Technical University Ingolstadt
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BACHELOR THESIS

Visualization of Contextual Information in the Field of Automotive Digital Forensics

by

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Declaration

I hereby declare that this thesis is my own work, that I have not presented it elsewhere for examination purposes and that I have not used any sources or aids other than those stated. I have marked verbatim and indirect quotations as such.

Ingolstadt, 26.01.2022

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Contents

Abstract

Digital forensics is struggling to keep up with the development of modern day products. There are different ways to resolve this rising problem, for example through standards. In this thesis, we will look at user experience design as a way of improving the situation and usability of digital forensics tools. More specifically the goal is to find a way of visualizing data from the field of automotive digital forensics investigations and develop the data representation with methods used in user experience design. The data used is depending on given contexts, therefore the research question is formulated as follows: *How can important information for automotive digital forensics investigations be visualized in different contexts?*. To be able to find a fitting form of visualization different design versions are created, using the methodology of Garrett presented in his work "*The Elements of User Experience*" [9]. The design then is implemented in form of prototypes. Subsequently both prototypes, implementing different forms of visualization, are tested with potential users by using the user experience questionnaire. The results of the versions were compared and there was no significant difference discovered. This possibly indicates that there is not one form of visualization fitting for every project, but that the application of user experience design methods in the development of digital forensics tools can enhance the overall experience of the user.

1 Finding a Connection Between the Fields of Automotive Digital Forensics and User Experience Design

According to Garfinkel in [8], the field of Digital Forensics (DF) faces a crisis, caused by forensic research, struggling to keep up with the development of modern day products. Tools used in the area of DF can not provide the needed results anymore. There are different approaches to improve the situation. For example McDermott et al. in [1], focus on standardizing DF approaches to handle the constantly growing amounts of data. An additional way to enhance DF tools could be the application of User Experience Design (UXD) methods in the development process. Sadiku et al. state the use of data visualizations "*[...] will benefit any field of study that requires innovative ways of presenting large, complex information.*" [23]. So finding possible forms of visualization for DF data by paying attention to the user, while developing a tool is a potential way to improve the created tools. In [9], Garrett describes the user-centered design process as an essential part of UXD. By keeping the user's needs in mind and developing accordingly, the overall experience of a product improves. The focus would be to establish this connection of both fields. The subject of this thesis is Automotive Digital Forensics (ADF). In this field data can depend on the given circumstances. Different contexts need different data to resolve the questions a DF investigation poses. On top of that, the relevance of information also differs depending on contexts. Information that is valuable in the context of a car theft might not be as helpful in the setting of a car software manipulation case. So visualizations have to be adapted to the available data that is provided by the available data sources.

So the question to be answered in this thesis is: *How can important information for Automotive Digital Forensics (ADF) be visualized in different contexts?*.

The thesis is structured as follows. In Section 2, background information is presented to provide a foundation for the coming sections. The following Section 3, treats the topic of already existing work that have parallels in their content to themes in this thesis. In Section 4, the core content of the research question is analyzed to specify the focus of the following sections. Section 5, sticks to the methodology of Garrett in [9], to develop two forms of visualization for DF data. The next Section 6, treats the implementation of the developed designs in different levels of prototypes. In the evaluation (Section 7), the decision on which prototype is to be further developed is described. Additionally a user testing with the help of the User Experience Questionnaire (UEQ), a standardized questionnaire known in UXD, to compare the two created forms of visualization, is explained. The results of the testing are also listed in this chapter. Section 8 summarizes the results and and presents future work.

2 Fundamentals

In this Chapter, the basics of DF, UXD and the architecture of a modern vehicle are described in order to provide a background for the subsequent chapters.

2.1 Digital Forensics

This Subsection provides some basic knowledge on DF. There will be a brief summary of the areas relevant to this work.

2.1.1 Definition of Digital Forensics

As DF includes the term forensics, it is not surprising that there are parallels to the field of conventional forensics. But the fields also differ from each other. According to Årnes, DF is the application of "*scientifically derived and proven methods*" [3] that help in "*preserving, collecting, validating, identifying, analysing, interpreting, documenting and presenting*" [3] evidence. The source for this information lies within digital systems and is gathered in order to "*reconstruct or anticipate events*" [3], that are considered to be illegal. There are essential questions in a forensic investigation that need to be answered in order to reconstruct an event. Based on Årnes [3] these questions are referred to as the 5 WH's:

- *Who*
- *Where*
- *What*
- *When*
- *Why*
- *How*

Answering these questions related to the 5 WH's, helps to find facts or prove the validity of existing ones.

2.1.2 Locard's Exchange Principle

A fundamental part of forensic science is the exchange principle. In [24], Saferstein defines "*Whenever two objects come into contact with one another, there is exchange of materials between them.*" [24]. This principal in common forensic science, also applies to DF but in contrast to physical evidence there are digital traces left behind [25].

2.1.3 Sub-Branches of Digital Forensics

The field of DF can be divided into further sub-branches some of which will be briefly examined in the following passage. The field according to Khanafseh et al. in [15], can be categorized like shown in figure 1.

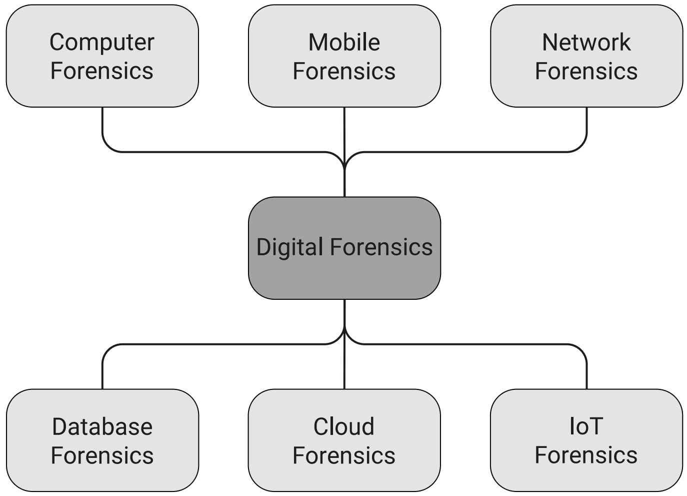

Figure 1: Subcategories of digital forensics

Computer Forensics: In [15], computer forensics is described as the usage of computer science and law related methods to investigate the "*state of a digital artifact*" [15].

Mobile Forensics: In mobile forensics, evidence is gained from extracting digital data from mobile devices like smartphones [15].

Network Forensics: Network forensics is the examination of network traffic that is considered to be a part of criminal affairs [15].

Database Forensics: In [2], database forensics is described as an area where "*database content and metadata*" [15] help to expose criminal activities.

Cloud Forensics: Cloud forensics combines computer forensics, DF and network forensics in a "*cloud computing environment*" [15].

Internet of Things Forensics: The authors of [15], constitute the Internet of Things (IOT) forensics as a system composed of networks, services and more, where parts like smart devices connected to this system can be searched for evidence.

2.2 User Experience Design

Additional to DF, the field of UXD is of importance in this thesis. Hereafter information about core elements of the domain will be presented.

2.2.1 Definition of User Experience Design

Defining UXD is a difficult task. There are various definitions available. One of them is introduced by Mike Kuniavsky: "*The user experience is the totality of end users' perceptions as they interact with a product or service.* [16]. This experience can be judged according to a few factors which are "*effectiveness, efficiency, emotional satisfaction and the quality of the relationship with the manufacturer*" [16]. So there are some factors involved in creating good user experience and each of them will have an impact on the perception of the product or service.

2.2.2 User-Centered Design Process

But how is a good and enjoyable user experience created? The key here is a process called user-centered design. As the term already implies, the user is in the center of the product development phase. Of course there are limits as to how much you can focus on the user. One limitation, for example may be the available budget for a project. The idea is to develop a product while having the user in mind and not just creating an idea without considering the final customers' expectations [9].

2.2.3 Added Value through User Experience Design

In [9], Garrett writes about a phenomenon that appears with users who use websites. If they can not figure out how to interact with it, they make themselves responsible and not the potentially sub-optimal developed page. To keep the user invested in the product, you would want to spare them from getting this negative feeling in order to prevent them from getting frustrated and leaving. Here the design of the user experience becomes an issue to prevent this undesired situation from happening.

2.3 Modern Vehicle Architecture

In this part, the components and the communication of a modern day vehicle are explained. The information provides a background, necessary to understand correlations in later chapters.

Vehicle Components: The architecture of a modern vehicle includes many different components. A lot of them are somehow connected to exchange information. In [20], Reif describes the architecture as a combination of topologies, used protocols and physical implementation of the system.

The topology defines the type of connection the users of the system have. Protocols implement a set of rules the communication has to follow. These rules apply to all participating units.

Electronic Control Unit: An Electronic Control Unit (ECU) is a computer system that is installed in a vehicle. It receives data from e.g. sensors and processes data to send out signals to other units which are also connected to the same network. The main part of an ECU is the micro-controller, responsible for input, output and many more tasks [21].

Vehicle Communication: Bus systems play a central part in the in-vehicle communication. They represent the core of the network and come in different forms. Commonly used bus system technologies are Controller Area Network (CAN), Local Interconnect Network (LIN) and Media Oriented Systems Transport (MOST).External communication refers to technologies like telematics, LTE, Bluetooth and WIFI. Some of the mentioned systems will be briefly explained hereafter.

Controller Area Network: The CAN bus is a protocol for messages where each message can be exactly identified through a unique ID. A message sent through the system will pass through every single participant of the network. The participants identify and evaluate the message. If the content is rated relevant the message is read and if not, it will be ignored [20].

Local Interconnect Network: The LIN bus system is also a protocol for messages, but in comparison to the CAN bus system, within a LIN bus system not all involved components in the network have the same rights. Instead there is a hierarchy with a master knot and associated slave knots [20].

Media Oriented Systems Transport: MOST is a bus system used for multimedia systems with a high data rate. In a MOST network there are a number of MOST knots arranged in a ring structure. The knots involved in this network are able to communicate with each other.

Bluetooth: "*Bluetooth is a low-power, low-cost, short-range wireless communication system.*" [7].

Telematics: Telematics is used for "*[...] wireless communications, remote services, entertainment [...]* [18] and other purposes.

3 Related Work

This section covers research that has already been done in the areas of DF and UXD.

As shown in [22], Golden and Vassil highlight the increasing complexity of DF investigations. Hence increasing attention is required to achieve high-quality results. The article mentions a need for better tools in the area of DF, because of the growing number of cases and ever larger forensic targets. The authors propose two different methods to handle the complexity of the problem. One recommended way to improve the situation, is to analyze the existing tools and adapt them to today's target sizes. Another way is to enhance the acquisition of digital evidence. Both are valid options to help to update DF in order to handle the amount of data of forensic targets. What is missing in this article is the user. For example the investigator that has to deal with the growing amount of digital evidence. This is where a good visual presentation would help the investigating party to keep the overview and orientation in the project.

DF can be used in a lot of different contexts. One of these is the vehicular environment, where many sources for digital forensics work can be found. In article [17], Lacroix et al. write about data that can be retrieved from a vehicle to then use it for forensic analysis. They also list the vehicle components and architecture, which are quite complex. What is missing here, is an efficient possibility to explain where usable data can be found by authorities, who need to use the available data, for example investigators.

In DF there is one essential part, called "*the chain of custody*" [3]. In [3], Årnes presents it as an essential part in the investigation that is needed for a case to hold up in court. It is important to document every step of the investigation and that includes a good presentation. In this case, the presentation refers to the presentation of a case in court. But a good presentation of data is not only helpful in the court room. It is also helpful in the previous steps by making big amounts of data easier to grasp. Furthermore he mentions the scene of the incident. Usually the first one arriving at a crime scene are police officers, who are in charge of finding and marking evidence at the scene. On top of physical evidence, like fingerprints or hair, there is a lot of digital evidence saved on a smartphone, laptop, security camera or a music player that might be the key to solve the case. The investigator has to identify the potential evidence sources. This scenario can be transferred to the context of a car. The scene of the incident is the vehicle itself and the sources of potential evidence are control units. In modern cars there are a lot of these units. An efficient and effective way to identify the most interesting parts of the system for this specific case would be helpful.

In [1], MacDermott et al. focus on the problem of rising numbers of digital devices and their connection to the internet of things. Because of this problem, DF faces a bigger complexity of cases. Now in an investigation there are not only single devices to be examined, but whole clusters of connected devices. On a similar note in [8], Garfinkel predicted a crisis coming from different triggers, one of them being the increasing number of devices with storage capabilities. Both papers mention the problem of keeping up with the amount of data that has to be investigated in DF and focus on improving the situation through standardization of the approach. What is not considered, is the point of view of the user, e.g. the investigator, that has to be able to deal with this data in the end. The presentation and organization of this big amount of data would benefit from a user-centered development process.

The combination of UXD and DF so far is a field of research, where not a lot of work has been conducted. One article discussing this merge of fields is [28]. Talib et al. examined DF tools regarding their user experience. They consider the factors "*effectiveness, productivity, efficiency, error safety and cognitive load*" [28]. But they assess already existing tools in relation to these factors. The next step would be the development of DF tools with their user experience already in mind.

To this point there is not much research done linking UXD with DF. It is a very new, but promising combination and each field can complement the other. So in this thesis the author will apply UXD methods to find possible forms of visualization for DF data and implement them in tool prototypes for testing purposes.

4 Analysis of Context, Relevant Information and Visualizations

This section will focus on analysing the main question of this thesis which is *How can information important for vehicle forensics be visualized in different contexts?*.

4.1 Contexts in Automotive Digital Forensics

There are a lot of different scenarios, where DF plays a role. Car manufacturers develop more and more digital features to be implemented in their vehicles. Covering all those different contexts would exceed the extent of this thesis, so the focus will be on two selected scenarios that are used as an exemplary case. But to give an insight, here is a short listing of possible contexts. According to Thomas Käfer in [14] exemplary cases of ADF would be:

- Manipulation of car software: Manipulation of ECUs, for instance to increase the car's performance (car tuning), is an intervention that might impact the passengers' safety by willingly or unwillingly altering safety features
- Data protection: Each person has the right of information self determination and this right might be violated by attackers. For example by gathering personal data about the user through private data processed by the car's system
- Manipulation of data in car sales: A car's mileage could be manipulated to convince a customer that the car is newer than it is
- Clarifying the question of guilt in an accident: Logs of last known speed and other important data can be extracted from the car's ECUs.

The contexts that will serve as example for the following chapters will be accidents and car theft.

4.2 Relevant Information

The goal is to visualize relevant information for the user, e.g. for the inspector, to help them understand and give them a better overview. But in order to be able to visually display the relevant data, it is necessary to define what is perceived as relevant information.

Of course the relevance of an information is not always the same, it depends on the context. For example gathered data about the car's user, might be helpful in the case of a car theft, whereas in the scenario of a car software manipulation, this data has not the same relevance. So what is important, differs with the associated context. But in general, there is only limited data that can be extracted from a vehicle, irrespective of the context. This data can be integrated into wider categories to describe the nature of the information. According to Gomez et al. in [10] there are different categories of information. The following list will go through all categories presented by the authors in [10]:

- Firmware Data: "*incorporates the operating system [...], frameworks [...], device drivers, applications and other data*"
- User Data: Data that is "*created, modified or removed through the interaction of any party [...] interacting with the vehicle [...]*"
- Safety Data: "*[...] data about the safety state of the vehicle and its components. Devices that store information about safety critical events [...]*"
- Security Data: "*[...] information that is either directly linked to security events [...] or provide implicit information towards security.*"
- Communication Data: "*[...] all data that gets transmitted both inside the vehicle and from the vehicle to any other receiver.*"

This information now has to be evaluated in the given context to be able to visualize it accordingly. The relevance of the data for the specified context will be based on an assumption.

4.3 Visualizations

In [9], Garrett explains UXD and why it is relevant. He mentions there is not a perfect design solution that will fulfil every user's aesthetic taste, because what someone perceives as aesthetically pleasing differs from individual to individual. But there are different disciplines in the trade of design. Functional design specializes in making sure a product is working correctly, for example a volume slider accurately regulates the volume of a system. Meanwhile aesthetic design has the task to make the slider look appealing to the user in terms of e.g. "*shape and texture*" [9]. The aesthetics of the design are primarily developed in a way that it pleases a broad group of users so that in the end the number of people interested in buying the product, will be as high as possible. But there is no guarantee that the aesthetic design will please the user. With UXD it is a little bit different. UXD incorporates functionality as well as aesthetics and compares them in context to verify if it meets the requirements of the intended use. To be able to design a product that fits the user's needs, you first of all need to define who your target group will be and then highlight the needs of these customers.

Furthermore, the book [9] lists the "*elements of user experience design*" [9] in a sort of layered model. The elements give a frame for developing a product having the user experience in mind and are described as follows:

- *Surface Plane*: Consists of visible content like images and text
- *Skeleton Plane*: Defines where the content elements are placed in an optimized way to enable the user to operate the product in an optimal way
- *Structure Plane*: Determines the available categories to choose from and the architecture of the website, what options are available for the user to navigate to the previous or following site
- *Scope Plane*: Establishes a base of which *features and functions* are planned for the website
- *Strategy Plane*: Lays down, what the operators and users expect from the website

This development process is worked from bottom to top. The start is the lowest layer meaning the *Strategy Plane* and from there it goes up until the *Surface Plane* is reached [9]. The planes are displayed in Figure 2.

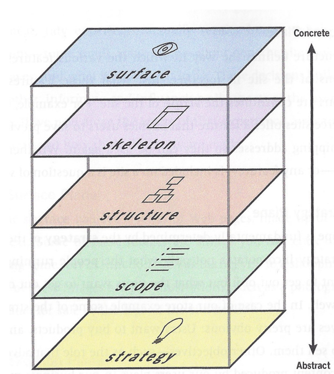

Figure 2: Model of the *Elements of User Experience* from Garrett in [9]

5 Design of Two Visualization Forms for Data relevant in Automotive Digital Forensics

In this Chapter, the focus lies on the development of visualization options for specific contexts in ADF.

The first chosen context is *vehicle theft.* According to the Bundeskriminalamt in [6], theft is one of the most common criminal offenses in Germany. Due to these circumstances, theft is one of the chosen contexts for further inspection.

The second context will be car accidents. The “Statistisches Bundesamt” in Germany published the total number of accidents from 1950 to 2020 in Germany in their study [5]. Although the total number of accidents in 2020 dropped, all the previous years showed an upward trend. This trend is the reason to take a closer look to the context of accidents. An overview of car accident numbers is displayed in 3.

Figure 3: Statistics on car accidents in Germany from 1950 to 2020 x-Axis: Year y-Axis: Number of car accidents [5]

The design will be developed around the methodology established by Garrett in [9]. A bottom to top approach is chosen going from the lowest layer of elements, the “*Strategy Plane*” [9], to the layer on top, the “*Surface Plane*” [9]. The goal is to create multiple visualizations. To determine the most suitable one, these visualizations can then be evaluated according to determined evaluation criteria. Not all steps of the methodology have to be done for each concept, because some conditions apply to all of them. For example the target group remains unchanged.

5.1 Strategy Plane

This plane is laying the basis for the steps to follow. The main points to define are "*developer goals, user needs, user segmentation, success metrics and user persona*"[9]

Developer Goals Usually there is a commercial enterprise involved in developing the user experience of a product. In this case, there is no economic objective driving the development. Therefore, profit is not the goal, but the experience of a user interacting with the product. The main focus lies on providing information in an understandable way with a fitting form of visualization. Operating the tool should be supporting the user in handling their tasks. Also a pleasing aesthetic look is an objective to reach. Agreeable visual appearance might be helpful when working with a tool over a longer period of time.

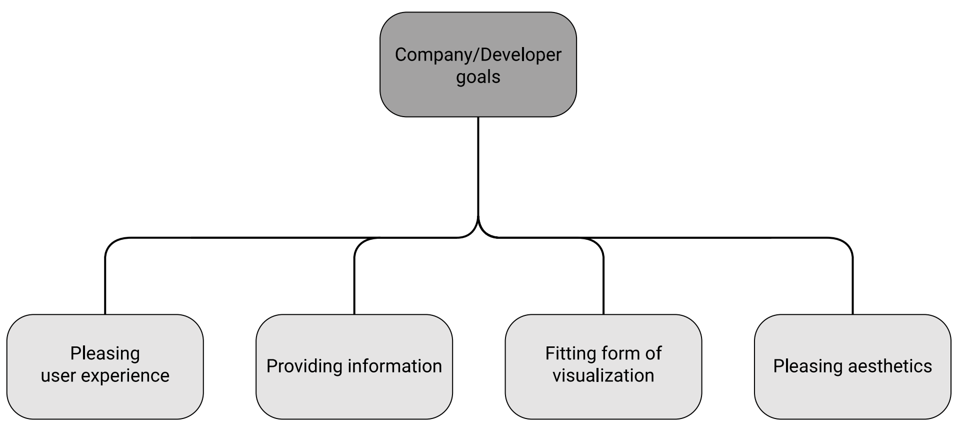

Figure 4: Company/Developer goals

User Needs In this layer, the user will be closer examined. The product is not designed to please the developer, but rather to fulfil the needs of the user. Therefore, the type of user that will interact with the tool has to be examined. In this case, the target group consists of people belonging to the community of ADF. According to Gomez in [11] the main groups working in this field are *Insurer*, *Approval Authority*, *Criminals* and *Business Car Owner*, who are working in this field. Therefore, they have a connection to this product. These entities have a background with technology and are experienced users. It is a technical field. That leads to the assumption of a younger user audience. This does not mean that older people are completely excluded as potential users, but rather that the focus will not be on pleasing the needs of the older generation. There is a profound knowledge about cars how their architecture works, what components are responsible for a task and a lot more. The user may be an expert on the vehicle they predominantly work with, but elements can differ, depending on the manufacturer. Working in the field of ADF, the user is familiar with forensic methods and questions. Although they deal with matters of ADF, the majority of cases they process may focus on a specific context, that mainly occurs, for example accidents. Therefore the knowledge about other areas of the field may not be as in-depth as in their main work area. Given the circumstance the user is working with the tool, he or she may have to spend a lot of time using it. This implies the visualization has to be adapted to the circumstances of long term use.

User Segmentation Now the described user from the last section will be summarized by representative characteristics.

- Expert in their field
- Experienced user of computers
- Still working, younger than pension age
- Existing knowledge about cars
- Familiar with forensic methods and questions
- Uses a lot of digital tools at work over long periods of time

Success Metrics In order to be able to declare a goal as completed in the evaluation part 7, success metrics are defined early in the development process. Quality of information, user experience, aesthetics and the form of visualization should be in a state, that satisfies the user. The quality of presented information will be judged by an expert in the field of ADF. If this expert comes to the conclusion that the whole content of the tools is correct, the point of quality of information can be marked as completed. User experience can be difficult to review. But there are factors that can be tested in order to measure the user experience. One possibility to test the user experience of a product is the User Experience Questionnaire (UEQ). The UEQ provides a set of six scales: "*attractiveness, perspicuity, efficiency, dependability, stimulation and novelty*" [27]. In [27], Schrepp et al. assign to each scale word pairs with opposite meanings. For example on the attractiveness scale the participant has to decide which word, annoying or enjoyable, describes the product better on a seven point Likert scale. With this questionnaire hedonic and pragmatic quality parameters are evaluated [26].

Aesthetics, as already mentioned in 4, are a matter of subjectivity. To evaluate the aesthetic design of the tool, the UEQ provides information about the attractiveness and stimulation. The results can be interpreted to find out, what the user thinks about the aesthetics of the visualization.

To determine the most suitable form of visualization, this thesis will provide multiple visualizations. Later on they can be compared with the help of the UEQ and the form that provides better results from the questionnaire is the more fitting visualization for the task in this project.

User Personas By asking a potential user some typical characteristics for a user persona could be established. Based on these information two personas were developed. As shown in Section 4, there are multiple stakeholders for the chosen two contexts. Out of this group of possible users, first an ADF investigator and second an insurance investigator, were chosen. They were chosen because of the relevance the ADF tool and data visualization would have for them. Although other target groups would also be relevant in this context, they do not meet the requirements in this case. For example criminals and business car owners are also stakeholders, but for them the ADF tool and data visualization have no relevance, because they do not resolve forensic questions. Therefore, only two personas were developed to guide the future development of the visualization.

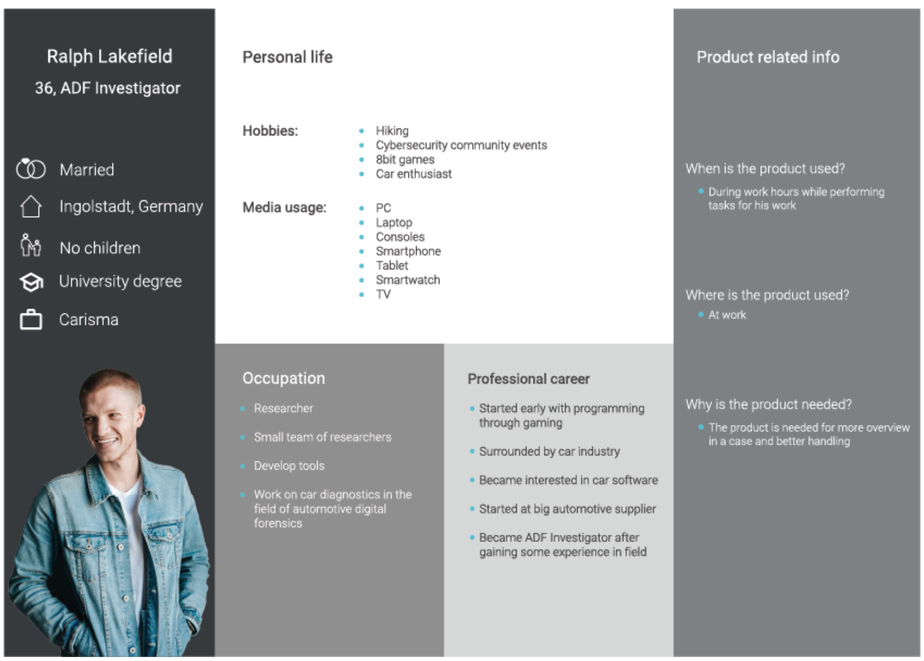

Figure 5: Persona A, Ralph Lakefield, ADF Investigator

Persona A: Ralph Lakefield Forensics Investigator The first persona is Ralph Lakefield. He is 36 years old and works as an ADF investigator. He is married, but has no children. He works at the CARISSMA research institute in Ingolstadt. Before working there he studied automotive informatics at university and graduated with the bachelor's degree. In his personal life he likes to hike, takes part and organizes events in the cybersecurity community, collects and plays old 8bit games and is a passionate car enthusiast. Digital devices are part of his daily life. He often uses his PC, laptop, smartphone and smartwatch. A console, tablet and TV are also in his possession, but he rarely uses them. At work he functions as a researcher in a small team. They develop tools to simplify digital forensic investigations on cars. Programming has been a part of his life for a long time. Games drew his interest towards programming and developed first skills in this field. In his hometown the car industry is the main employer. This circumstance creates a surrounding filled with cars fueling Ralph's enthusiasm for cars. At university he favoured courses allowing him to combine both, his interest in cars and programming. After that, he started working at an automotive supplier. After gaining some experience he found his way into ADF investigations. Due to this background he has profound knowledge of ADF investigations, vehicles and their architecture, forensic questions and methods and computers. He gained a superficial insight into the investigation of accidents and thus only has limited experience.

Persona B: Lauren Mills Insurance Investigator The second persona is Lauren Mills. She is 28 years old and works as an insurance investigator. She is married. Allianz is her employer, where she works, among another things, on investigations of for example car accidents and thefts. In her free time she likes to go running, painting, creates "Do it yourself" projects and plays the guitar. She is pretty confident in her skills using digital devices like her laptop, but she has no deep knowledge of software development. She predominantly uses her smartphone, TV and laptop. Sometimes her tablet and Amazon Echo are in usage. At work she deals with digital forensic investigations of insured events. But she is new to this area and only joined the department after passing advanced training courses on DF. The company she works for, is medium-sized and her team is rather small. The investigations try to resolve insurance questions. For example they try to find out about the at-fault party of an accident. Lauren studied economics at university. There she completed some basic courses on software programming. After finishing her Bachelor's degree, she started to work at an insurance company. She joined the company as a trainee and gained experience in various departments to gain insights into the activities of an insurance company. The task she enjoyed the most, was insurance investigations. That is the reason why she started to work in this area. After some time she passed an advanced training on DF to be able to handle her tasks more efficiently. She developed most of her skills by actually working on cases. She has acquired basic knowledge of ADF investigations. On top of that she has profound experience with forensic questions and methods and with computers.

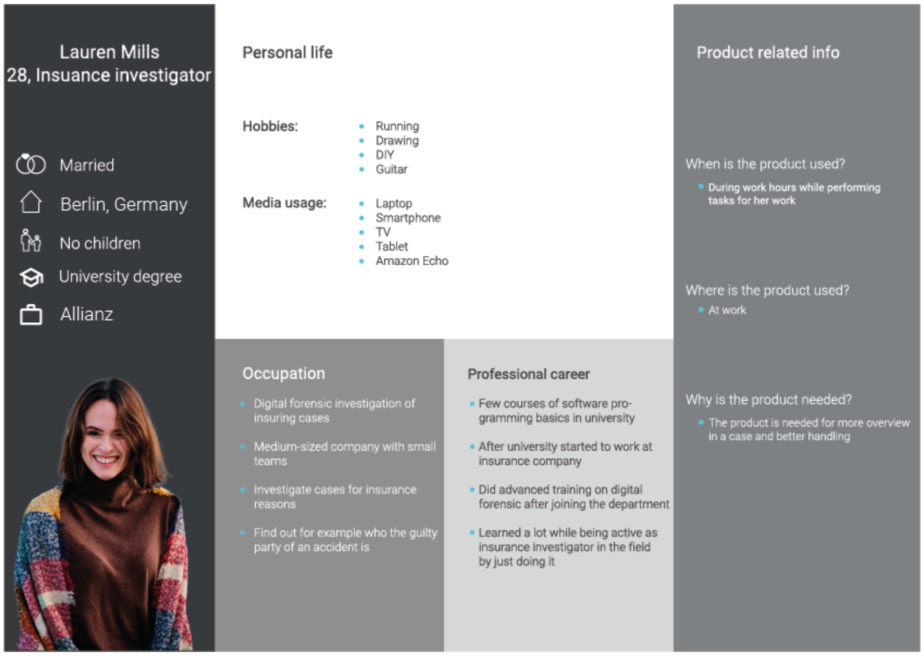

Figure 6: Persona B, Lauren Mills, insurance Investigator

Her knowledge about vehicles and accident investigations is exceedingly good, due to the insights she gained while absolving the trainee program.

5.2 Scope Plane

The purpose here is to define the scope by taking a closer look at functional specifications and content requirements.

Functional Specification This step helps to point out which features of the final product are relevant. For example if a login option is a functionality that has to be implemented. The functional specifications are usually compiled by the users and stakeholders. In this project, the list of functional specifications is developed by a stakeholder, who also belongs to the target group. Within this addressed list items are divided into required and optional categories. The content of these specifications was developed in a brainstorming session with an ADF researcher and stakeholder of this project.

Required

- List with context options

- List of vehicle models that can be chosen
- Dataclass and datacomponent information according to vehicle
- Highlight system for most important information in chosen context
- Application of UXD best practices

Optional

- Login option
- Supported Web browsers Google Chrome and Mozilla Firefox
- Interaction medium standard computer, no touch required
- Mouse over to reveal additional information
- Project owner logo
- Respect colourblind condition

Content Requirements Now the content requirements refer to the information that are transferred by the product. There are different ways to exchange information. A video or audio clip can fulfil this task, as well as text. In some situations a video will be the best choice, whereas in other areas, text might have its specific merits.

The information that has to be included in this product is depending on a context. These contexts are already determined to limit the extent of this thesis. Therefore, content that is required in this case is:

- Context that is currently relevant
- Type of information that can be found
- Importance of information in correlation to context
- Available options for interaction
- Dataclass and datacomponent where information is stored
- Model of car

5.3 Structure Plane

This Plane's focus is on *Interaction Design* and *Information Architecture*.

Interaction Design Interaction Design refers to the interaction between user and product. The system reacts to the input of the user and the user reacts to the output of the system. What the developer of the system now wants to do, is to anticipate the user's behaviour. By finding out how the user behaves in certain situations, the designer can adapt the system to adequately serve their requirements. Garrett in [9], states that most of the time it is best to use elements the user is accustomed to, unless you have a reason to introduce a new way of interaction.

So for this visualization the used elements will be commonly implemented ways of interaction. Keeping to drop down menus for selecting one of multiple prepared options, submitting selected input with standard buttons, click on elements for further information and a navigation bar with tabs to click on for navigating the site.

Conceptual Models In this process conceptual models are important. A conceptual model according to Garrett in [9], describes how the user thinks the system will respond to an interaction. A designer can now apply existing models and anticipate the user's behaviour when interacting with components of this system. This project focuses on identifying fitting forms of visualization for ADF data. The visualization of data has the purpose of conveying information and is thus also a main goal. A conceptual model after Johnson and Henderson in [13], should include the points "*metaphors, concepts, relationships and mappings*" [13].

Metaphor A metaphor for this product could be a sort of guide or lexicon that helps to find a desired information, with the focus still remaining on the visualization of DF data. Although the users are professionals in their field there are a lot of different car models, each of them using different storage spaces for information than the ones you might be used to. So this should not be a step by step guide that explains how to conduct a complete digital forensic investigation on for example a car that has been involved in an accident. It rather should fulfill the purpose of providing and giving a sense on how to visualize the information when you are not sure, where in this specific context and in a specific type of car you can find the searched for data. Due to the request for fast information delivery, user input and adaptability, a standard paper format would not suffice. Therefore, a more interactive system, like a web application would be more appropriate to fulfill the given requirements than a non interactive medium. The metaphor would then be more of a digital guide or lexicon, such as a wiki page.

Concepts The concept would include a search through given terms, that are presented in form of lists. One list would contain the available contexts, the other one the available car models. Based on the combination of those search terms, a presentation of the available information would be given to the user. At first these information would be more general and categorised and not broken down to the lowest level of data. Then the most important categories for the relevant context would be highlighted to guide the user to the requested information. The categories then contain the associated data components. To round up the product, additional information to the data types should be provided. Context and car model should be exchangeable throughout the whole process, to provide adaptability and comparability.

Relationships Context and car model are superior to other parts of the concept, because the following information always depends on this input. The categories of available information in the chosen context contain the data components.

Mapping The input on context and car model is given through the real circumstances of a case. For example a car accident involving a Tesla Model 3. Each data type that can be found in the system corresponds to real data that can be acquired from an ECU.

Error Handling Part of the interaction design is also the handling of errors. The possible errors in this application are low due to the low number of available interactions. User input is limited to choosing a context and vehicle from a list with given terms and clicking on data classes for further information. An error that can occur would be a wrongly clicked context, car model or data class. To handle this error, the user must be made aware of his current position in the system. This means the currently selected context and car model must be displayed in a way the user notices them. A solution for this problem could be a headline, including the current context and car model or the drop down menus where the user can choose the context and car model are displaying the chosen options. Additionally the current layer of information displayed must be presented to the user. This for example could be implemented in the navigation bar by highlighting the current section the user is located in.

Information Architecture The information architecture is used to transfer information in a "*structured manner*" [9]. By providing data in this way it is easier for people to process it. Essentially, after Garrett in [9], there are two possible ways to construct an information architecture the "*top-down approach*" [9] and the "*bottom-up approach*" [9]. Top-down means the source for creating the architecture lies within the strategy plane. This implies that by starting with superior categories, you start breaking them down into "*subsections*" [9] until on the lowest sections are reached, which hold the content. Bottom-up works in a similar way, but with a different starting point. From "*content and functional requirements*" [9], which were defined in the scope plane, you take the elements that represent your content. These content elements now will be sorted into "*subsections*" [9] and categories.

For this project a bottom-up approach is the better option. The reason for this decision is the defined content in the scope plane, which in parts already exists. Especially the data components that have to be visualized.

The developed information architecture can be seen in 7.

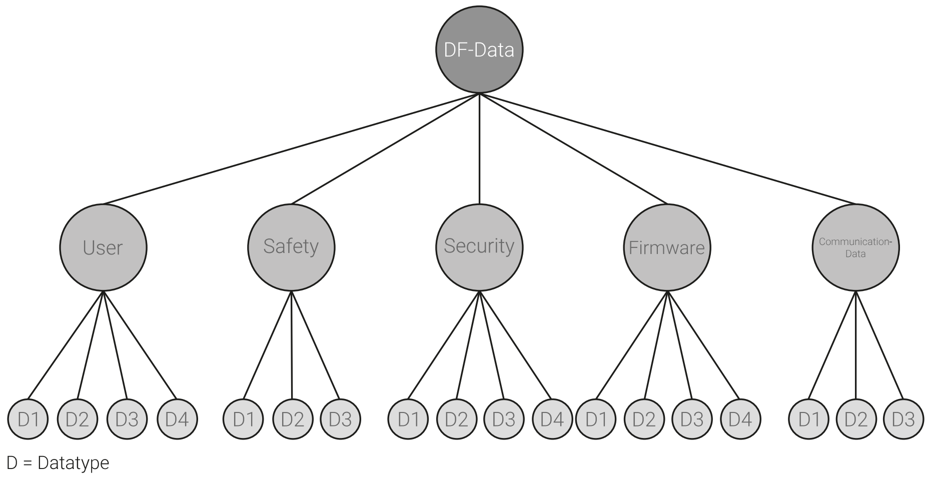

Figure 7: Information architecture

5.4 Skeleton Plane

The main aspects of the *Skeleton Plane* are "*Interface Design, Navigation Design and Information Design*" [9]. The areas are not completely separated from each other, but rather have an influence on some aspects contained in the other ones. In this part the details of the functionality defined in the previous plane will be developed. It becomes clearer how the targeted functionalities are to be implemented.

Interface Design Interface design deals with the displayed interaction elements the user utilizes for the input. Exemplary components are radio boxes, action buttons and more. The interface elements will stick to the known and commonly used components. The lists that are part of the functional specifications will be designed as drop down menus. There are only few elements included in these menus now, so radio boxes or similar options would give a better overview of the available choices. But the application is designed in a way that it can be extended with more options to choose from. This leads to confusion, since too many elements would be displayed at the same time. If the amount of options would rise to a level where the user would need a lot of time just scrolling through the drop down menu, a search bar could be the better choice. Disadvantage of this component would then be a higher risk of errors through the user's input. For this project that is designed so it can be developed further with more options, the drop down menu was chosen to accept the user's input. To reach the next page, the input has to be submitted. For this purpose an action button is implemented. In the section following the index page the categories will be displayed as custom forms. They will be represented in different sizes to illustrate the importance of the category for the chosen context. The elements will work like a standard action button and link to the data components that are related to the selected category. A link to the index page will be provided through a home section presented in the navigation bar that will be available throughout all sections of the application.

Navigation Design Navigation design defines a way to navigate between the available sections. Every application needs an entry point. In this case all given information is depending on two factors: context and car model. So before any data can be visualized the user has to give their input to initiate the process. Therefore, an entry page was created that prompts the user to select the parameters they are looking for. The form of navigation used for the project is called "*Supplementary navigation*" and is presented by Garrett in [9]. In this form of navigation the user is given the options of reaching all content that is associated with the current element. From the index page you can navigate to the next section which is, according to the information architecture, an overview of different DF-Data categories. To provide flexibility the context and car model should be exchangeable at each section. The next page contains the previously selected data class and additionally the associated data components. To ease the navigation, a link to the index page is displayed on every single page. This enables the user to start over, when they wish to do so.

Information Design Information design is all about clustering data in an understandable way easy to grasp for the user. In this case the existing information are the data components. They can be described as the ground level information. To better understand what knowledge can be gained from these data components, a higher-level category is introduced. This category summarizes all associated data. The level of importance of a category in a specific case depends on the chosen context. The highlighting of the relevant category is adapted to the context the user enters and the car model specifies what data types exist to gain insights from.

5.5 Surface Plane

The *Surface Plane* is concerned with "*sensory design and presentation of the logical arrangements[...]*" as presented by Garrett in [9]. Furthermore, these were pointed out in the last discussed plane in Section 5.4.

Sensory design describes the use of the five human senses in correlation with the product. In [9], Garrett explains the kind of product to be designed and determines the senses that can be of use in developing it. The senses are smell, taste, touch, hearing and vision.

Smell and Taste The product in focus here is a software. Therefore, smell and taste can not contribute anything to a better user experience. As of today, there are no olfactory and gustatory elements assigned to the product. Both senses can not be used to enhance the user's experience.

Touch Touch could be a factor even in software. For example through vibrations or touchscreens. In this specific case the listed requirements in Section 5.2, state there is no need for a tactile interaction. Since there is no physical product to be developed there also is no requirement regarding its haptics, as there would be in the case of designing an industrial object. In this context, surface feel of textures would play a more important role.

Hearing The next sense is hearing. Auditory information appears more often in software applications than one might have imagined. In [9], Garrett mentions the example of a car equipped with all different kinds of alarms. In this project only a few interaction possibilities are implemented. This also limits the feedback given to the user about an action they performed. The purpose of the tool developed in this thesis, is to provide a possible way of visualizing data in the area of ADF, supporting the user by guiding their attention and provide them with information. With the focus on the visualization, the addition of sounds may not be the best way to enhance the user experience. Through the limited possibilities of interacting with the software, the risk of errors is expected to be rather low. This makes warning sounds lose a lot of their purpose and exclude them from being an option for the tool. Overall the application does not benefit from acoustic signals as much, as other software products do.

Vision The last sense is vision. It is the sense that has the most impact on the user experience of this software project. Like stated in Section 4, aesthetic design is a matter of subjectivity. But there are elements that provide a common understanding of what the product wants to communicate. Garrett in [9] refers to fonts as an example. If the goal is to communicate a serious attitude, a comic font is not the optimal choice to express what you want to. A reduced sans serif font will serve this purpose much better. Different font examples can be seen in Figure 8.

The tool is designed to give the user an overview in a quick and understandable way. It is made for use at work. Therefore, the product should communicate the values of professionalism and simplicity. Giving the elements enough space and displaying only necessary information, provides the user with a good overview. With only a few elements present the sites' content is easy to perceive and no unnecessary components disturb the user's attention. Garrett lists "*Contrast and Uniformity*" [9], as central elements in designing visual elements. Contrast gives the user an indication of where to focus their attention. To enhance the contrast and therefore emphasize the core elements, a commonly used technique is white space. In [12], Hahn explains that white space strengthens the impact of other components and gives a sense of professional-

Figure 8: Top: Font Roboto Middle: Font Comic Sans MS Bottom: Font Amsterdam Graffiti

ism. Based on the previously stated facts, the visualization should only contain relevant elements and leave sufficient white space to ensure a professional look that enables the user in gaining a good overview of the pages' content. On top of that, a contrast in colour, highlighting the core components, supports the user in perceiving important information. Part of giving the elements enough space is the previously established information architecture. By distributing the elements to different layers of the application, each part gets enough space to unfold its full potential. The uniformity of used items can be achieved in many ways. For example the sizes of objects can mark them as interrelated. For this visualization groups of elements are uniform in their form and alignment. In [12], Hahn explains elements aligned next to each other in reading direction are perceived as belonging to the same group. Another way to express uniformity of objects, is the *law of proximity* mentioned by Hahn in [12]. Elements placed close to each other are perceived as being uniform.

5.6 Strategy Plane for the Second Form of Visualization

The objectives of this project do not change and still apply to the second form of visualization. Therefore, in Section 5.1 established points are also used as a foundation for the second visualization.

5.7 Scope Plane for the Second Form of Visualization

Functional specifications and content requirements can be adopted from the first visualization in Section 5.2. A different illustration is still based on the defined requirements of this plane.

5.8 Structure Plane for the Second Form of Visualization

Due to the defined contents of the page, the options for interacting with the application are limited. For the interaction design, the ways of interacting will be kept like in Section 5.3 described. The established conceptual models also apply to this second form of representation.

What changes in this plane is the information architecture. For the second visualization the amount of information displayed at once has increased. The goal is to provide the user with all available information in a quick manner. This gives them a better overview of the whole picture and available information in one view. The hierarchy will be flat, because there will be no subordinate elements. Still there is the entry page where context and car model have to be chosen that will be superior to the content information.

5.9 Skeleton Plane for the Second Form of Visualization

Interface Design Entering the landing page is consistent to the first visualization. The context and car model are essential for the following components to be displayed and need to be chosen as early as possible. For choosing the context and car model, a drop down menu will be implemented as well as an action button for submitting choices. The reasons are explained in Section 5.4. Depending on the input of the user, the page containing the information about data classes and components will be displayed. This level contains all information that should be communicated to the user. What changes here in comparison to the first visualization is that the user no longer needs to go further down in the information architecture to gain insight into the available data components. That implies that there is no need for the displayed data classes to be interactive and link to another page. All categories and data components will be included on this site and the highlighting is implemented by changing the size of clustered information.

Navigation Design Entering the application remains unchanged for this second form of visualization. The user is shown the choice of context and car model, which then have to be submitted. Following that, the second and lowest level in the websites' hierarchy is displayed, containing all the information about data classes and data components. By displaying a link to the entry page, the users can start over whenever they like.

Information Design Essentially the information design stays unaltered as defined in Section 5.4. The data components are summarized in data classes that are assigned to the according context and car model.

5.10 Surface Plane for the Second Form of Visualization

Applying the senses of smell, taste, touch and hearing still proves difficult to the second form of representation, since the type of product remains software-based as in Section 5.5 described.

The impressions on the visual sense on the other hand are changed. Displaying more elements at once, reduces the white space available to focus the user's attention on specific elements. What benefits from the increased amount of displayed components, is the sense for cohesion of categories and the according data components. The form of the objects still represents a kind of uniformity, but with more elements displayed some parts get smaller and the form might not be an optimal unique identification for relatedness. Colour is used to establish a connection between data component and data class, but may not be sufficient due to the lack of space. Therefore, connecting lines, drawn from each related element to the next, form a comprehensible network linking related components to each other. In [12], Hahn explains that higher amounts of displayed elements demand a higher need for dividing the objects into reasonable classes. Drawn connections meet this requirement.

6 Implementation of the Developed Designs in Form of Prototypes

The design has been defined in Section 5. Fundamental decisions and objectives of the project have been specified. The next step is to implement the design decisions into a prototype.

Implementation Medium There are different forms of media available for the implementation. Exemplary options are paper prototype, interactive click prototype and software prototype.

In Section 5.2, the functional requirements state that there is a necessity for a highlighting system for the most important information in the chosen context. Therefore, a certain level of interactivity is required. Also adaptability of the representations has to be given, due to the highlight system, which needs a form of adjustment to properly highlight an information. This makes the paper prototype a less viable option.

6.1 Implementation of the Click Prototypes

Both visualizations developed in Section 5, are now to be implemented as a click prototype. There are different software options available to create a click prototype, for example Figma, Sketch or Adobe Xd. For the development of this project, Adobe Xd was used. The software used for the creation of the prototype was Adobe Xd, because the author's knowledge about this tool is more advanced than it would have been the case with the other options. A major advantage of click prototypes is that ideas can be implemented quickly and easily. Adaptations of components are fast to implement and different approaches can be tested. So this sort of prototype is a way to compare different options of visualizations, without dedicating too much time to the development, as it may be the case with a software prototype. As time is a limited resource in this project, creating each visualization option as a working software prototype would exceed the scope of this thesis. The chosen approach is to implement the variations of visualizations as click prototypes and then implement the most promising option as a software prototype. In this way the representations can be compared and advantages and disadvantages can be carved out.

First Form of Visualization A major focus of the first representation is to emphasize the relevant components to make them easily perceptible for the user and position them in the center of their attention right away. Using white space as a design tool, offers the possibility to catch the user's attention immediately. White space supports other components by creating an uninterrupted environment, where the placed elements have more effect [12]. By creating the information architecture with different layers containing only one set of information at a time, the items to implement for each page were reduced to a minimum. This leaves more room for white space, enhancing the user's focus on the information to be communicated. To convey a sense of professionalism, the chosen font is a sans serif font called Roboto, that is commonly used in applications. In [12], sans serif fonts are described as having a modern character and are often used in screen design. Reason for this, is the enhanced readability in small sizes compared to serif fonts. Additionally this type of font is often used in textbooks, because the reader has to invest more time to perceive the text and therefore focuses more on the content. Another thing to keep in mind, are the colours used in this implementation. The colours for the core components have been chosen, in a way that the overall temperature is balanced. In order to not overextend the users perception, when working with the tool, the saturation has been reduced to lower the contrast and make the elements easier to look at for a longer time. The necessary amount of contrast is still guaranteed by the white space.

For the interactions the defined procedure from Section 5.4 is pursued. The click prototype is built as seen in Figure 9.

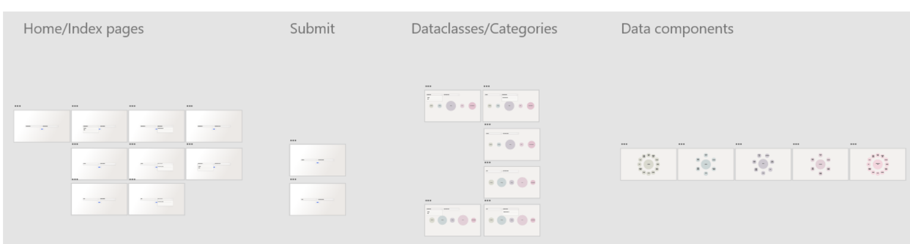

Figure 9: Overview of prototype states

The entry page is presenting two drop down list menus where context and car model can be chosen and a submit button. They are placed in the center of the screen to have the surrounding white space emphasize on these elements. The user's focus is guided towards the only elements displayed and those are the two drop down menus and the submit button. To reach the next page, the chosen list entries have to be submitted by a simple action button. The page can be seen in Figure 10.

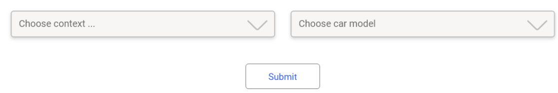

Figure 10: Index page with two drop down list menus and submit button

Depending on the chosen context and car model, the next page is altered to highlight the fitting information. The elements holding the data class are visualized as circles positioned next to each other. Information more relevant for the current context is emphasized through the size of the circle. A bigger circle implies higher relevance and accordingly a smaller circle lower relevance. The advantage of a highlighting system based on sizes in comparison to using for example colours, is that it also works for people with colourblindness. To keep the user aware of the section they are currently located in, the selection of context and car model is displayed on the top of the page. For further information on the data components a data class summarizes, the circles displaying the data class are clickable and link to the next layer. The representation of this page can be seen in Figure 11.

The lowest layer displays the data components linked to the superior data class. To keep the design consistent and establish a connection between the current and the last layer, the colours of the clicked data class and the displayed data components have the same colour. The associated data components are arranged in a circular form around the data class. This helps to draw a connection between the class and component and see them as interdependent and not separated from each other. This formation also adds the factor of symmetry to the page. In [12], Hahn gives symmetry the attributes of "*aesthetics, balance, stability and harmony*" [12]. Symmetrically arranged objects tend to support the user in better memorizing these items, which helps to establish a connection between tool and user. In Figure 12 the exemplary case of a data class with components is displayed.

Figure 11: Representation of data classes with highlighting of context relevance

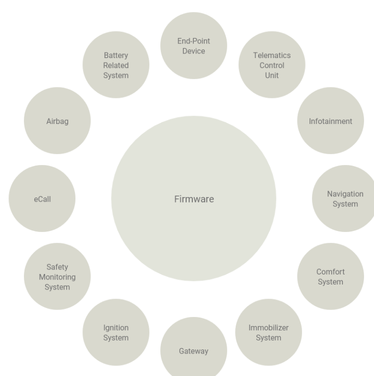

Figure 12: Data class surrounded by corresponding data components

Second Form of Visualization In the second representation, the focus lies on displaying all important information and their connections at first sight. It should give an overview of all classes and components in one single image. With more elements to be perceived at the same time, it gets harder to direct the user's focus in the targeted direction. The main element for guiding the focus, namely white space, is reduced by the components placed on the page. This does not apply to the index page. The index page stays as it was designed in the first form of visualization, see Figure 10. The reason here is as described in Section 5.4, that this is a fitting form of input to use for the needed information of context and car model.

After submitting the input from the index page, the data classes and components are displayed. As described, they are all illustrated on the same layer. Clusters that present more relevant information, depending on the chosen context and car model, are scaled to a bigger size. Clusters holding less relevant information are smaller. This sort of highlighting system respects the needs of colourblind people. With all the elements displayed, the connections might not be evident from just the clustering and the matching colours. To support the association of linked components, connecting lines clarify the relations. Data classes are displayed in a bigger circle, whereas the associated components are represented by smaller circles. The proximity of these elements, as mentioned by Hahn in [12], mark them as interrelated. To make the user aware of the context they have chosen, the context is displayed in a central element. The described visualization can be seen in Figure 13.

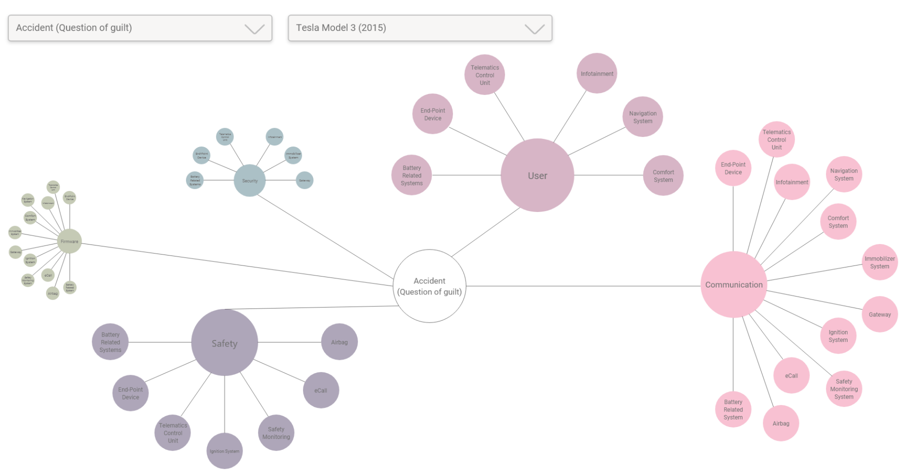

Figure 13: Data classes and components displayed on one layer

6.2 Software Prototype

The content to be displayed in this project is limited to the elements listed in Section 5. Therefore, there is no need for a big web application including a lot of sub pages. An application with a simple design and navigation will be sufficient to provide the user with the required information.

There are different ways to create this prototype. One would be, to use standard HTML, CSS and JavaScript. Another way would be to use a framework like Vue.js or React. In this case Vue.js was selected, because of its advantages in the field of single page applications.

Setting Up the Project The Vue project created with the Vue-cli can be setup with different options to choose from. There are default versions available, but in the case of this project the features were selected manually. From the listed features the necessary ones are Babel, Router and Vuex. As for the version, Vue 2.x is chosen, due to the supported plugins. The history mode for the router is not needed in this application. For the configuration files the package.json option is chosen. After initializing the project with the mentioned settings, a project folder is created containing the basic components as seen in Figure 14 for the Vue project to start.

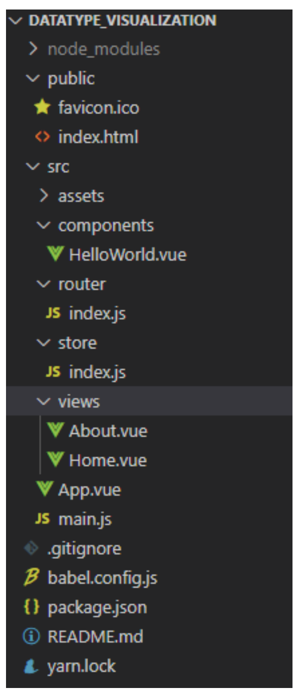

Figure 14: Vue auto generated files

After the initial project is set up, the Vuetify framework plugin has to be installed, in order to access the provided User Interface (UI) elements. "*Vuetify is a complete UI framework built on top of Vue.js.*" [34]. The plugin can for instance be installed via the yarn package manager.

Automatically Generated Files The favicon.ico file can be ignored as it will not be used in the course of this project. The first relevant file is the index.html file. According to the Vue.js documentation in [31], index.html "*[...] is a template that will be processed with html-webpack-plugin. During build, asset links will be injected automatically.*" [31]. Next are the components. Components in Vue.js are "*[...] reusable Vue instances with a name [...]*" [29] that can be used in root Vue instances. For example a button used on many occasions throughout the web application can be defined as a component and later on just has to be implemented through a simple tag. Vue router is used to "*map our components to the routes and let Vue Router know where to render them.*" [30]. Basically it links components or views and defines what is rendered where. The router information is defined in the index.js file under the router folder. The store contains another index.js file defining the Vuex store. Vuex is used for state management in Vue.js. "*It serves as a centralized store for all the components in an application [...]*" [33]. With Vuex, states can be defined that are usable in all components by using getters, even if they do not have a relationship like parent or child. On top of accessing the state, it can also be altered in defined ways through so-called mutations. The views can be skipped for this project, as they will not be used. App.vue is attached to a Document Object Model (DOM) element and controls it. The index.html is just serving as an entry point [1], while the Vue instance is controlling all other parts [32]. Elements like a navigation bar that are displayed on every page, are implemented in App.vue. Main.js functions as the application's entry file. It includes the plugins, that are used in the project. Gitignore is also not relevant for this project, as git is not used in the development process. Babel.config.js is a file containing data relevant for the Babel feature. Babel is a tool used to ensure that applications also work on older browsers with no updated java script versions [4]. The package.json lists necessary dependencies and project information. This information is summarized in the json file and not in dedicated files, due to the project's setup. And finally there is the yarn.lock file. According to the yarnpkg documentation in [35], yarn requires more data on the dependencies than the package.json provides to be able to install the application across machines.

Components The developed components are displayed in Figure 15.

The components called Datatypes_Communication, Datatypes_Firmware, Datatypes_Safety, Datatypes_Security and Datatypes_User are all files, that only contain a svg representation of the data class, the associated data components and a back button. The svg is surrounded by structuring elements like a container and a row. These elements will be displayed, depending on the data class the user clicked on the previous layer that is implemented in the DataComponents.vue component. The DataComponents.vue component consists of a container element holding the Datatypes_ components. But there is a condition for the Datatypes_ to be displayed. This condition is a String stored in the

[1] Also option for including google fonts for icons

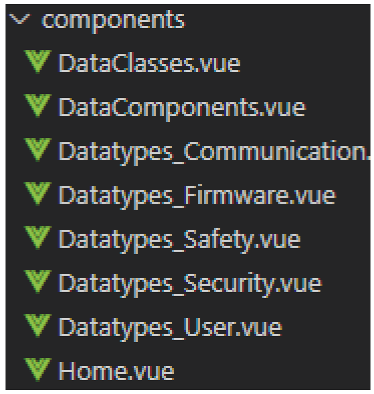

Figure 15: Components developed for prototype

Vuex state datatype and is accessed through the getter allDatatypes(). This String changes, when the user clicks on a data class element in the previous layer. Only one Datatypes_ component is displayed at a time. An example of the representation of a Datatypes_ component can be seen in Figure 16.

In the DataClass.vue component, there are two drop down menus displaying the chosen context and the car model. This helps the user to be aware of the current input they have given. The main elements are five circles displayed in a svg graphic. Each circle contains a data class: firmware, safety, security, user and communication data. These elements are surrounded by a router link tag that forwards the user to the associated data components. This is done by a click event changing the state of the current data class in the Vuex store. Depending on the selected circle, a different data component set will be displayed on the next page. Depending on the chosen context and car model, the circles are highlighted by using different sizes. The context is stored in a state that uses the user's input through the drop down select menus on the Home.vue component. More relevant data classes in the chosen context are highlighted by bigger scale.

Home.vue contains two drop down select menu elements and a centrally positioned submit button underneath. It is the entry point to the application and serves as the user's main input. The menu items provide the option to choose the context of accident or theft and the car model. Currently only the Tesla Model 3 (2015) is offered as an option. Figure 17 shows the Home.vue page.

Router The Vue router is defined in the associated index.js file. Here the path to router components is defined. These components can then be accessed through a router-link tag. This enables the linking of components to be displayed. The available router options are described in an array, holding objects with path and component.

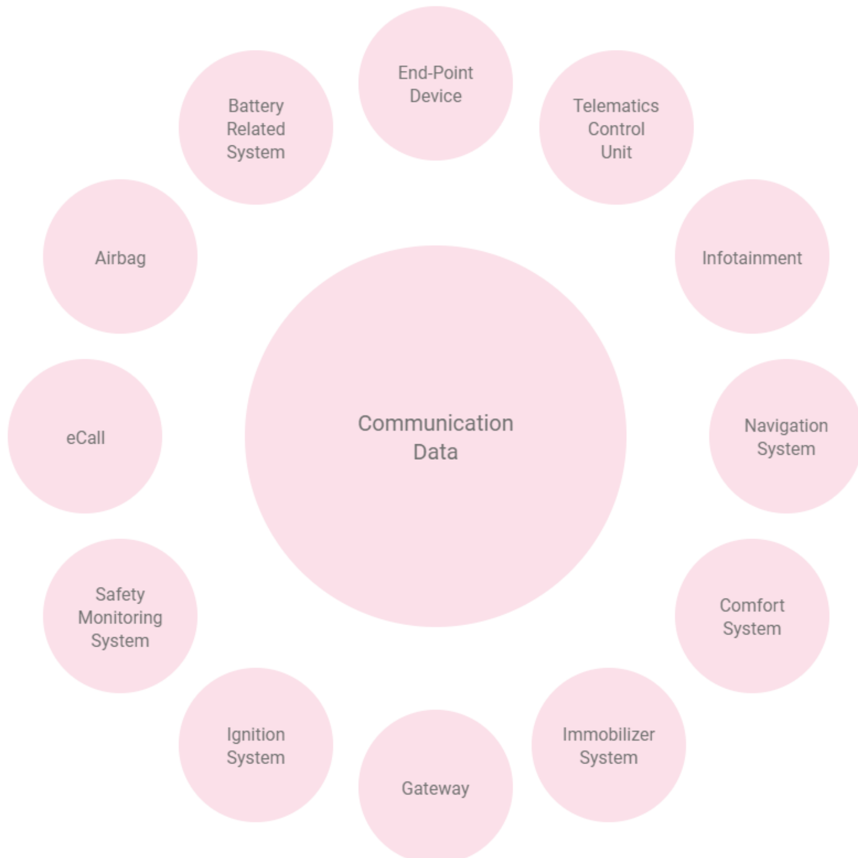

Figure 16: Communication data displayed on the data components' layer

Vuex Store The Vuex store, consists of two files. One is the index.js file. This is where the store is created. For this project the modules option was chosen. There is only one module used called datatypes. This module is defined in datatypes.js. Here the states, getters, actions and mutations are described.

Views App.vue represents the only view in this project. It is the main page with the navigation bar and the router view implemented, that renders the current routed component.

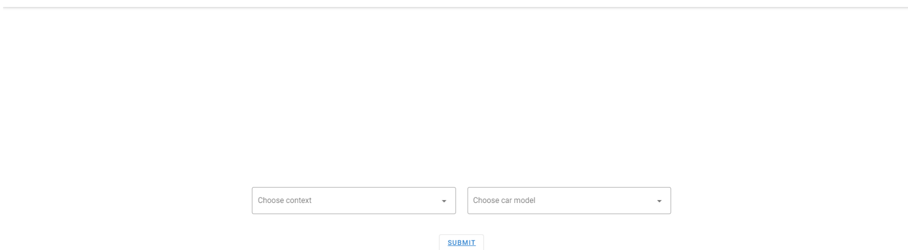

Figure 17: Entry page for application with user input

7 Evaluation by Testing the Implemented Prototypes

This section is about evaluating the designed and implemented forms of visualization developed in Sections 5 and 6. First, the evaluation criteria are defined, then the evaluation is performed by testing the prototypes implementing the two forms of visualization, verifying if the requirements are met.

7.1 Evaluation Criteria

In Section 5, the success metrics were developed according to the methodology of Garrett [9]. The state of quality of information, user experience, aesthetics and form of visualization should be in a state that satisfies the user. Aesthetics are evaluated by comparing applied design techniques of the Adobe Xd prototypes. Like mentioned in Section 4, aesthetics is a matter of subjectivity and therefore the perception of aesthetics can differ from person to person. To be able to compare implemented designs, the used principles of design will be judged according to the purpose they serve. For example if the purpose is to drive the users attention towards an element of interaction there are different design elements to use like the element of white space [12]. Now both variations of visualization can be compared according to the criteria of white space they provide. Depending on this comparison, one design is chosen for further development in form of a software prototype. The choice of implementation medium is also discussed.

In regards of user experience, the evaluation is performed with help of the UEQ. First the questionnaire itself is described, then the realization of testing and finally results of the test are documented. By comparing results of the UEQ of each tested prototype, the fitting form of visualization should be decided.

Quality of information is evaluated by an expert in the field of ADF or can also be judged by an automated system that extracts information directly from the system of a car.

7.2 Choice of the Form of Implementation

There are different kinds of prototypes. In [19], McCurdy et al. mention fidelity reaches from low to medium and then to high. The degree of fidelity depends on "*visual refinement, breadth of functionality, depth of functionality, richness of interactivity and the richness of the data model*" [19]. Examples for prototypes are paper prototypes, HTML prototypes, click prototypes, scribbles, story boards and software prototypes. It is not possible, for example to declare the HTML prototype in general to be a high fidelity prototype. The factors within the limits of each prototype differ. A HTML prototype can have a high visual refinement, but still show deficits in the area of richness of interactivity. In the process of starting the implementation choosing the type of prototype that would suffice the requirements was one of the first steps. Paper prototypes, story boards and scribbles are good tools to be able to quickly develop new ideas and adapt them to get a feeling for what the user possibly wants or dislikes. The problem is that they have a rather low fidelity, caused by the lack of interactivity provided. In this project the requirements state that a context and car model have to be chosen and a highlight system is to be implemented to emphasize important information. For this level of interactivity, there are better options than these rather low fidelity forms of prototypes. HTML prototypes, click prototypes and software prototypes can all range from low to high fidelity. A HTML page can be used to solely display static content, but it can nevertheless include links to other pages, in order to be able to provide different levels of fidelity. The same applies to the remaining two forms. The click prototype can be implemented with software like Adobe Xd, Figma or Sketch. It offers a quick possibility to give design ideas a form of interactivity. Different ideas can be tested, as it does not take too much time to design new screens and implement the needed interactions. Of course the time needed depends on the level of visual refinement. Higher level of design details require more time than lower levels. In this case the click prototype was chosen as a first form of implementation, because it allows the development of different designs and the collection of feedback in a short period of time. The stakeholders as well as the users can get a first impression of what the product could look like in the end. They can tell if they are satisfied with the design idea and see, if their defined requirements are met by this product. By taking a look at different versions, preferences can be highlighted for further development. Click prototypes present a problem, as the difficulty to develop them increases, the more content is implemented. Each visual change has to be designed on an own page. In addition, data is not saved. The options of interactivity for the user are not based on available data, but on screens which the designer has either implemented or not. This makes it difficult for further development, when adding for example more contexts and car models to this project. A software prototype using a framework like Vue.js or React, can provide what the click prototype is missing. Therefore the click prototype was used to compare the design options with each other and based on the comparison one version was further developed and implemented in the form of a software prototype in Vue.js.

7.3 Comparison of the Design and Aesthetics of Two Click Prototype Variations

As seen in Section 5 and Section 6, there are two forms of visualization. The decision on which of these two forms should be implemented in form of a software prototype was based on a comparison of the design. The main difference of both visualizations is the depth of layers and caused by that the amount of content displayed on a page at once. The goal of this thesis was to find a way to provide a form of visualization that enables the user in getting an overview of the available data. Both options provide a different kind of overview. The first form of visualization conveys the overview step by step, guiding the user from one layer to the next one highlighting the more relevant information. The user's focus is guided to help them stay aware of which data is available, but also emphasizing relevant information in the current context. The amount of white space in the design is kept at a high level to be able to direct the user's focus onto the important parts of the displayed elements.

In comparison, the second form of visualization does not include these layers, but gives an overview of all available data classes and data components at first sight. All elements are simultaneously shown on one layer. In this form, the user gets a direct overview of the amount of data that can be found in the different data classes by watching the clusters that are building around the data classes. The more elements are connected to the class, the more different data components are associated with it. What can be noticed here, is the missing white space. It makes it difficult for the user to decide on which element they want to focus on. As it was the purpose of this project to find a good way to visualize ADF data and to direct the user's attention to relevant information, this form may turn out to be difficult.

Another point to be compared, is if connected elements can be identified as such. In form one, the connection between elements is defined by three factors. Factor one is the placement on a layer. Components that are located on the same layer can be assumed as having a connection. Factor two is proximity. Like Hahn describes in [12], the law of proximity gives the user a sense for the connection of elements. Components that are in close proximity are likely to be related. And factor number three refers to corresponding colours. Data components are tinted according to the associated data class, thus visualizing their connection.

In the second form, the connection of specific elements through the layer is not possible, because all components are placed on the same layer. The factor of proximity alone, may not be enough to clearly communicate a connection of elements to the user, caused by the fact that there is less space for each element and proximity could also be a side effect of this circumstance. Colour still provides the intended effect of establishing a connection between data components and data classes through matching tones. To compensate the decreased effect of proximity and layer, connecting lines have been added to clarify the connections between elements.

In terms of communicating connections between elements, both options fulfil their role.

With the goal of finding a form of visualization for ADF data and navigating the user's attention towards the applications more important information, which mainly is done through the highlighting of in context more relevant data, the next point for comparison is the perception of the highlighted elements.

The first form of visualization works with a lot of white space. This white space gives enough room for the elements to be adapted in size. Now bigger elements can be clearly perceived as more important and the user's focus is directed towards these elements.

The second visualization does not include much white space. All elements are displayed simultaneously, claiming a lot of space on the page. Adapting the sizes of more relevant clusters in the current context proves to be difficult, as the components only have small margins in which they can be scaled. Highlighted clusters can be identified as such, but it is more difficult to do so than it is in the first visualization.

In the field of highlighting information the first form of visualization bears more advantages than the second form.

For this project these three factors of providing overview, communicate connections between elements and the highlighting of in context relevant information are crucial. The visualization should support the user in their activity, navigating the user's attention from the top level of the information architecture, holding the more general categories to the lower levels with more detailed information and more single components. For this project specific case, the first form of visualization provides the better options, because of the above mentioned differences in the comparison of the required factors. This does not mean the first form of visualization is better than the second form of visualization, but it shows that form one has more potential for the purpose of this project. In other projects, where for example the focus lies on identifying clusters of linked data, the second form of visualization might be the better option.

The first form of visualization is therefore the chosen option that is developed as a software prototype.

7.4 Evaluating the User Experience with the User Experience Questionnaire

For the evaluation of the user experience the User Experience Questionnaire (UEQ) is used. In [26], Schrepp et al. describe the purpose of the UEQ as being a tool for "*fast and immediate measurement of user experience.*" [26]. The questionnaire is based on "*semantic differential*" [27], where each step to be evaluated by the user, consists of a pair of words with opposite meanings. Schrepp et al. explain in [27], that now the participant can decide, which word describes the tested product best on a seven point Likert scale. Examples for such a pair of words would be "*easy to learn*" and "*difficult to learn*" or "*annoying*" and "*enjoyable*". In [26], Schrepp et al. also mention the application possibility of the UEQ in order to compare different versions of a product. This can be adopted to the two different versions of visualization in this project.

Performing the Evaluation For the execution of the tests a group of researchers who are active in the field of ADF, were equipped with the software prototype of The first form of visualization and the click prototype of the second form of visualization. This group of participants represents users and experts at the same time. They were given a description of the tool's purpose and asked to test the first prototype, try out the interactions, discover all parts of the tool and then fill out the UEQ for this first visualization. Following that, the second prototype will be explored by the participants and subsequently the UEQ will be filled out again, this time evaluating the second prototype and therefore the second form of visualization.

To provide the test participants with the necessary information and access to the prototypes, a GitHub repository has been created. In this repository instructions on how to conduct the test have been documented in the readme file. Due to the COVID-19 pandemic this form of remote testing was chosen as an adequate way of evaluation. The repository can be found under `https://github.com/JulianGaensbauer/datatype_visualization_3/releases/tag/v1.0.0`. The release version used for this evaluation is v1.0.0. The repository includes the Vue project prototype with instructions on how to use it and also the Adobe Xd project prototype. Additionally the UEQ is included in pdf format. The project is available to the public on GitHub and the participants are able to download the necessary materials from there. The content of the repository is displayed in Figure 18.

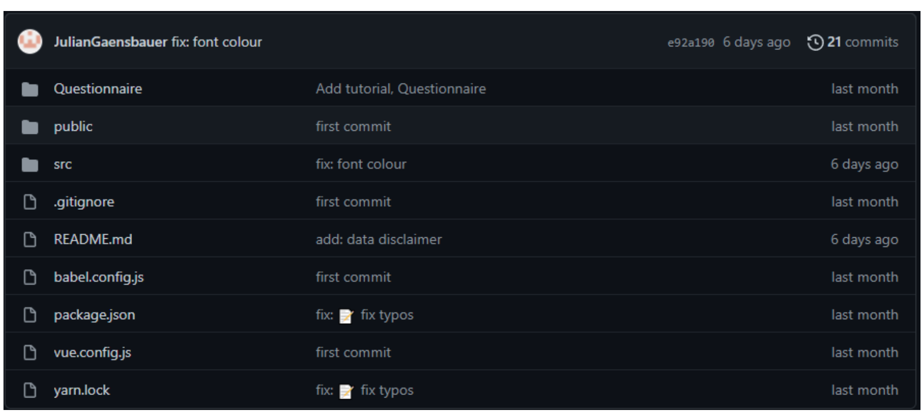

Figure 18: Content of the GitHub repository

Results of the User Experience Questionnaire For the evaluation of the results of the UEQ, the provided tool was used. It is based on an Excel sheet with multiple data sheets that uses the gathered information to perform a standard T-Test to check for a significant difference of the results. The data of the two evaluated questionnaires is entered into separate data sheets. Each semantic differential is rated on a Likert scale from 1 to 7. There are 26 items on the questionnaire in total and for each item now the participant's rating on the scale is filled in. This is repeated for the second UEQ. The performance of each prototype can then be compared with a T-Test. How the tested prototypes were rated in terms of the mentioned scales "*attractiveness, perspicuity, efficiency, dependability, stimulation and novelty*" [27] can be seen in the by the Excel tool provided diagram seen in Figure 19.

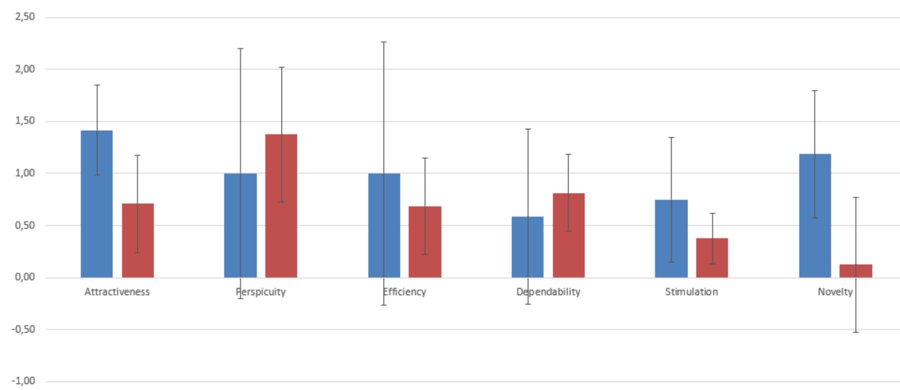

Figure 19: Comparison of scale results from UEQ blue: Vue prototype first form of visualization, red: Adobe Xd prototype second form of visualization

T-Tests were performed for each scale with an alpha level of 0.05. All results for each scale showed no significant difference. Although no significant difference could be discovered in the comparison of the two forms of visualization, the results show tendencies on each scale towards which version performed slightly better. Mentioned results in comparison can be seen in Figure 19. On the attractiveness scale the Vue prototype, implementing the first form of visualization, was rated better than the in Adobe Xd implemented second form of visualization. This could be due to the in Section 7.3 described design differences. The separation in layers enables the use of more white space, which after Hahn in [12], enhances the effect that placed design elements in this space have. There are more design elements that could be a possible cause for the differences in attractiveness and some of them are stated in Section 7.3. In terms of perspicuity, the second form of visualization shows more promising results. In contrast to the first form of visualization, the second variation shows all data classes and data components at the same time. They are visible on the same page and the user is provided with every available information without having to navigate through separate layers. With the data placed on different layers, it appears to be more difficult being aware of what information is available overall. According to evaluation results, the first form of visualization was perceived as more efficient. Reduced number of displayed design elements on the screen could be the cause for this effect. Through fewer used components guidance of users through the highlighting system is more efficient. Highlighted elements are identified through their size, a bigger scale represents more important information. With as many objects on the screen as it is the case in the second form of visualization, the elements have fewer space for scaling the size. Therefore the more important information may not be as apparent to the user as it is the case in the first form of visualization. The Adobe Xd prototype tends to be better in the area of dependability. A possible reason for that is, there are not as many interactions available. The only interaction is input of context and car model by the user. This reduces the amount of mistakes a user can make making the second form of visualization a bit more dependable as the first form of visualization. Another reason could be that the content may be more memorable, if it is not displayed on different layers and therefore the user gets used to the tool more easily. As for the scale of stimulation, the Vue prototype implementing the first form of visualization performed better. Attractiveness and additional possibilities for interaction could be decisive here. In terms of novelty, the difference almost reached a significant level favouring the first form of visualization over the second variation. A possible explanation for this could be that in the second form of visualization used design elements of clustering information and draw connections between them is a more commonly used way of visualizing data in the context of ADF. This form of visualizing information is similar to tree diagrams, which are often used in the field of software development.

All the stated reasons for the slight differences in the results of the evaluation are based on assumptions. These assumptions are explained by using the information gathered about the design and implementation throughout this thesis.

7.5 Fitting Form of Visualization

Based on the evaluation of both forms of visualization, no better fitting form of visualization could be determined. The T-Tests showed no significant difference in all evaluated scales. Based on these results, it can not be stated that one form would be the better choice in this project than the other. Maybe if the purpose of the visualizations had been defined more clearly, for example the focus is on giving the user all available information in one image, a more fitting visualization could have been determined.

7.6 Quality of Information

The quality of information has been assessed by an expert in the field of ADF, who is stakeholder and user. All provided information have been found to be correct.

7.7 Encountered Problems in the Evaluation

The evaluation revealed some problems. Some of those problems that had more impact in the course of this work are now listed.

One problem was the low number of participants in the evaluation of the visualization forms. Overall only four participants could be recruited to take part in the testing of both prototypes. This restricts the possible statements that can be made, because only a small selection of possible user opinions are gathered. With a bigger testing group the informative value of the user experience testing could be higher.

Due to the limited time available for developing the prototype implementations, the available choices for contexts and car models is very strictly limited. The amount of possible interactions is also restricted. With a further developed prototype, the testing scenarios could have been extended and the purpose of the visualizations may have become clearer.

What has been mentioned by some participants of the evaluation, was the rather complicated setup of the Vue prototype. To test the prototype preparations had to be made. Tools needed to get the prototype running were installed by the participants and would most likely have no further purpose for them after finishing the evaluation. For future tests, the testing environment could be set up in online tools like GitHub pages. Here created GitHub repositories can be turned into websites. That allows participants to test the prototype more easily as they do not have to do the setup themselves.

Further it was noted by users that when the evaluation is performed remotely, a PDF version of the UEQ is not the best option. On the Likert scale, the rating has to be marked with a cross. Usually the questionnaire is used when the tests are performed with users and interviewers physically present. In this scenario the UEQ can be printed and filled out with a pen. In digital form placing a cross in a PDF can be a challenge. Using a version of the UEQ that is more friendly for remote testing would make the testing experience for the participant easier.

To be able to make a clearer statement about the suitability of a visualization form for the purpose of this project, a clearer definition of mentioned purpose should have been established. Like explained in the previous Section 7.5, if the focus would have been for example on providing the user with all available information in one image, a clearer result could have been possible.

7.8 Evaluation Findings

Although no significant difference between both forms of visualization could be determined, a conclusion can be drawn. There is not the one perfectly fitting design solution that can be applied to all projects regardless of their purpose. The visualizations and user experience have to be developed in the course of creating the tool and adapted to the given circumstances. It is likely that the application of UXD methods in the development of DF tools has a positive effect. Reason for this is that in the end the goal is to create a tool designed for a user. Enhancing the user experience of this tool through stated methods can support the user in their work. The visualizations are an important part of the user experience, but like with the overall user experience there is no solution that fits all purposes. Instead the visualizations have to be developed while keeping the user in mind, which can be done by using a user-centered design process.

8 Conclusion and Future Work

Using UXD to improve DF tools, was the first step to find a way how UXD could be helpful for the field of DF. The focus in this thesis was on creating possible visualization forms for DF data. The visualizations were developed in an example project where ADF data was explored depending on different contexts and car models. Here data classes and data components were DF data that needed a way of visualization and a system to highlight important information according to current context and car model. So on top of visualizing the data, the representations were used to guide the user's attention towards specific elements. The design was developed with the methodology from Garret's "*The Elements of User Experience*" [9]. Methods mentioned in this book are implementing the thought of a user-centered design process. To decide if a visualization is fitting, an alternative version has been developed. The second version was created by following the same methodology, but design decisions were altered in some steps of the process. Now with two comparable visualization possibilities a comparison could be performed. This comparison was made by testing the application with both forms of visualization and gathering feedback through the use of the UEQ. Both variants were evaluated and then the results of the questionnaire were compared to clarify the research question: *How can important information for Automotive Digital Forensics (ADF) be visualized in different contexts?*.

To answer this question, the implemented visualization forms have been evaluated in Section 7.

There was no significant difference identified between the two forms of visualization. But the finding in this result is that there is no perfect form of visualization usable for every project. The user experience and as part of it the form of visualization has to be developed alongside the tool. This enables the adaptation of the design to the user's needs. To enhance DF tools, user-centered design processes like Garrett's "*The Elements of User Experience*" [9] can be used.

There are different ways to further develop this topic and the project in the future. The topic of UXD can be researched in a way to solve problems the area of DF is confronted with. Tools made for DF analysis or other purposes are still products that are designed to help users achieve their goals and help completing their tasks. And when there is a user, there also is an experience to design for this person. By focusing on the user's needs and keeping the prospective user in mind during the development process of the product, this will enhance the overall experience in handling the tool. Adding more detail in the area of functionality and information, could extended the tool in a way that it can also serve another purpose.

The tool developed in this thesis could also be extended with more information and additional functionality. Additional information consists of for example more contexts to choose from. Tuning could be added to the list or theft of personal information. The list of car models can be extended with more vehicles. In terms of functionality more options could be integrated to allow a direct extraction of data from a preferred source component or a database containing already extracted data from previous cases might be incorporated.

References

[1] Aine MacDermott, Thar Baker, and Qi Shi. Iot forensics: Challenges for the ioa era. *2018 9th IFIP International Conference on New Technologies, Mobility and Security (NTMS)*, 2018.

[2] Arafat Al-Dhaqm, Shukor Razak, Siti Hajar Othman, Kim-Kwang Raymond Choo, William Bradley Glisson, Abdulalem Ali, and Mohammad Abrar. Cdbfip: Common database forensic investigation processes for internet of things. *IEEE Access*, 5:24401–24416, 2017.

[3] André Årnes. Digital Forensics. John Wiley & Sons, 2017.

[4] Babel. What is babel?, 2021.

[5] Statistisches Bundesamt. Unfälle im deutschen straßenverkehr bis 2020 — statista, 2021.

[6] Bundeskriminalamt. Polizeilich erfasste straftaten nach straftatengruppen bis 2020 — statista, 2021.

[7] Ye Chen and Li Chen. Using bluetooth wireless technology in vehicles. *IEEE International Conference on Vehicular Electronics and Safety, 2005*, pages 344–347, 2005.

[8] Simson Leon Garfinkel. Digital forensics research: The next 10 years. *Digital Investigation*, 7:S64–S73, 2010.

[9] Jesse James Garrett. The Elements of User Experience: User-Centered Design for the Web and Beyond. Pearson Education, 2010.

[10] Kevin Klaus Gomez Buquerin, Christopher Corbett, and Hans-Joachim Hof. A generalized approach to automotive forensics. *Forensic Science International: Digital Investigation*, 36:301111, 2021.

[11] Kevin Klaus Gomez Buquerin and Hans-Joachim Hof. Identification of automotive digital forensics stakeholders. *SECURWARE 2021, The Fifteenth International Conference on Emerging Security Information, Systems and Technologies*, pages 8–13, 2021.

[12] Martin Hahn. Webdesign: Das Handbuch zur Webgestaltung. Rheinwerk, 2 edition, 2017.

[13] Jeff Johnson and Austin Henderson. Conceptual models. *Interactions*, 9(1):25–32, 2002.

[14] Thomas Käfer. Car-Forensics: Digitale Forensik im Kontext von Fahrzeugvernetzung, eCall, KFZ-Unfalldatenschreibern und Smartphone-Kopplung. Books on Demand, Norderstedt, 1. aufl. edition, 2015.

[15] Mohammed Khanafseh, Mohammad Qatawneh, and Wesam Almobaideen. A survey of various frameworks and solutions in all branches of digital forensics with a focus on cloud forensics. *International Journal of Advanced Computer Science and Applications*, 10(8), 2019.

[16] Mike Kuniavsky. Smart Things: Ubiquitous Computing User Experience Design. Elsevier, 2010.

[17] Jesse Lacroix, Khalil El-Khatib, and Rajen Akalu. Vehicular digital forensics. *Proceedings of the 6th ACM Symposium on Development and Analysis of Intelligent Vehicular Networks and Applications*, pages 59–66, 2016.

[18] Qian Luo and Jiajia Liu. Wireless telematics systems in emerging intelligent and connected vehicles: Threats and solutions. *IEEE Wireless Communications*, 25(6):113–119, 2018.

[19] Michael McCurdy, Christopher Connors, Guy Pyrzak, Bob Kanefsky, and Alonso Vera. Breaking the fidelity barrier. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pages 1233–1242, 2006.

[20] Konrad Reif. Automobilelektronik: Eine Einführung für Ingenieure. ATZ-MTZ-Fachbuch. Springer Vieweg, Wiesbaden, 5., überarb. aufl. edition, 2014.

[21] Konrad Reif, editor. Diesel Engine Management. Springer Fachmedien Wiesbaden, Wiesbaden, 2014.

[22] Golden G. Richard and Vassil Roussev. Next-generation digital forensics. *Communications of the ACM*, 49(2):76–80, 2006.

[23] Sadiku, Matthew, Shadare, Adebowale, Musa, Sarhan, Akujuobi, Cajetan, and Perry, Roy. DATA VISUALIZATION, volume 12. 2016.

[24] Richard Saferstein. Criminalistics: An introduction to forensic science. 2007.

[25] John Sammons. The Basics of Digital Forensics: The Primer for Getting Started in Digital Forensics. Elsevier, 2012.

[26] Martin Schrepp, Andreas Hinderks, and Jörg Thomaschewski. Applying the user experience questionnaire (ueq) in different evaluation scenarios. *Design, User Experience, and Usability. Theories, Methods, and Tools for Designing the User Experience*, 8517:383–392, 2014.

[27] Martin Schrepp, Andreas Hinderks, and Jörg Thomaschewski. Construction of a benchmark for the user experience questionnaire (ueq). *International Journal of Interactive Multimedia and Artificial Intelligence*, 4(4):40, 2017.

[28] Manar Abu Talib, Reem Alnanih, and Adel Khelifi. Application of quality in use model to assess the user experience of open source digital forensics tools. *International Journal of Electronic Security and Digital Forensics*, 12(1):43, 2020.

[29] Vue. Components basics, 2021.

[30] Vue. Getting started — vue router, 2021.

[31] Vue. Html and static assets — vue cli, 2021.

[32] Vue. Introduction, 2021.

[33] Vue. What is vuex? — vuex, 2021.

[34] Vuetify. Why you should be using vuetify, 2021.

[35] Yarn. Yarn, 2021.