper (Appendix 1)	A.1. AUTOMATION	A.1. CHARACTERISTIC	A.1. DESING IDEALS	A.1. USER FEEDBACK	A.2. PERMANENT	A.2. STATUS CHANGE	A.2. PERFORMANCE	A.3. VERBAL	A.3. NON-VERBAL	A.3. STRUCTURE	B.1. DRIVING	B.1. ENVIRONMENT	B.1. SYSTEM	B.1. DRIVER STATE	B.2. CRITICALITY	B.2. VALUE	B.2. LEVEL OF DETAIL	B.2. CHARACTER	B.3. START	B.3. DURATION	B.3. END	C.1. SENSES	C.1. ATTENTION	C.1. MENTAL EFFORT	C.1. AFFECTIVE	C.1. DRIVER RESPONSE	C.2. INPUT DEVICES	C.2. OUTPUT DEVICES	C.2. PLACEMENT	C.3. MAPPINGS	C.3. COUPLINGS	C.3. CROSS-CHANNEL	C.3. PERSONALIZATION
1	X	X	X		X			X		X		X			X		X	X	X	X		X		X	X				X	X		X	X
2		X				X			X	X					X	X		X															
3			X		X							X		X													X						
4		X						X	X	X				X						X	X						X						
5			X						X	X						X												X			X		
6		X		X	X	X		X	X	X								X	X	X	X						X						
7									X						X							X									X		
8									X															X			X	X					
9				X		X			X						X									X									
10							X		X				X																				
11							X		X				X												X								

Nr of paper (Appendix 1)	A.1. AUTOMATION GOAL	A.1. CHARACTERISTIC	A.1. DESING IDEALS	A.1. USER FEEDBACK	A.2. PERMANENT	A.2. STATUS CHANGE	A.2. PERFORMANCE	A.3. VERBAL	A.3. NON-VERBAL	A.3. STRUCTURE	B.1. DRIVING SITUATION	B.1. ENVIRONMENT	B.1. SYSTEM OPERATION	B.1. DRIVER STATE	B.2. CRITICALITY	B.2. VALUE	B.2. LEVEL OF DETAIL	B.2. CHARACTER	B.3. START	B.3. DURATION	B.3. END	C.1. SENSES	C.1. ATTENTION	C.1. MENTAL EFFORT	C.1. AFFECTIVE	C.1. DRIVER RESPONSE	C.2. INPUT DEVICES	C.2. OUTPUT DEVICES	C.2. PLACEMENT	C.3. MAPPINGS	C.3. COUPLINGS	C.3. CROSS-CHANNEL	C.3. PERSONALIZATION
12																						X	X			X	X	X		X	X	X	X
13				X					X															X									
14					X	X																		X	X			X					X
15	X									X	X		X											X	X								
16			X		X																												
17	X	X	X								X														X								
18											X	X		X					X					X	X								X
19																X	X							X									
20																							X	X									
21									X	X												X		X							X		
22					X	X			X						X									X				X			X		