Bringing the human factor back in Digital Twins

Thesis MSc. Interaction Technology

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Figure 1: Futuristic image of Digital Twin [4]

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Abstract

To support the life cycle of structures, the civil engineering field is investing in digitization, an important part of industry 4.0. Digitizing is a complex problem due to large amounts of data and the many differences within the field. A new concept of a smart system that aims to solve the challenges in maintenance is a Digital Twin (DT) A DT is a digital entity that reflects its physical entity's behavior. It can be a powerful tool, when designed correctly, to support and optimize its users efficiency. Therefore, it is important the DT adapts to the needs of involved stakeholders. The problem is that use cases that help create a DT which can be of most value of its users are yet to be identified. Therefore, Arcadis commissioned this research to define the customer experience of DTs. The aim of this thesis research is to understand what the added value of a modular UI based on user profiles is, for a single DT back-end used for asset management in a civil engineering context. Previous interviews with Arcadis employees resulted in six user profiles, leading to the conclusion that one DT would not be sufficient to support all identified user profiles. An information architecture for a DT that includes the user profiles is formed based on requirements that are developed by applying a Reflexive Thematic Analysis on the resulting interview and observations, and have been tested in an usability study. Additionally, an user study for an immersive technology prototype is developed based on use cases related to inspections and remote collaboration. An important conclusion is the quality of maintenance can be improved when a modular UI in combination with a suitable interaction technology is used for a DT. The objective of this thesis research is to achieve design and implementation of a novel use case for DT in such a way that it is accessible, understandable, useful and offers a good user experience. Leading to the research question "What is the added value of a DT with a personalized/modular UI to support the user in comparison to a DT with a single UI?"

Keywords: Digital Twin, Civil Engineering, Remote Collaboration, Interaction, HMI, User Profiles, Maintenance, Mixed Reality

Contents

1 Introduction

To support the life cycle of structures, the civil engineering field is investing in digitization, an important part of industry 4.0 [33, 27]. Digitization is a relatively new development in the civil engineering field, because it is a complex problem that deals with large amounts of data and the many differences within the field [27, 35, 46]. The goal is to create a smart system that will be beneficial for many stakeholders to make maintenance, repair and rehabilitation of structures more efficient and sustainable [27]. Therefore, it is important to collect all relevant data that is needed to solve the challenges in maintenance in a central place. A new concept of a smart system that is based a on this principle is a Digital Twin (DT) [24].

Liu et al. [34] performed an in-depth analysis and concluded the following definition: "Digital Twin is a digital entity that reflects physical entity's behavior rule and keeps updating through the whole lifecycle". Moreover, the interaction between the physical structure and digital layer has an influence on the definition of the model or system that can be considered a DT [13]. A DT must have an automatic, bidirectional, real time data exchange between the physical and digital layer [13, 24]. A not real time information flow between the physical and digital layer is called a Digital Model [13]. A state change in the physical layer that leads to an instant change in the digital layer is called a Digital Shadow [13].

A DT could be able to predict, analyse and create recommendation, which boosts the productivity and skills of its users [16]. Researches like [41, 43, 37] show potential of using a DT in O&M. This is why the DT is being massively investigated by large enterprises [16]. However, creating a DT should not become the goal itself [46, 14]. Its strength comes from optimizing its users efficiency, skills and knowledge. "True added value of DT use cases are not driven by technology but rather by subject matter, industry expertise and experience in understanding and solving the clients' problems" [14]. The DT should adapt to the needs of involved stakeholders [46]. Therefore, it is important to properly integrate Human Machine Interaction (HMI). "At present, the research is just in the infancy and it needs more works to improve the integration of HMI and DT" [36]. The fundamentals of creating a good user experience (UX) are efficient interaction design, a user friendly user interface (UI), intuitive collaboration and a suitable choice of interaction technology [13].

One of the large enterprises that is investing in DT development is Arcadis. Managing assets as a service to provide to its customers is one of their focus areas. The assets that Arcadis work with can relate to buildings, environments, infrastructure or water [44]. The size of an asset can differ from a small static bicycle tunnel to a large dynamic bridge, like the Dordrecht road bridge [44]. The greater the level of complexity and size of an asset, the greater the amount of data will become that has to be collected, processed and analysed. This is why it is important to identify use cases that help create a DT which can be of most value for its users [14]. Therefore, Arcadis commissioned this research to define the customer experience of DTs. The objective of my thesis research is

to achieve design and implementation of a novel use case for DT in such a way that it is accessible, understandable, useful and offers a good UX.

I completed a preparatory literature research [25] with the objectives describing potential users of the DT from Arcadis, and understanding what important factors are to include in a DT in a civil engineering context. Based on interviews with Arcadis employees, I identified six user profiles *(asset owner, asset manager, inspector, risk analyst, education, and asset operator)*, all having different interests, problems and needs. Therefore, I concluded that one DT would not be sufficient to support all identified user profiles. Furthermore, I found that an asset that can be represented as a 3D model, might benefit from using an immersive technology as interaction technology. It would be recommended to use virtual reality (VR) at the office, and mixed reality (MR) for on-site use. Thus, the interaction technology for on-site use should be a see-through Head-Mounted Display (HMD), like the Microsoft Hololens [8, 9], and for remote use a video display HMD. These topics are elaborated in more detail elsewhere [25].

The focus of the research reported here is exploring opportunities to establish the foundation for a good UX for DTs used in operate and maintain (O&M). I concluded in [25] that the novel objectives are based on breaking down the UI of the DT in smaller versions, and including asynchronous remote collaboration. Leading to the following main research question for the continuation of this thesis research: *"What is the added value of a DT with a personalized/modular UI to support the user in comparison to a DT with a single UI?"* [25].

In order to answer the main research question, there are a couple of sub research questions that need to be investigated. The following text originates from [25].

> First of all, it needs to be determined what data need to be included in a module or profile. Leading to the sub research question *Which data to include for each profile?*
>
> Accordingly this data needs to be structured in such a way that it forms the basis for a user friendly, modular UI that provides support for DT users. Resulting in the sub research questions *How should the modular UI of the DT be designed to support its users?*
>
> When users do not have a single UI it can have a negative influence on the communication, since they have no reference of what the other person is seeing. To assure effective and intuitive remote collaboration when using different UIs, the sub research question *How to prevent hindering remote collaboration when using different UIs?* needs to be answered.

This report aims to answer the research questions by looking into the current situation of identified DT users, and exploring potential, practical solutions. The content of the user profiles will be portrayed by requirements that are based on a reflexive thematic analysis of interviews and observations. An understanding of a user friendly, flexible UI design is related to the DTs' usability, that comes from its information architecture and interaction technology. To validate

the information architecture content, and the added value of the recommend immersive technologies (focus is only on MR for this thesis research), prototypes have to be created and evaluated. These studies will also provide insights about the effect of having different UIs on remote collaboration.

The contribution of this work is exploring the possibilities to design a good UX for a DT in O&M, capturing what works, and establishing an advice for Arcadis and future research. An important conclusion is that the quality of maintenance can be improved when a modular UI in combination with a suitable interaction technology is used for a DT. Based on this thesis research, Arcadis becomes closer to their mission to not only improve the quality of maintenance, but also the quality of life.

2 Methodology

A suitable methodological framework is needed for this thesis research in order to follow a process that puts the user first. To answer the research questions, information has to be collected, analyzed and evaluated. This sections discusses several frameworks and methods that focus on users, to achieve a design that can form a good UX for DTs used in O&M.

2.1 User Centered System Design

Perdomo et al. [38] proposed a methodological framework called User Centered System Design (UCSD) for web application development. The process is centered on the user and divided into multiple stages; planning, design, prototype, and evaluation.

The planning stage involves identifying the objective of the site and the potential audience, needs, and requirements [38]. Therefore, the designer has to understand the needs and objectives of the user and the provider [38]. Data about the user can be collected using different types of user studies.

The collected information in the planning stage needs to be summarized, also referred to as modeling, to define user profiles. Important attributes to include in a user profile are information need, experience, and knowledge [38]. These profiles form the basis for the design stage, in which information gets structured [38]. The structure of a website refers to the connections and relationships between pages and the topology of pages [38]. Techniques that can be used to prioritize information in a web page design are based on the elements' size, space, color contrast, and typography [38].

In the early stages of the development process, a prototype can be used to test the basic aspects of the interface [38].

To evaluate the prototype, two different methods are given by Perdomo et al. [38]; heuristic evaluation and a user testing method. A heuristic evaluation is an inspection method that evaluates several attributes of an application. Perdomo

A large part of the introduction is paraphrased from Gankema [25]

et al. [38] mentions attributes like structure and navigation, lay-out, search, accessibility, help, control and feedback. The user testing method refers to a usability study. Usability is defined, as indicated by ISO, as "the level of efficacy, efficiency and satisfaction which specific users can reach specific objectives, in specific using contexts" [38]. By observing real users using the prototype, problems can be recognized which can solved later [38].

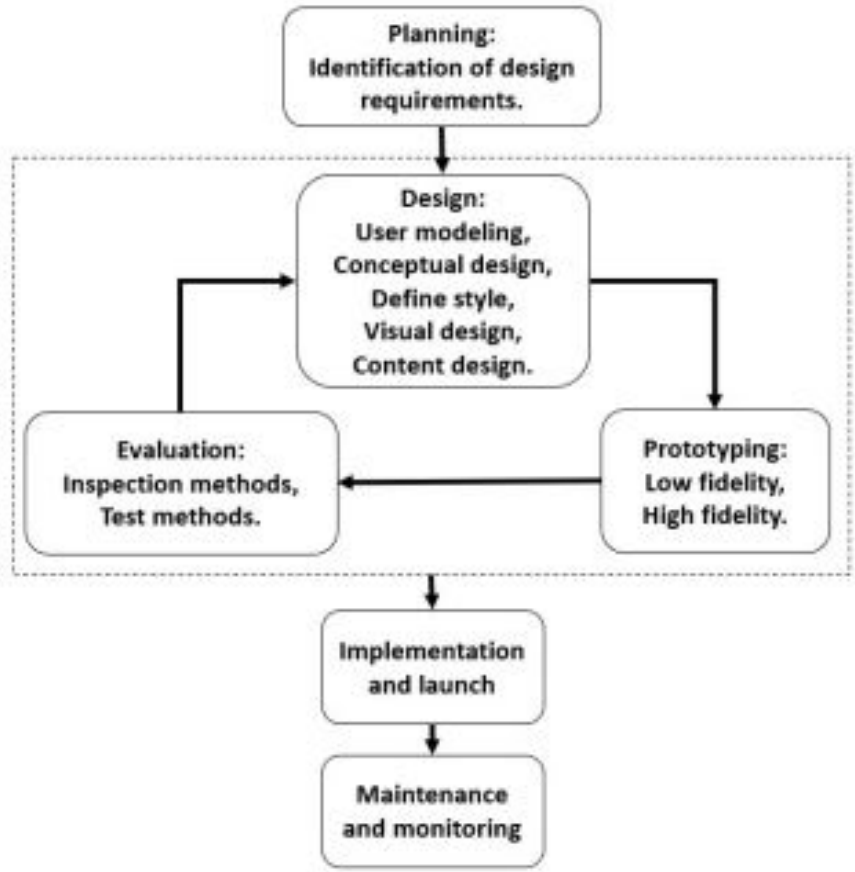


Figure 2: User Centered System Design scheme [38]

2.2 User Centered Design

User Centered Design (UCD) places the user in the center of design decisions [45]. The goal of this qualitative method is "profiling users and defining their behaviors of use of and preferences for various aspects of a given application, and using that information to then make design decisions about the web appli-

cation." [45]. It is important to understand the level of knowledge, context of use, reason of use, performance patterns, and preferences [45].

First of all, the designer has to understand who the users are and what their needs are during the design research phase [45]. A high level design research involves multiple steps related to planning, conducting, analyzing, and reporting [45]. Common analytics techniques that are listed by Williams [45] are debriefing, listing, and clustering.

The goal of the design phase is to use the findings from the design research to conceptualize and sketch drafts [45].

A created design need to be tested for its usability during the evaluation phase [45]. Other evaluation techniques than usability testing are heuristic or expert reviews, satisfaction questionnaires, or walkthroughs [45]. However, the usability study is the most common [45].

2.3 Activity Centered Design

Activity Centered Design (ACD) focuses on the activity of the user. The designer wants to understand what tasks or activities must be enabled by the application [45].

ACD can be seen as an approach that "emphasizes the design of computer-mediated environments to support and structure the interactions and interdependencies of an activity system" [26]. ACD does not know a definite process, method and deliverable [45]. According to Williams [45] the reason for this is related to the complicated nature of ACD, which can be seen as rich, complex and largely theoretical.

2.4 Goal Directed Design

Goal Directed Design (GDD) focuses on the goal of the user [45]. The designer wants to understand why the user must perform certain tasks or activities to obtain an insight into their value, meaning or purpose [45].

According to Williams [45], the process of GDD is similar to the process of UCD. Research forms an important part in the GDD process. Useful design research activities are interviews, literature reviews, prototyping, and user observations or ethnographic field studies [45]. An example of a deliverable of the GDD process are personas. In section 2.5 more information about personas is provided.

2.5 Personas

Gudjonsdottir and Lindquist [28] define personas as "fictitious persons that represent the needs of larger groups of users in terms of their goals and personal characteristics". The goal of personas is to understand the needs and desires of users in order to communicate these with involved stakeholders [28]. Comprehensive user research is required to develop personas that accurately represent

the end users [28]. To explain how the persona will fulfill his/her goal using the developed application, scenarios are written [28].

In addition, personas help the designer during the the design process to develop an application that supports the users, since personas can be used as a reflection for real users [28]. However, personas can not be seen as a replacement for user-centered design activities [28].

Gudjonsdottir and Lindquist [28] researched whether the persona method is primarily a design tool or a means for communication. They concluded that using personas is mainly interesting as a communication tool, and much less as a design tool.

2.6 Reflexive Thematic Analysis

The framework called Reflexive Thematic Analysis (RTA) developed by Braun et al. [20] focuses on extracting information from collected interview data.

Thematic Analysis (TA) is a method for across dataset analysis, that focuses on identifying new patterns of meaning [20]. There are several approaches to TA. Coding reliability TA is a partially qualitative approach to TA, in which qualitative data is collected and analyzed using qualitative techniques for coding and theme development [20]. A theme in a domain summary, summarizes what an interviewee said in relation to a topic of interest [20]. However, this is not compatible with the approach of Braun and Clarke [19] for TA theme development. Braun and Clarke [19] state that the aim of a theme should be to "capture the diversity of meaning in relation to a topic or area of focus". They are abstract ideas of the researcher based on codes that try to capture the meaning of the data [23].

Codebook TA is a structured approach to TA in which some or all themes are determined in advance of the full analysis [20].

Reflexive TA (RTA) is a fully qualitative approach, in which themes can be seen as meaning-based patterns [20].

The phases in RTA do not strictly form a linear process. The first phase is about familiarizing yourself with the data. Codes are formed by the researcher after having explored the data and developed a good understanding of patterned meaning between datasets [20]. Coding is an iterative process that the researcher uses to conceptualize the data [20]. The coding phase is about systematically identifying meaning throughout the dataset by giving chunks of text a code (or label) [20]. The codes will help to organize the data around meaning-patterns [20]. Coding based on an inductive orientation refers to the researcher starting the analytic process from the data, identifying meaning without including the ideas of the researcher [20]. Coding based on a deductive orientation involves the researcher exploring the data with various concepts, theories and ideas in mind [20]. When staying at the surface of the data, capturing explicit meaning, semantic codes can be used [20]. When a deeper, more conceptual level of meaning is required, latent codes would be used [20].

The codes form the basis for the construction of themes. To develop codes into candidate themes, the codes need to be clustered based on meaning. The

obtained candidate theme should tell a story about a particular part of the data. A common pitfall in theme development is that that a theme describes a feature of the data, instead of meaning-based patterns [20]. "Good themes are those that tell a coherent, insightful story about the data in relation to the research question." [20]. The aim of coding and theme development is to provide a coherent and compelling interpretation of the data [20].

To revise and define themes, the candidate themes need to be reviewed to ensure that they relate to a concept of interest. It important to keep in mind that not every candidate theme will be substantial enough to keep as theme. Accordingly, the themes should be checked against the whole dataset. Furthermore, it is important to obtain an understanding of relations between themes [20]. Thematic mapping can be useful to visualize possible overlap and relations between potential themes [18]. Writing a report about the RTA can serve as a final test to see how well the themes work.

2.7 Most suitable method

This thesis research wants to achieve understanding about what the added value of a DT with a modular UI would be in comparison to a DT with a single UI. Therefore, I want to know what data needs to be included in the user profiles, how this data should be structured, and whether a modular UI has a bad influence on remote collaboration between different user profiles. The most suitable method for this thesis research is able to find the answers to these research questions. Therefore, the needs to find the answers have to be clear.

First of all, a better understanding of the user profiles need to be obtained. These detailed user profiles have to be translated into requirements. The requirements need to be grouped to modules and functionalities and organized in an information architecture. To validate the requirements and information architecture, the stakeholders have to be involved again. Some kind of study has to be created to determine how do these results influence the requirements.

Moreover, to understand more about the influence of a modular UI on remote collaboration, some kind of immersive prototype should be created. This prototype can also be used to validate the added value of implementing an immersive technology as interaction technology for a DT. Eventually, the prototype has to be evaluated again during a test with users that represent the user profiles.

Therefore, the method that forms the best fit for this thesis research is the UCSD framework, since it includes a process that is similar to the described needs. However, it does not describe how the collected data can be translated into requirements. The only framework that offers a structured process to extract themes from qualitative data is RTA. Therefore, it would be best to combine the UCSD with RTA to analyse the collected qualitative data.

3 Defining detailed profiles

To enrich the profiles that have been formed in the research topics [25], more data has to be collected. By interviewing and observing people who match the description of the user profiles, a detailed description of the user profile can be created. Section 3.1 contains more information about the data collection and summarizes the findings for each profile.

The collected data has to be analyzed to determine which information and functionalities need to be included in which profile. The most suitable method for extracting data from interviews and observations according to the literature research in Chapter 2, is RTA. Section 3.2 explains how the RTA has been done to analyze the collected data. Resulting connections are described in section 3.2.3.

3.1 Interviews and observations

Information of interest is collected using a guided conversation, also referred to as an interview. A method that is based on a carefully planned conversation, similar to a script, is called a structured interview [17]. An ordered list of questions is prepared before the interview. During the interview the order of the list represents the order in which the questions will be asked during the interview. The goal of this method is to be able to compare the given answers [17].

Another method that is used to develop an understanding of the interviewees' work environment and situation, is via observation [28]. The interviewer spends time with the interviewee in the work place, and participates in activities [28]. When an interview is combined with observations, this is called a contextual interview [28]. The observations can be seen as a way to validate the answers obtained in the interview [28]. Since it takes place in the interviewees work environment, an in depth understanding of the requirements, needs and work situation of the interviewee can be deduced [28]. Therefore, it is an effective method for requirement extraction [28].

To obtain a more detailed understanding of the needs and activities of identified potential DT users, structured and contextual interviews have been conducted. Some of the interviewees indicated that they have no typical work day, because their activities on a day can vary. Observing them for just a day would not provide a realistic and complete representation of their work. In these scenarios a structured interview was used to collect as much information as possible. The inspectors follow a structured protocol, allowing to use the contextual interview method. In total three structured interviews and two contextual interviews took place, which is in line with Braun et al. [20] recommendation for small projects.

The questions that have been asked in the actual interview are based on the research of Gudjonsdottir and Lindquist [28]. They asked questions related to the interviewee's role, typical work day, tasks, and problems. To get some more perspective, they also asked the interviewee to describe a workday that

was experienced as good, and one that was experienced as bad. The questions aim to get an understanding of the current work situation of the interviewee. Additionally, for this research it is also important to get more information about the needs, desires and wishes of the interviewee in regards to the DT.

Part of the preparation process to be allowed to observe an inspection, is having basic knowledge of safety, health and the environment. Therefore, I was asked to get a Safety for Operational Supervisors SCC diploma (SOS-SCC). I successfully completed the exam and managed to get the certificate so I could safely join the inspection at the Waterwolftunnel (WWT) and an inspection at the Biesboschsluis.

Sadly I could not get in contact with an asset owner within the time frame. However, luckily there was a kind Arcadis employee who offered to ask around among asset owners about their DT functionality preferences. Resulting in an overview of functionalities that asset owners with different responsibilities would like to incorporate in a DT. This list can be found in Appendix B

This section contains the summaries of all interviews and observations. The full interviews and observations can be found in Appendix A

3.1.1 Inspector from an external company

I joined a monthly inspection of the WWT. This visual inspection is done by two inspectors from an external company. Because of safety regulations, inspections need to be done in pairs. For example, when one inspector enters a confined space, the other inspector needs to stay outside as hole watch. A mobile phone is used for note taking during the inspection.

The inspectors receive a list that contains the objects that need to be inspected in advance, so they can prepare. Their main task is to inspect and report. However, if they encounter a small malfunction, like a light bulb that needs to be changed, they are allowed to change it (with permission of the asset manager).

Before the inspectors start, they have to announce their presence on-site to the asset manager. The asset manager asks them about their activities and checks if they have the right work permits.

External employees that are not familiar with the asset can struggle with finding the things that they need, for example something simple as a toilet. Sometimes an asset has different owners, and during inspections it can be difficult to determine who is the owner of certain objects.

The documentation that belongs to an object is printed and placed on-site near the object. Documentation can differ form instructions to circuit schemes. The objects themselves are labeled with a code that refers to the decomposition, blueprint or circuit, which makes it easier for the inspector to find the needed information in the documentation. However, these paper documents can be eaten by mice or get out-dated. After a change in the asset that requires a documentation change, these documents need to be changed, printed and replaced on-site.

When a malfunction is discovered, a photo is taken of the situation. It is not always clear if a malfunction is new or already reported. Sometimes it looks like there is a malfunction, but it has been done on purpose. In this case the object would be labeled with the reason for a certain action.

When all of the objects are inspected, the notes and photos are reported in an Operation Management System (OMS). This should be done as quickly as possible after completion of the inspection. Eventually the inspectors need to report about the state of each object on their list. The asset manager expects a detailed report, a level of detail that does not always makes sense to inspectors. Resulting in not everything being reported. What mainly frustrates inspectors is that you can not report similar type of objects simultaneously; if you have 20 cameras, you need to make 20 individual reports.

The level of detail that is requested from the inspectors in their reports depends on the asset manager.

In the tunnel there is not always a good reception. However, the inspection also takes place outside. In this case the weather conditions were quite rough; rain, hail, wind and pretty low temperatures. In total we took around seven hours to complete the inspection for that day. The duration of an inspection depends on its type. It can also take place during the nights.

The integration of sensors would make it easier and faster for some objects to monitor them. Malfunctions can be detected earlier and inspectors would spend less time on-site waiting.

3.1.2 Inspector from Arcadis

Because of bad weather, the Biesboschsluis had to be visually inspected by two inspectors from Arcadis, who allowed my to tag along. Before we are allowed to visit the sluice, we had to change into the right personal protective equipment. Including a helmet, safety jacket, safety shoes, and a life jacket. After changing we have to inform the sluice keeper that we will be on-site. Sadly, the sluice keeper turned out to be on his break. One of the inspectors had to call their supervisor to ask permission to enter the site. After obtaining permission, a last minute risk assessment (LMRA) was performed on an app. This app is specially developed for their team to take notes during inspections.

The goal of this app is to increase efficiency, since you can fill in digital forms directly which makes it is days faster. Their group is the first in Arcadis Netherlands that implements such a methodology for registering inspection data.

Usually the inspectors take notes in the app or on paper during an inspection. However, this is not a regular inspection. This inspection is meant as check, to see if the bad weather caused any issues. Therefore, only pictures are being taken.

From almost all objects photos are being taken. The reason to do this is related to a way of being able to look back when at the office, and to be able to compare previous or future pictures to monitor an objects decay. When objects are difficult to reach, external parties (like drone pilots, divers or other experts) are involved to to take pictures based on the instructions of the inspector.

These inspectors have a civil engineering background, so they only look at the objects that are related to their expertise. During the inspection, the inspectors seem to get a little annoyed by a malfunction that they have encountered multiple times before. They explain to me that they only provide an advice to the asset manager and/or owner, which they can choose to ignore. The reason for not acting upon the findings of an inspection is unclear.

Other type of inspections are; condition measurements, zero measurements, focused technical inspections, condition inspections and repetitive visual inspections. The inspectors told me that they usually do not perform repetitive visual inspections, the other types are more common. The focused technical inspection is the most troublesome type of inspection, because of its organizational complexity.

It takes about eight hours to complete an inspection. Therefore, not only a mobile phone, but also a power bank and camera are taken during inspections.

3.1.3 Asset manager of a large asset

I interviewed the asset manager of the tunnel technical installation called Waterwolftunnel. The main goal of managing such a large asset is guarding the preventive maintenance process by improving the quality of maintenance while decreasing the costs. This can be seen as an iterative process that consists of legal processes, corrective maintenance, ensuring safety, bookkeeping, and creating detailed schedules for contractors.

A typical workday does not exist, every day is different. At the office tasks like checking reports and attending meetings are common. When on-site, the asset manager is the point of contact for contractors, inspectors and operators. Sometime an inspection is performed by the asset manager himself.

It is difficult for the asset manager to keep a clear overview of all the different activities and tasks. A specially designed tool is used to keep track of malfunctions, work permits and the controls of the asset. What is missing is the ability to quickly see what kind of maintenance is performed on a certain object.

The asset manager forms the center point of communication between all of the different parties involved. They are in contact with contractors, inspectors, operators, cybersecurity and safety experts of municipalities, surrounding projects, and emergency services.

3.1.4 Asset manager of a small asset

I spoke to a project manager for buildings from Arcadis Belgium. He is responsible for and/or involved in multiple projects related to different types of assets. A smaller asset does not mean that you have less responsibilities. His responsibility is to plan everything which can be planned related to an asset. It is a structured process with targets that needs to be achieved, but it is executed in an unstructured manner. It is important to keep track of irregularities, understand them and repair them in a structured manner. It is his responsibility

to secure a good quality of the asset via inspections and structural reporting.

The main difficulty he encounters is related to the spontaneity of the work, which makes it hard to prioritize tasks. You need to be strategic.

A distinction between internal and external collaboration can be made. Internal parties are asset owners, health safety and environment, HR and other employees. External parties are suppliers, contractors and other companies that are included in the ecosystem of the asset. You have to make sure the communication goes smoothly, which sometimes means putting your foot down.

A DT is a synonym for always being able to access the data from your asset. Based on his experience with DTs for operate and maintain, he mentioned that difficulty from developing such an application can come from miscommunication due to lack of domain knowledge.

3.1.5 Risk Analyst

A risk analyst explained his job to me by comparing it to the definition of an asset. An asset is a system that fulfills a certain function. This function is based on systems, which consist of subsystems that support the main system. The whole system needs to be safe throughout its life cycle. Based on the relevance of a (sub)system and its influence on the performance of the function, a risk analyst analyses potential risks. There is a certain structure for analysing an asset for risks factors. This is done via a Failure Mode, Effects and Criticality Analysis (FMECA).

A risk analyst works on different projects and can have different and/or multiple roles within a project. For example, when data needs to be collected to do a FMECA, they can perform the inspection themselves. Sadly it is not unusual to discover that there is not enough data to properly analyse a risk. When the data can not be collected for some reason, it is a risk in itself.

Due to the variety of tasks that a risk analyst can do, they collaborate with a broad range of people like inspectors, asset owners and experts. Usually communication takes place via email, so everything is in one place, resulting in a to do list.

3.1.6 Asset owner

An asset owner can have different functions; administrator for an asset or a district, project leader, project manager, and/or technical coordinator. Depending on the amount of assets they administer, they have different demands for what a DT should include.

An asset owner who is in charge of multiple assets wants to obtain a quick overview of an assets' current condition. Important functionalities that a DT should include are related to risks, real time data, malfunctions and circularity. Real time data refers to energy consumption, running processes and sensor data.

When an asset owner only has to administer one asset, more detailed information needs to be included in the DT. The same requirements apply, but on

a higher level of detail so they are able to analyse the situation. Another functionality that is mentioned is a visualization of the maintenance phases. They would like obtain a quick overview of which parts of the assets are out of use or closed. Another interesting request is the inclusion of the danger zones in the asset, which can form the basis for instructions to visitors.

3.2 Reflexive Thematic Analysis

The RTA framework is used to analyze the collected data in the previous section. The goal is to extract information that can be used as a base to develop requirements that need to be included in a user friendly, profile based DT for O&M. This section explains the steps that have been taken to derive information.

3.2.1 Coding

The first step of a RTA is going through the collected data in detail. To do this, all of the interviews and observations are put in an excel file. Each interviewee got its own sheet. Each sentence of the elaborated interviews and observations was put in a row, in a column. The next column was used to attach codes to the sentence in the same row. A code can be seen as a way of summarizing the intention of that sentence. A semantic way of coding the data is used, meaning that the code reflects the explicit content of the data [20]. All sentences that have relevant content are coded.

3.2.2 Grouping themes

After going over every sentence in detail to code them, a large variation of codes have been generated. Since each interview has been coded individually, it is difficult to observe relations and connections with other interviews. Therefore, all coded sentences are combined in one large overview.

In this overview, every column represents an interviewee. The codes that belong to an interviewee are clustered. Codes that have the same meaning, but are worded differently, are combined into one row. Codes that have been used multiple times are counted and the total amount is added to the end of the code.

In the end, each row contains all codes that have the same meaning. This makes it easy to see which codes are mentioned by who. Moreover, grouping codes allow for summarizing different codes into one theme. Braun and Clarke [19] conceptualises a theme as a pattern of shared meaning or a merger based on a core concept. The advantages of grouping is that the number of codes gets reduced, without losing content. It can be seen as a way to identify significant broader patterns of meaning, that are translated into a theme [20].

Lastly, the themes need to be compared to the original dataset to determine if the themes form a good summary of the dataset. Furthermore, it should be checked if the themes result in a logical answer to the research question. In case of this research, that means that the themes should form clear requirements to

determine which information and functionalities need to be included in which profile. This can result in themes being adapted.

3.2.3 Thematic mapping

Based on the results of the RTA, similarities and collaboration between profiles could be identified. These connections are visualized in figure 3. It can be seen that some of the profiles have overlap; the inspector and the operator, the asset manager and the risk analyst, and the asset owner with external stakeholders. Three UI types can be derived:

- On-site users (Inspector and operators)
- Full overview (Asset manager and risk analyst)
- Status visualization (Asset owner and external stakeholders)

The Full overview UI is a combination of all users, because the asset manager and risk analyst have to communicate with (almost) all other profiles. Their main goal is to obtain a quick overview of the status of the asset, analyze data, and add new data to the DT. However, that does not mean that they need the same information and functionalities included in their UI. The asset manager for example needs to be able to manage all documentation that is assigned to the asset, while this is not of interest for a risk analyst.

The UI for On-site users will be used on-site. These profiles both have a goal that they want to accomplish as fast and easily as possible. Even though they have a lot in common according to figure 3, this does not mean that they need an identical UI. The operator profile has still different requirements for a DT in comparison to the inspector profile, according to the results of the RTA. The inspector also needs to be able to assign data to the DT for example. It would be interesting to recycle these modules and functionalities in the Full overview UI.

The asset owner and the external stakeholder profiles are almost identical. Both are interested in obtaining a quick overview of the status of the asset using visualizations. Also important aspects for the other profiles. The status visualization can be seen as the basic or minimal UI for a DT.

4 Requirements

In order to measure if a future DT application meets the standard for a structured and functional profile based UI, requirements have to be formed. Additionally, requirements help to get a grip on the design process since they form a checklist for items that have to be included when creating a profile based UI for a DT.

To determine which information and functionalities need to be included in which profile, the resulting themes of the RTA and the research of Gankema [25]

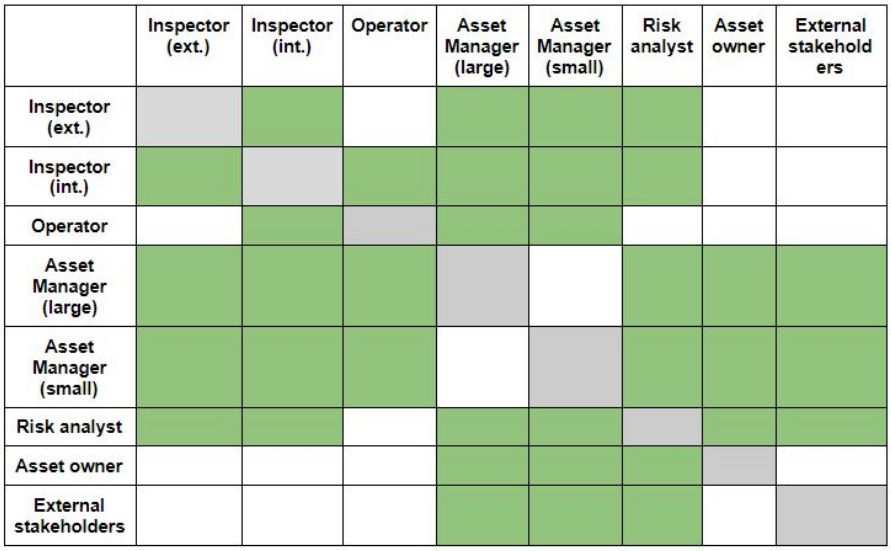


Figure 3: Communication between profiles

are used. A detailed overview of the formed requirements are listed in Appendix C.

Here I will explain the themes of the requirements. The requirements are categorized as general or profile based. The general requirements apply to all users and consist of the main topics interaction technology, and content of the UI. The profile based requirements only apply to one or multiple user profiles, and focus on content for a profile based UI.

4.1 Requirements based on RTA

The resulting themes of the RTA form the foundation for the requirements. general requirements include themes like monitoring, personalization, functionalities, and having a detailed decomposition. The decomposition of the asset needs to become interactive, by incorporating the linking and brushing technique. Making it easy for the user to visualize the object of interest or finding its code in the decomposition. Monitoring should form the foundation for data analysis by creating an overview of multiple data sources like condition score, sensor data, and malfunctions. Personalization refers to having a flexible UI, that consists of modules that can be turned on or off. Preferably, not every user can turn each module on due to restricted access. A basic DT should include functionalities for search, notifications, visualization, note creation, and personal task list creation. The search functionality should make it easier for the user to quickly find objects and documents. Moreover, incorporating filters for quickly highlighting objects that have a certain condition score for example is desired. The DT itself should give notifications related to malfunctions and

a user tagging system. Users need to be able to add notes to object, and to a personal task list. Created tasks should be labeled with a priority level. The visualization functionality relates to monitoring. To make monitoring easy and clear, a couple of topics are important to visualize; real time data, malfunctions, condition scores, and risk areas. Moreover, it should be possible to highlight objects that are important, risky or incomplete.

When developing a UI for a DT, it is important to choose an interaction technology that fulfills a couple of requirements. First of all, the interaction technology should be user friendly, portable, and allow for hands free interaction. When used in an office environment, the device should be able to visualize a model of the asset. Preferably, the technology allows to virtually walk through the model, and to visualize hidden parts. On-site users want to use a camera, track their position, and preferably also have access to the DT when offline.

Profile based requirements often apply to multiple profiles. A Theme that applies to all profiles excluding the asset owner is inspection. Themes that also exclude risk analysts are work permits, document management, and work orders. In addition, there are a couple of themes that apply to just a couple of profiles. Visualizing changes in the asset for example is only interesting for inspectors and asset managers of large assets. Only the risk analyst wants to assign risk/condition scores to objects. However, the same user can also have the role of inspector. The FMECA that the risk analyst makes, is also interesting for the asset manager to have access to. Then there are a couple of themes that are profile specific. The asset manager wants to have access to specific documentation and software, and have an overview of people who are on-site. The asset owner is interested in visualizing maintenance phases, circularity, and certain processes that are related to the asset.

4.2 Additional requirements based on previous research

To check the completeness of the requirements that are formed based on the RTA, I read again through my research topics [25] to identify additional requirements. The general requirements are supplemented, and extended with requirements that relate to UI and interaction design.

General requirements that are straight-forward, but valuable to add are related to the DT being identical to the physical asset, and intuitive to use. The data of the Maintenance (Onderhouds) Management System (OMS) that is used for maintaining an asset needs to be included in the DT. Preferably this data is interactive by connecting it to the model. The interaction technology of the DT needs to assure a quick performance, a wide camera viewing angle, and enable direct communication between users. These requirements support an intuitive use of the DT in general. For on-site use it is important that safe use can be guaranteed and the device is able to deal with harsh weather conditions. A DT that is used in an office environment should be more focused on the interaction with the model. The user should be able to look at the asset from all sides, obtain quick insights about the assets' state, and highlight points of interest during remote collaboration.

Other than the content of the profiles, it is also important to form requirements for UI and interaction design, in order to create a user friendly DT. An easy and user friendly UI should become modular by integrating modules that can be turned on or off. Interactive objects need to be clearly indicated. Changing the color of an selected objects is a clear way to visualize that its active. The UI for an immersive technology should indicate off-screen (outside of the users Field of View (FoV)) objects and events. Task relevant material that is projected in the FoV of the user should be transparent. A task that requires instructions, should visualize these instructions as static models. The interaction with objects in a DT should be based on the linking and brushing technique. By selecting an object it should reveal detailed information and related documentation. Preferably the DT should provide the possibility for intuitive remote collaboration. Natural interaction with an immersive technology can best be achieved using a pointing ray, in combination with dynamic gestures.

There are a couple of profile specific requirements that are deduced from the interviews in the research topics [25]. Asset managers need document management to keep control over the documentation that is attached to an asset. Risk analyst mentioned the visualization of risk zones of the asset. The profiles that add data to an asset, referring to every profile except the asset owner, need a way to consistently report detailed data. This is a request of asset owners, because having structured data sets decreases the chance of having to delete data and increases the amount of hours needed to analyze data.

5 Information Architecture

"Although for most users *the interface is the application*, since it is the part they see and through which they interact, we must understand that the usability of the application depends not only on the interface design but also of its architecture - structure and organization - in other words, of the non-visible component of the design." [38].

The structure behind an application is called information architecture (IA). Perdomo et al. [38] defines an IA as organizing information spaces to support users in their information needs. An IA is formed based on structuring, classifying and labeling content. Classifying refers to the defined user profiles and labeling content to grouping the formed requirements. Accordingly that data needs to be structured in a way that meets the information need of the users.

The resulting IA for a DT in O&M can be divided into five different profiles. The profiles can be compared to information levels, of which the basic profile has the lowest level of information and asset manager the highest. Every profile builds upon the previous one. The following sections describe a part of the IA. An overview of the IA as a whole can be found in Appendix D.

5.1 Basic

The basic IA includes functionalities that are relevant for each user, forming the basis of the DT structure. The main menu exist of six options; decomposition, monitor, search, notes, tasks list, and explore.

The decomposition page contains an overview of the decomposition of the asset. When an object is selected in the hierarchy of the decomposition, the model will visualize the selected object. Since it can be difficult to find objects in a large decomposition, there is a filter/search functionality that allows for a targeted search to speed up the process. The results are listed and/or visualized in the model. By selecting an object, a sub menu will open that contains detailed information.

The goal of the monitor page is to create a quick overview of the assets' status. The monitor page contains three functionalities; condition scores, real time data, and malfunctions. When the condition score functionality is selected, each object in the model changes to the color that relates to its condition score. The user can select an object to obtain more detailed information. There is also a filter to focus on one or multiple condition scores. The model will visualize the objects corresponding to the chosen filter options. Again, it is possible to select an object in the model to obtain more information. The real time data page contains an option for looking at overall asset data, or only at a selected object. When for example all sensors that measure vibrations needs to be shown, the overall functionality has to be selected. The linking and brushing technique is applied to show which data point in the graph responds to which object in the asset. If you want to know more about the real time data of a specific object, you can select that object in the model and the related real time data will show. For both it should be possible to look at historic data as well. The malfunctions page contains a list of active malfunctions. Objects related to the malfunction in the list are highlighted in the model. It is possible to search/filter for specific malfunctions. When a specific malfunction is selected, a side menu will open that contains further information about the malfunction and the object.

The search functionality is always present and allows the user to search by a keyword. The results are shown in a list and highlighted in the model. By selecting an object or row in the list, the according information will be opened.

The note functionality provides an overview of added notes to the asset in a list. The notes are labeled. Notes that contain the label 'important' are highlighted in the list. It is possible to search for a note via the filter functionality. Furthermore, there are functionalities to visualize important notes and their related object in the model, and to list notifications that are created by the DT itself or colleagues.

The task list is meant as a personal to do list. Each user will see a different set of tasks that will be shown here. The user can search for a specific task or create a new task. New tasks can be assigned to other users.

The explore page allows the user to freely look around the asset. By selecting objects, related information will appear. The first mode that is shown contains the regular model of the asset. Other modes allow for the model to change

into a wire-frame or see-through version, visualize risks zones in the asset, or highlight recent changes made in the asset.

5.2 Asset owner

The IA for the asset owner profile is based on the basic IA as described in the previous section, extended with two modules in the monitor page. These modules are called maintenance and circularity.

The maintenance module visualizes the different phases of a maintenance planning. It contains a filter to focus on a certain phase of the maintenance planning.

The circularity module consists of two functionalities; filter on state or material. When the material filter is selected, the different materials in the asset are shown. The user can select the materials of interest. Only the objects that contain the selected material(s) are highlighted in the model. The state filter allows to highlight objects that correspond to a selected condition.

5.3 Inspector

Inspecting requires the need to assign data to objects and request documents that contain detailed information about objects. Therefore, the basic IA is extended with modules for assigning new notes to objects, requesting and opening documents, visualizing new work orders, creating notes in general, and a menu option for performing an inspection.

In the monitor page it is possible to select an object and assign a new note to it. When the option 'create new note' is selected, an empty form will open. The user has to fill in the form. There are options for uploading a photo from the photo album of the device and for labeling the note (whether it is an important note that needs to be highlighted for example). When the user saves the note, it gets added to the list in the note page.

The sub menu that opens after selecting an object also contains a functionality to watch the documentation that belongs to the object. A list of relevant documents will show. A document can be opened by selecting it.

The monitor page of the inspector profile contains a module to visualize new work orders. Objects that contain an open work order are highlighted in the model. Moreover, a list of all new work orders are shown. It is possible to filter the work orders. When an object is selected, the related work orders are listed in its sub menu. More information can be obtained by selecting a specific work order. By directly clicking on a work order in the list the detailed information can directly be obtained.

The inspector profile has permission to create new notes in the note page. By filling in am empty form and saving it, a note can be created. When the user wants to connect the note to a specific object, there is the option to manually fill in the NEN-code of the object, or scan the QR-code of the object. Furthermore, photos that are taken or form a photo album can be uploaded. If the note is important, the option to highlight it can be selected.

The main menu of the inspector profile is the same as the basic IA, extended with a module for performing inspections. The inspection page contains three functionalities; filter by owner, work permit, and registration on-site. As preparation for an inspection of a large asset, it can be useful to see the objects that are owned by a specific asset owner. This functionality contains a filter that makes it easy to visualize which parts of the asset are owned/managed by who. Moreover, often work permits need to be requested before the start of an inspection. This can easily be done in via the work permit functionality. It also provides an overview of assigned work permits, so they can be checked before the start of an inspection. When performing an inspection, it is important that you register the people that will be on-site. This can be done in the registration functionality. After registration, five more functionalities will appear; sign off, LMRA, track my position, test protocol, and report.

At the start of the inspection, you have to do a LMRA. By selecting the LMRA functionality, the related form can be filled in and saved. When you want to know where in the asset you are, it is possible to let the device track your position in the asset via the track my position functionality. The tracked location is visualized in the asset. Some objects have to be tested in order to properly inspect them. The test protocol functionality offers the option for visualizing objects that have a test protocol, and to scan an object for obtaining the related test protocol. Inspected objects have to be reported. This can be done easily and quickly on-site via the report functionality. By scanning the QR-code of the object, an empty report will open that will automatically be linked to the scanned object(s). Moreover, it is possible to upload photos and label the report. After saving the report, a notification is created based on the selected label(s) and the report is added to the new work order module. After you finished the inspection and you leave the asset, you can select the sign-off function.

5.4 Risk Analyst

The IA of the risk analyst profile is based on the IA of the inspector profile. The inspection page of the risk analyst profile is extended with the option to assign a condition score to an object. In the model the user has to select an object. The sub menu that contains detailed information related to this object will open. Accordingly, the user can fill in the field for a new condition score and/or the field for a risk zone score. When saved, this data gets assigned to the object.

The main menu is extended with a page for documentation management. The documents that are listed here are related to FMECA. By selecting a file, the user can select the option to open, edit, copy or delete it. The user can also upload new documents.

5.5 Asset manager

The IA of the asset manager profile is based on the IA of the inspector profile. The asset manager profile should provide a quick overview of information related to the status of the asset. When data is incomplete or incorrect, this profile allows for adding and editing data. Therefore, the asset manager profile is extended with the functionality to change existing documents.

The asset manager is responsible for the people who enter the asset. To quickly see who is on-site, the registration functionality in the inspection page is extended with an overview to watch all registered users on-site.

The documentation page manages the documents that are assigned to the asset. The documents are organized in categories related to FMECA, maintenance planning, inventory management, critical parts, and other documents. New documents can be uploaded in a selected category. In the 'other' category, the documents can be filtered. By selecting a document, the user can select the option to open, edit, copy or delete it.

6 Prototype to test IA content

To test if the developed IA contains logical ordering and clear labeling of requirements, a prototype to test IA content is created. By translating the IA in a tangible prototype, the IA becomes easier to understand and therefore is more suitable for testing. This chapter describes the used software to make the prototype and resulting designs for the profiles and modules.

6.1 Software

The prototype to test IA content is developed in Adobe XD [5]. This UI/UX design software allows for creating interactive wireframes that can be shared privately. The prototype can be viewed in a browser, so it will look and feel like a dynamic web application. However, each page is a static image. By connecting all pages manually, the illusion of an interactive dynamic web page is created.

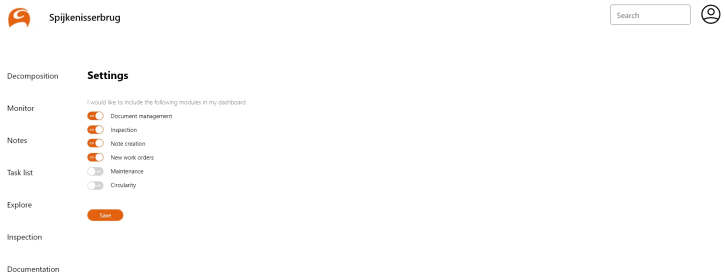
6.2 Profile based UI

The designs of the prototype to test IA content are based on existing DT applications. By using its predefined layout and color scheme, an ideation process could be avoided. Thereby more time could be spent on the realization of the prototype to test IA content.

6.2.1 Static content

The first page of the prototype to test IA content is the profile selection page (see figure 4a). The user can select the profile most similar to their job description. Based on their choice the module selector in figure 4b opens to personalize the UI, or the related dashboard (figure 5a).

(a) Profile selection page

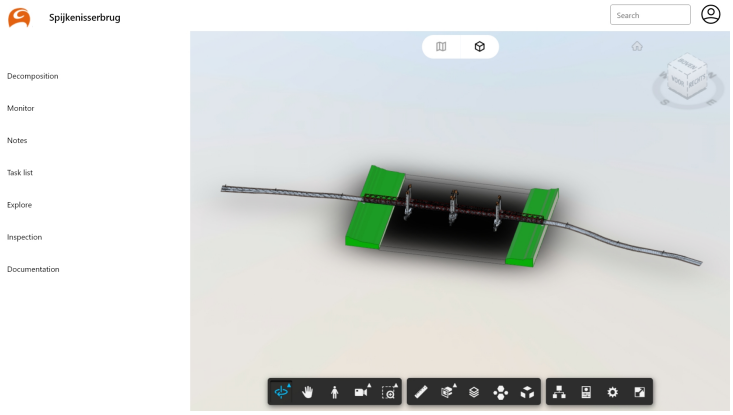


(b) Settings to select active modules

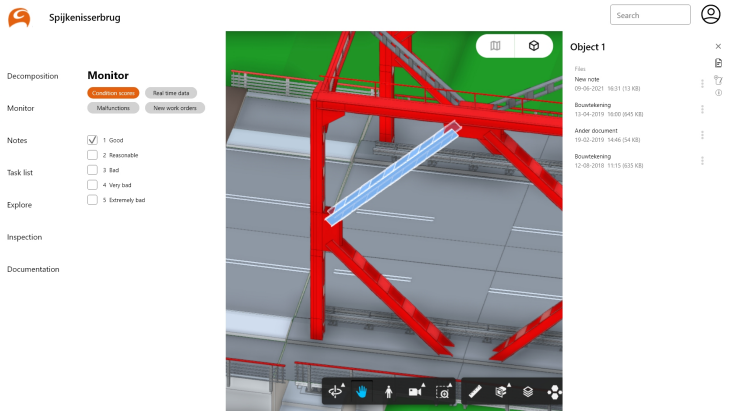
Figure 4: The starting pages of the prototype to select the right profile and according modules

The layout has the main menu option at the left side of the page, as can be seen in figure 5a. The modules that the main menu include are based on the chosen profile. Next to the main menu is a vertical strip that shows the content of the select main menu item. The rest of the page is filled with the 3D model of the asset. When an object or specif item in the page is selected that is related to detailed information, a sub menu will open on the right side of the page. Depending on the profile and active main menu item, the content of the sub menu will include detailed information, related documentation, and/or note creation. An example of the asset manager profile can be seen in figure 5b. At the top right of the page is a search box, which is a static item on every page.

The decomposition, task list, and explore page are the same for each profile. The decomposition page shows the top level components of the assets' decomposition. A component can be expended with objects from the next level



(a) Dashboard



(b) Sub menu of a selected object

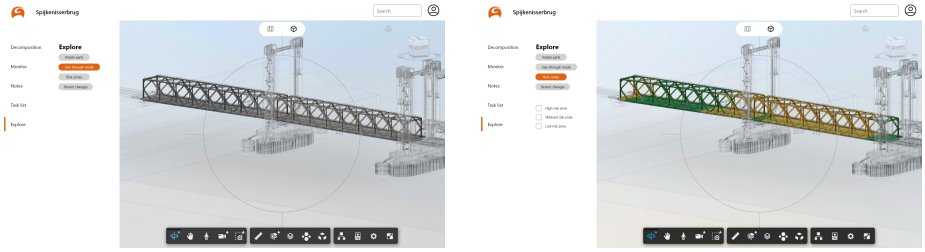
Figure 5: Overview of all menus in the prototype

by clicking on a component. Going to the decomposition tree like this, should make it easier for the user to navigate to the object of interest. Because the user only sees a part of the data, instead of being overwhelmed by the confrontation of the whole decomposition tree at once. By selecting an object, its related information will show.

The content of the task list page is linked to the user. An overview of tasks the user still has to do are listed here. New tasks can be created and assigned to one or multiple users.

The explore page contains four different ways of visualizing the model. The default one is the standard model, showing all visible objects. The see-through mode changes the visualization of the model into a 3D wireframe BIM structural model (figure 6a). Selecting the risk zones mode changes the color of each object to a color that corresponds to a risk score, creating a visualization of the risk zones in the asset (figure 6b). The last mode only applies if the physical asset

is altered in such a way, that the model needs adaptation as well. Changes that are made in the model are highlighted in the recent changes mode.



(a) Exploring model in see-through mode (b) Exploring the risk zones in the model

Figure 6: Two examples of data visualization in Explore mode

6.2.2 Operator and external stakeholder

The profiles operator and external stakeholder have a predefined UI, which is based on the basic IA. The main menu contains the modules decomposition, monitor, notes, task list and explore.

The monitor page offers the possibility for visualizing condition scores, real time data and malfunctions. By selecting the condition scores button, the colors of the objects change to a color that corresponds to its condition score. One or multiple condition scores can be selected to filter the visualization in the model. The malfunctions button opens a list of current malfunctions in the asset. The objects that are malfunctioning are highlighted in the model as well. By selecting either a highlighted object in the model or a malfunction in the list, a detailed description of the malfunction opens at the right side of the page. Clicking on the real time data button leads to the choices whether you would like to see data related to the asset in general or to a specific object. All sensors that collect vibration data in the asset for example fall under the top level. All the data related to this category are collected in a graph. Historic data can be obtained by changing the time line of the graph. The linking & brushing technique applies here, meaning that clicking on a data point in the graph will highlight the related object in the model (see figure 7). When the graph would contain too many data points, resulting in an unreadable data visualization, filtering on components could be added. Selecting an object in the model to show all of its related real time data falls under the object level.

The note page contains a list of all notes in the asset. Notes that are labeled as important are highlighted in the list. Only important notes are listed and highlighted in the model by clicking on the important notes button. Selecting an item in the list or a highlighted object opens a detailed overview of the note. Notifications that are generated by the DT application fall under the notifications button. When the notification is not of interest, it can be deleted.

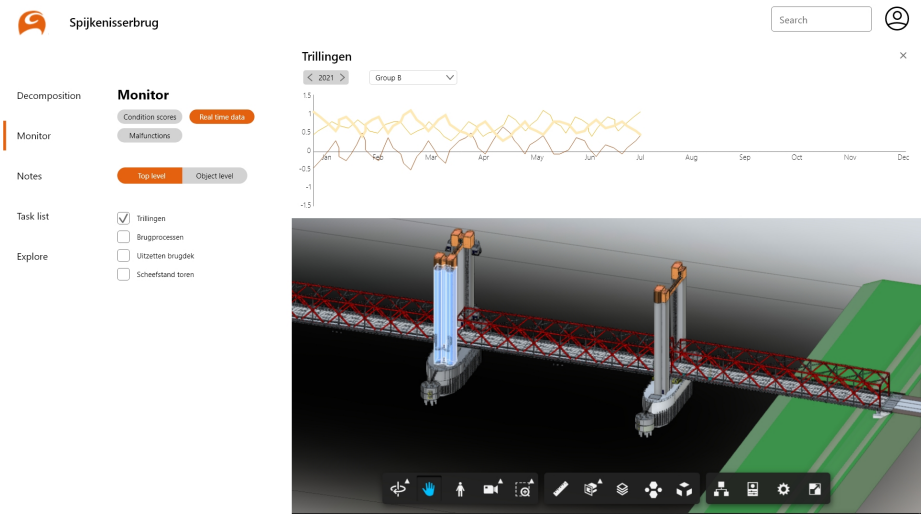


Figure 7: Example of graph in monitor page to visualize real time data

6.2.3 Asset owner

The pages based on the basic IA, relating to the profiles for operator and external stakeholder, are also used for the asset owner profile. The monitor page of the asset owner profile is extended with a button for visualizing circularity and a button for visualizing maintenance phases.

The circularity visualization of the asset can be based on state or material. Furthermore, by filtering on a material or state of that material, objects are highlighted. The object will get the color that responds to its material or material state. When it is not selected in the filter, it will turn grey.

The maintenance button provides an overview of the different planned maintenance phases. Each maintenance phase is visualized by coloring the related objects, so each phase gets a different color in the model. It is possible to isolate the visualization of a maintenance phase by the use of the filter.

6.2.4 Inspector

The pages of the profiles for operator and external stakeholder, are also used for the inspector profile. New wireframes are made for the monitor, note, and inspection page.

The main menu of the inspector profile is extended with a page for inspections. The inspection page includes three main buttons (see figure 8a). The work permit button allows the user to request a work permit or to see the assigned work permits. The owners button visualizes which components in the asset belong to which owner. A filter allows for highlighting the components that are owned by a specific owner. When the inspector wants to enter the asset, (s)he has to register him-/herself. This can easily be accomplished by

pressing the registration button. A form appears that can be filled in to register that you will be on-site. When registered, the five new functionalities in figure 8b appear.

The first button is used when you want to leave the asset and need to sign off. This automatically removes your registration from the registration list. The LMRA button opens the LMRA form that can easily be filled in and saved. When the user wants to see where in the asset (s)he is, the track my position button can be used. This will start a localization process in which the device tries to work out where in the asset it is located. Accordingly the tracked position is linked to the model. The test protocol button can be used to highlight objects in the model that have a test protocol, or to scan the QR-code of an object to obtain its test protocol directly. The highlighted objects in the model can be selected to open the related test protocol. Writing a report after inspecting an object also requires the need to scan the objects' QR-code to open the report form. The form can be filled in quickly, and automatically gets assigned to the object. It is also possible to assign the report to multiple objects. Furthermore, the form includes options for labeling, highlighting and attaching photos.

The monitor page of the operator and external stakeholder profile is extended with a button for new work orders. The new work orders are listed and highlighted in the model. A work order can be opened by selecting it in the list. When an object in the model is selected, the related work orders will show at the right side of the page. The work order can be opened by selecting it.

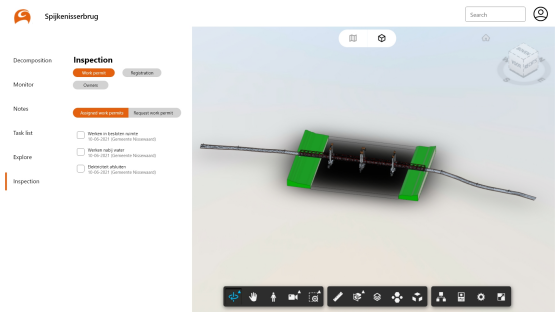
The inspector profile has permission to add data to the DT. Therefore, the note page is extended with an option for note creation. A new note can be created by filling in an empty form. The note needs to get a title, description and type. The note can be attached to an object. It is also possible to highlight the note as important and attach photos to the note.

The sub menu at the right that appears when an object is selected, is extended with an option to see related documentation. Files can be opened to see its content.

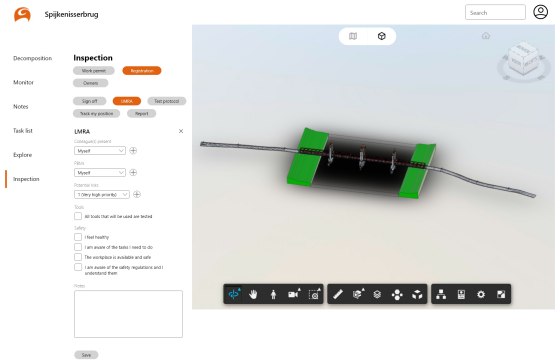
6.2.5 Risk analyst

The risk analyst profile includes the same pages as the inspector profile. However, after selecting the risk analyst profile, the user will first get to see the settings page (figure 4b) in which the UI can be adapted according to their preferences. The setting page contains six items that correlate to the modules document management, inspection, note creation, new work orders, maintenance, and circularity. As a default, the modules for document management, inspection, note creation, and new work orders are turned on. Based on the selection made by the user, the UI will adapt itself.

When the documentation management module is turned on, the main menu gets extended with an item named documentation (see figure 9a). The documentation page contains all the FMECA files that are connected to the asset. The user can upload new files as well. Each document has a little pop-up menu that



(a) Inspection page when not registered



(b) Inspection page when registered

Figure 8: Two examples of the inspection page depending on being registered on-site

appears when it is selected. This menu contains options for viewing, editing, copying or deleting the document.

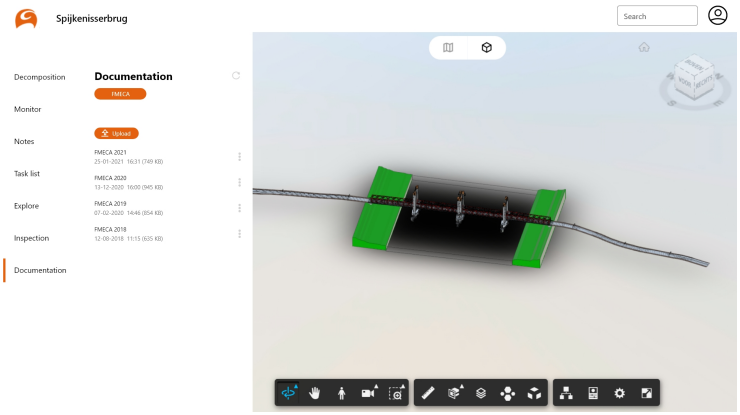
By turning on the inspection module, the inspection page gets extended with a button to assign condition scores. assigning a condition score can be done by selecting an object in the module or search for it using the filter. Information of the selected object is shown at the right side of the page, just as fields for filling in a condition and/or risk score.

6.2.6 Asset manager

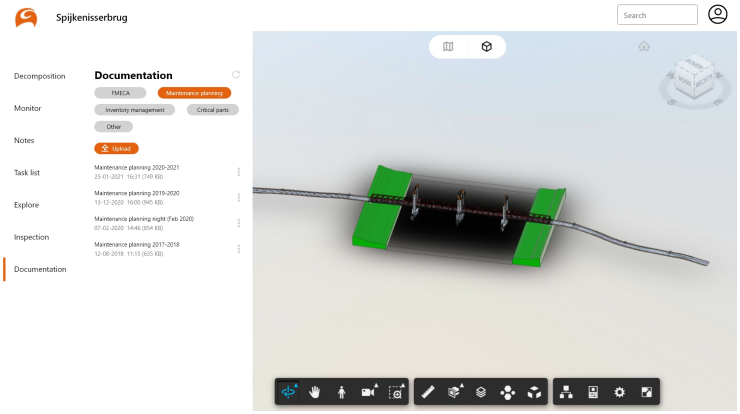
The asset manager profile uses the same pages as the inspector profile and is based on the same principal as the risk analyst profile. The asset manager can also adapt the UI by turning modules on or off. These modules are the same as for the risk analyst. Also the same default modules are turned on. However, the documentation page is extended with four other categories.

The documentation page is used for documentation management. The documents are categorized in FMECA, maintenance planning, inventory manage-

ment, critical parts, and other (see figure 9b). By selecting a category, the related documents are listed. New documents can be uploaded in a category. By selecting a document, a pop-up menu appears that provides the option to view, edit, copy or delete it. Since the other category can contain all kinds of documents, a filter is added.



(a) Risk Analyst profile



(b) Asset manager profile

Figure 9: Two examples of documentation pages depending on chosen profile

6.3 Modular UI

Users that select the asset manager or risk analyst profile, are supposed to compile their own UI by turning modules on/off. However, the chosen software did not provide dynamic content creation. Therefore, the decision was made to create static UIs for both profiles that are manually linked by animations.

7 Validation of prototype to test IA content

To determine whether the developed requirements form a good representation of the identified user profiles, and whether the IA is user friendly, easy to navigate and complete, a usability study is created to test the developed prototype. According to Tu et al. [42] usability testing is fundamental in HMI for UX design. This chapter explains the goals and objectives of the usability study, and the used methodology. The results of the usability study are analyzed to form recommendations for Arcadis for future implementation of the IA.

7.1 Goals and Objectives

The goal of the usability study is to research the possibilities and conditions for sensible use of a modular UI for a DT in O&M. It is not about validating whether the created prototype meets the requirements, but about understanding the potential chances, design space, issues and limits. The lessons learned from this usability study will help others with drawing up requirements that suits their needs for a DT.

The objectives that are of interest to measure if the goal is achieved are based on effectiveness, efficiency and satisfaction of the participant. Effectiveness refers to the level of success that participants achieve when they perform a given task. Leading to the question; can users effectively complete their goal? Moreover, I want to know whether or not the tasks are relevant for them, in order to get a better understanding of which functionalities are useful to who. Efficiency is the ability to accomplish a task quickly, with the least amount of effort. An important factor to establish efficient task completion is a good designed IA. Leading to the question; are the items in the IA easy to find? Can users efficiently accomplish their goal?

Effectiveness and efficiency are objectives that can be measured based on task performance. Satisfaction is a subjective objective that is based on a users' experience, feelings and opinions. Observing task performance is not enough in order to create an understanding of the satisfaction level of the user. Therefore, several questions have to be asked that respond to the experience of the participant. Does the user feel like the IA contains a complete overview of required data? Is the naming of navigational items an functionalities clear? Do the modules make sense? Was it difficult to complete tasks? Do the tasks correlate to the reality of their jobs? The answers to these question will provide insights about the satisfaction level of users about the developed prototype to test IA content. Additionally, the participants should get the opportunity to provide feedback about adding or leaving out things in the current IA.

7.2 Methodology

After completing the prototyping phase, the next step in the UCSD methodology is the evaluation phase. Perdomo et al. [38] proposes to evaluate the prototype using an inspection method or user testing method. Since this is

the first developed prototype to test IA content, the user testing method is a more suitable approach to evaluate the usability of the system. The inspection method could be interesting to use in a later stage of the development, because it evaluates the system in a higher level of detail.

A usability study is a study that puts the usability of a product (or service) to the test, by letting the user complete tasks with the product [17]. The attempt to complete the tasks are observed, in some way, by the researcher. To create a usability study, a usability test plan has to be created. According to Williams [45], this plan should include the following topics:

- Goals and objectives
- Description of participants
- Description of the session (environment, protocol, scenarios)
- Performance measures

This section explains the usability test plan based on Williams [45], that is used to generate the recommendations.

7.2.1 Participants

The focus of this usability study is to research the possibilities and conditions for sensible use of a modular UI for a DT in O&M. Therefore, the participants do not need to form an exact representation of all defined user profiles. In this stage of the development process, quantity is more important than a qualitative representation of the target group. Moreover, due to several reasons (like the holiday period, COVID-19, and lack of time) it is a more realistic choice to test with a broader spectrum of participants in order to collect a large amount of responses that could potentially be statistically significant. However, it is preferred that participants are familiar with the DT concept and asset management. Therefore, the decision has been made to only invite employees of Arcadis to participate in the usability study.

40 to 50 potential participants are contacted by email. The email contains the information brochure that can be found in Appendix E, and a private link to a SharePoint page that contains the link to the usability study.

Due to the period in which the usability study takes place (end of June) and no need of personal contact, it is expected that there will be a low response rate. The chances are high that the email will get lost in full mailboxes or participants forgetting about it after reading it. The aim is to get a response rate of about 40% to 50%, resulting in about 20 responses.

Participation is voluntarily. Since a large amount of potential participants can be reached, no incentives are given to participants after they finished the usability study.

7.2.2 Performance measures

Measuring the usability of the prototype is complex, because it is composed of multiple elements such as task performance, confidence in the correctness of the task, and interaction flow [29]. Performance measures exist of objective and subjective data. Johnson et al. [29], Kolkmeier et al. [30] and Kratz and Rabelo Ferriera [31] use objective variables like task completion time and error rate to measure task performance.

To collect subjective data in relation to usability, a post-task questionnaire has to be administered [29]. The created survey for this usability study, that can be found in Appendix F, is based on multiple studies [39, 29, 31]. Piumsomboon et al. [39] collected subjective data that is related to usability by asking questions that are based on ease of use, collaboration, experienced level of stress, and confusion. Kratz and Rabelo Ferriera [31] also asked questions in relation to the quality of visualizations and task difficulty. Next to objective and subjective measures, Johnson et al. [29] describes a third measure; the behavioral measure. Behavioral measures are based on the behavior of the participant, like where someone clicked.

Additionally, to measure usability by effectiveness, efficiency and satisfaction, Kolkmeier et al. [30] uses the System Usability Scale (SUS) from Brooke et al. [21]. SUS consist of 10 questions (which can be found in Appendix F.3) that are answered using a 5-point Likert-scale. The other closed-ended questions in Appendix F, related to the user experience and the usability of the system, are also answered using the 5-point Likert-scale [39, 29, 22].

In order to link the collected performance measures to a certain profile, participants should be asked about their demographics [30]. The following dependent variables are used to measure task performance, and the user experience related metric SUS.

- **Objective measures**
  - *Task performance*
    - Task completion time
    - Number of clicks (error rate)
- **Subjective measures**
  - *Usability*
    - 5 point Likert-scale
  - *Feedback*
    - Open-ended questions
- **Behavioral measures**
  - Where did user click?

7.2.3 Session

The ethics committee that is assigned to Interaction Technology at the University of Twente approved the assessment for the usability study. Before the participant starts the usability study, they are asked to give consent for using the obtained data in this thesis report. Participants that do not give permission can close the study before data will be collected.

The usability study is created in Useberry [1], which is a user testing plugin for designs that are developed in Adobe XD [5]. The basic plan of Useberry had to be purchased in order to collect more than ten responses.

Potential participants are invited by email. The email contains a general explanation about the thesis research, the usability study, and a private link to a SharePoint document. Attached to the email is an information brochure (Appendix E) that contains detailed information about the thesis research and the usability study. The SharePoint document can only be entered when the email address of the participant is given permission to enter by the researcher. In the document the link to the usability study is provided. Since this is a public link, the document also contains a clear message that explains that the Useberry link should not be shared outside the organisation.

Depending on the execution and interest of the participant, completing the usability study takes around fifteen minutes. The user has the possibility to skip questions or tasks when desired. The usability study is divided into five parts; introduction questions, tasks, questions relating to the experience, freely exploring the prototype, and feedback.

The opening screens of the usability study instruct participants about the researcher being interested in the performance of the prototype, instead of their performance. Afterwards the participant is asked to give permission to use the collected data in this thesis research, and to not share the Useberry link. When a participant selects no, they are asked to close the page. The participant can continue when permission is granted. To assure anonymous data collection, participants are asked to give themselves a nickname. Accordingly, the participant has to answer two multiple choice questions related to their demographics and interests. An overview of all the questions and tasks that the session contains can be found in Appendix F.

The tasks are based on the research of Kolkmeier et al. [30] who described three types of tasks; navigational tasks, recognition tasks, and manipulation tasks. The tasks are grouped based on profiles. Task 1 until 13 in Appendix F.2 represent the basic profile (the operator and external stakeholder), and is extended with the module for asset owner. An introduction is provided for a group of tasks that correspond to a certain profile. A task is presented to the participant, as can be seen in figure 10. After pressing the button, the participant can freely navigate through the prototype. When the screen is reached or action is performed that was needed to successfully complete the task, the screen in figure 11 appears.

After completing the tasks that correlate to the basic profile, a new introduction screen appears to introduce the inspection profile. Tasks 14 until 19

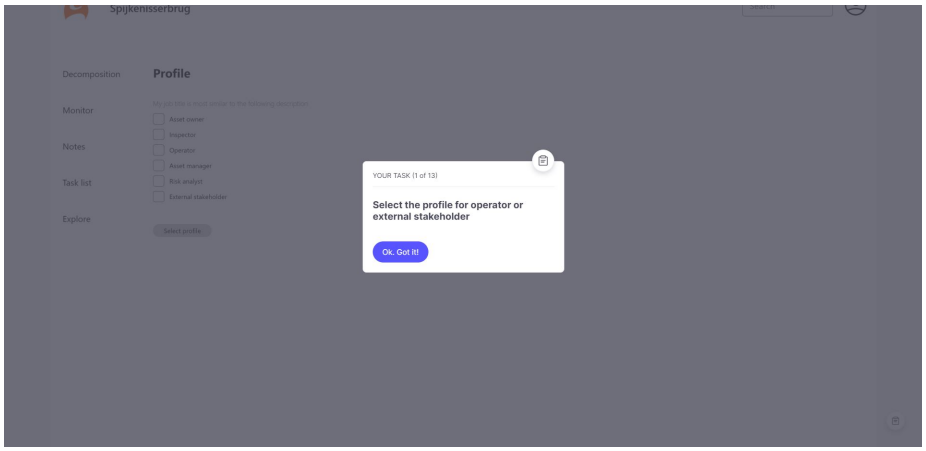


Figure 10: Task presentation in usability study

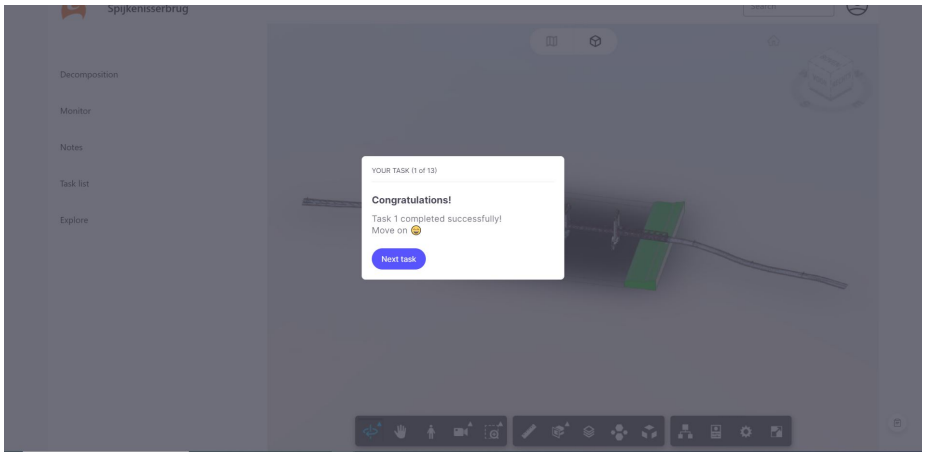


Figure 11: Task accomplished presentation in usability study

in Appendix F.2 correspond to modules for the inspection profile. During the completion of these tasks, the participant will discover a malfunction. Sketching this situation functions as an illustration for a real case. The lasts tasks (tasks 20 until 27 in Appendix F.2), build on this case to show the added modules and functionalities that relate to the asset manager and risk analyst profiles.

Accordingly, participant are asked about their experience using the SUS form (Appendix F.3) and the survey in Appendix F.4.

The next part is integrated to obtain as much useful feedback as possible. During this part, participants get the opportunity to explore the prototype by themselves. There is no time limit. When the participant is done exploring, the 'task' can skipped and the final questions will appear.

The last part asks for feedback about the prototype. The open-ended questions in Appendix F.5 allow the participant to explain their thoughts about their experience with the prototype. Finally, the participant is thanked for their participation and is told to close the tab in the browser to exit the usability study.

7.3 Results

This section contains the most interesting results of the usability study in relation to the tasks and the survey. A complete overview of the survey results can be found in Appendix G.

7.3.1 Tasks

Figure 12 shows a bar chart that provides an overview of the amount of participants that started a task, relative to the amount of participants that completed the task. It can be seen that fifteen participants finished all tasks.

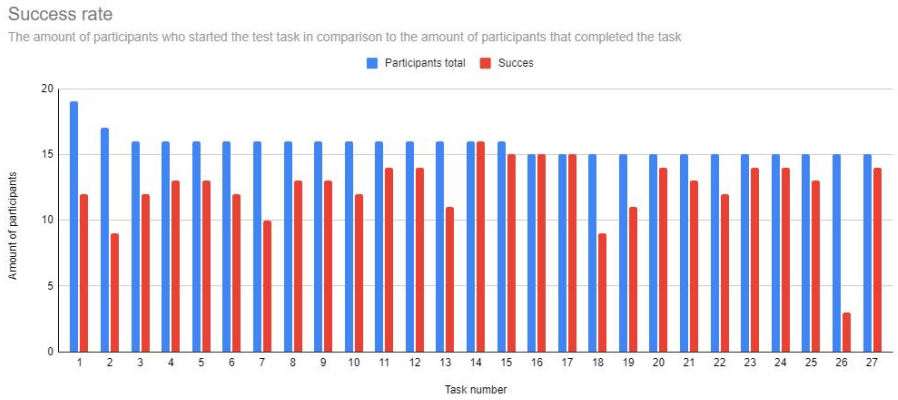


Figure 12: Success rate of usability study

The scatter plot in figure 13 visualizes the amount of clicks a participant used before completing or skipping a task. The crosses represent the participants. Each color stands for a different participant. The pink squares show the minimum amount of clicks that could be used to complete a task. The green circle represents the average amount of clicks used for a task. When a participant skipped a task after more than 20 clicks, the amount of clicks was set to 30.

The variables for average amount of clicks, average completion time, and success rate are combined in the bubble chart in figure 14. Each bubble in the chart represents a task. The size of the bubble visualizes the amount of successful completions; a large bubble means that more participants successfully completed the task in comparison to a small bubble. The x-coordinate of the of bubble represents the average completion time of a task, and the y-coordinate relates to the average amount of clicks used.

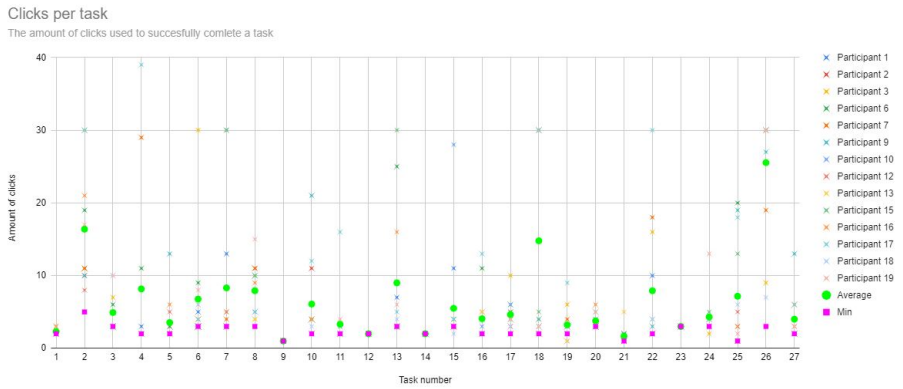


Figure 13: Amount of clicks used by participants per task

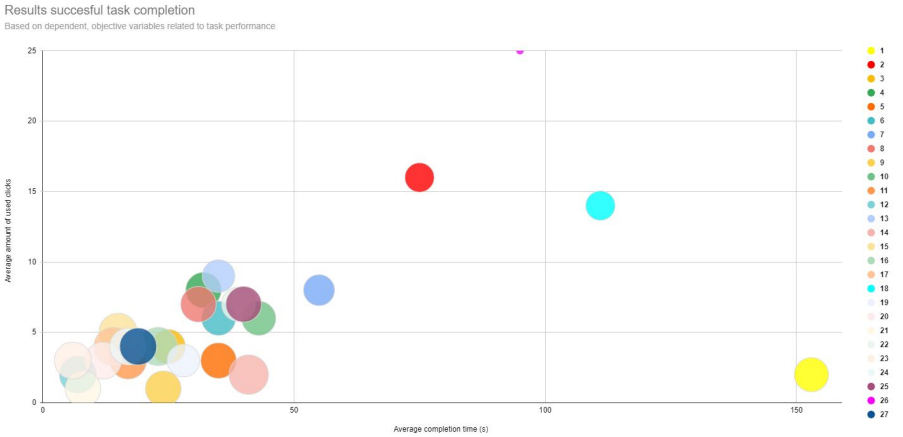


Figure 14: Results of successful task completion, based on dependent, objective variables related to task performance

7.3.2 Survey

Each user is asked to choose the profile that best fits their job description. Accordingly, they have to select the modules that are of interest to them in a DT. The results are visualized in the bar chart in figure 15. In the bar chart can be seen which modules are chosen by who. The larger the colored bar, the more often it has been chosen by that particular profile. As a simple example, the participant that selected the inspector profile chose the module for inspection and maintenance.

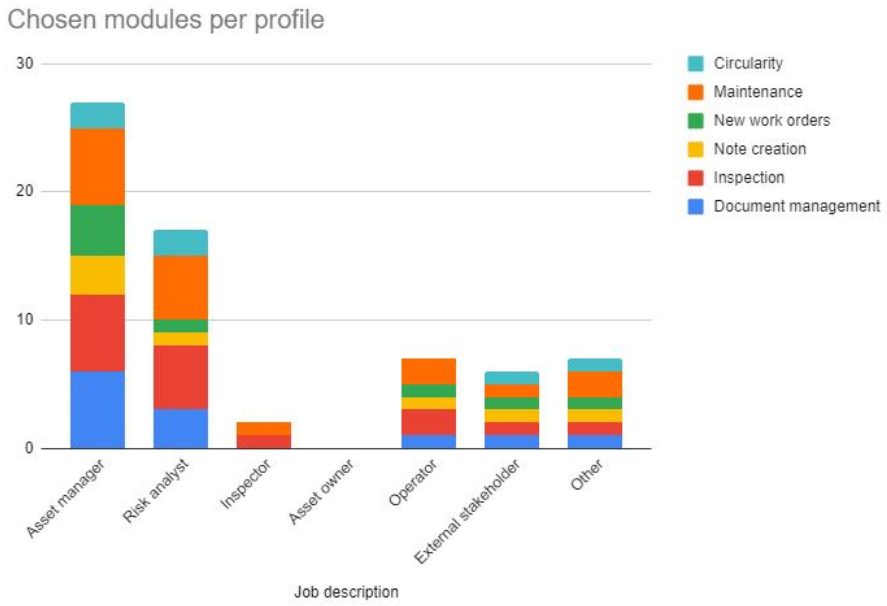


Figure 15: Modules of interest for each profile

7.3.3 Observations

The screen recordings of participants going trough the tasks are being viewed by the researcher. A couple of things stood out. First of all, there were a couple of participants that did not do what was stated in the task. For the first task, the user had to pick a specific profile. However, a couple of participants picked a different profile, probably the profile that is of interest to them. Accordingly, these participants started exploring the prototype by themselves, ignoring the task for a while. After a couple of minutes the participant usually got back to the task and tried to complete it. These events make the dependent, objective variables for task performance not always reliable.

Another issue that appeared is related to fixed screens for task completion. It was expected from users during task two, to not only select an object in the decomposition, but also to open the details in the sub menu that opened. When users did not select information in the sub menu, the task did not get marked as completed. Some users just starting clicking in the prototype at this point.

Moreover, the prototype seems to have some bugs. For one of the participants, a random page appeared after selecting an item. The problem is that you can not click on anything anymore when this happens, so the participant gets stuck. The only way to solve it, is to skip the question. Luckily Useberry [1] has a skip function. Participants also used the skip function when a task was too difficult to complete. On the other hand, skipping tasks also happened at random, leading to inconsistency in the data.

Next to technical issues that could not have been prevented, some design choices that resulted into technical issues, could have been prevented. In task seventeen, the user has to register him- or herself in the DT. Accordingly, new functionalities appear that are needed to complete task eighteen. However, as soon as one of main buttons is selected in the inspection page, these functionalities disappear. Making it very difficult to complete task eighteen. A potential reason for users selecting other options, is that the visualizations in the model are not visible enough. Only one participant clicked on a highlighted object.

Some observations revealed issues in the IA. In task 22, in which a condition score has to be assigned, some participants started looking in the monitor page for the condition score functionality. A larger issue, that almost every participant experienced, is finding documentation that is attached to an object. The majority of participants started looking in the decomposition page or in the model of the documentation page.

7.4 Analysis

To give meaning to the collected results, and to form a better understanding of what the results mean, an analysis is performed. The results of the tasks, closed- and open-ended questions, and SUS are analyzed differently. This section provides information about how each part is analyzed, and what was found based on the performed analyses.

7.4.1 Tasks

The bar chart in figure 12 shows nineteen participants started the tasks that are related to the asset owner, operator and external stakeholder profile. Sixteen of these participants completed the tasks. The subsequent tasks, that relate to the inspector profile, are completed by fifteen participants. One participant dropped out after the second tasks of the inspector profile. The tasks that relate to the asset manager and risk analyst profile have been completed by these fifteen participants. It is not clear why participants skipped tasks or dropped out of the usability study completely. Potential reasons are that they got distracted by something else, they were not interested, it took too much time, or tasks were too difficult to complete. When looking at the red bars in figure 12, it can be seen that the success rate (see formula 1) is 100% for only four tasks. The low success rate of the tasks could explain why participants potentially got frustrated and would skip tasks or drop out. However, when calculating the success rate over all tasks (the average), the success rate turns out to be pretty high. The average success rate is 79.5%, when ignoring the drop-outs it becomes 80.1%. For a first prototype this a good success rate to have.

$$Success\ rate = \frac{number\ of\ participants\ successfully\ completed\ task}{number\ of\ participants\ at\ beginning\ of\ task} \quad (1)$$

When looking at the individual tasks in figure 12, it can be seen that task 14 up to task 17 are successfully completed. These task belong to the inspector

profile. Issues start to appear when the participant is registered on-site. According to figures 13 and 14, task 18 took on average about 2 minutes and 14 clicks to complete. Based on observations these bad statistics are partly related to the way the prototype works. When a user pressed a button other than the registered functionalities, the buttons for these functionalities would disappear. Another issue based on observations is the visualization of highlighted objects. The highlighted objects were not visible enough for the participant to quickly spot them. Nothing indicates that the IA should be changed. The average amount of clicks used to complete task 19 seems not to deviate too much from the minimum amount of clicks needed. In combination with the observations, it could be that participants not always understood that they had to click on the QR-code to complete the task. Therefore, it does not indicate a flaw in the IA.

Another task that stands out in figure 12 is task 26, due to its low success rate of only 20%. The charts in figures 13 and 14 clearly show that this is related to a bad IA choice. The average amount of clicks used is around 23 clicks higher than it should be. Moreover, the completion time is higher than for the other tasks. Based on observations, the documentation that belongs to an object should be added to the decomposition and documentation pages.

An interesting observation in figure 14 is that task 1 and 2 seem to be outliers. Mainly for task 1 this seems odd, since the average amount of clicks is equal to the minimum amount of clicks. However, the completion time of task 1 is extremely long, almost 3 minutes. The observations indicate that this is because some of the participants decided to look around for themselves and ignore the task. Mostly, after a while the task would be resumed. The clicks used for exploring the prototype are ignored in figure 13. Task 2 does have a divergent average amount of clicks. Nevertheless, the observations clearly point out why. To complete the task, the participant had to open the details in the sub menu of the selected object. However, this was not stated in the task description. Therefore, this was a mistake of the researcher. Thus, both task 1 and 2 do not indicate flaws in the IA.

Furthermore, there are a couple of tasks that contain some outliers based on clicks used, as can be seen in figure 13. These tasks are task 4, 6, 7, 10, 13, 22 and 25. In figure 14 it can be seen that these tasks form a cluster, since the average completion time also lays higher compared to the other tasks. However, task 13 is not relevant, since this task is based on exploring the additions made in the asset owner profile. Based on observations, task 25 indicates a design issue. Not all participants selected the dots directly, but tried to select the item itself to edit the document. Task 22 does indicate a potential change in the IA. The observations suggest that the functionality for assigning a risk score could also be placed in the monitor page, underneath the condition score functionality. There were two participants that struggled with successfully completing task 4. After watching these participants performing the task again, one of the participants just seems to be clicking around randomly and the other tries to look up the object in the decomposition page. Therefore, it can be concluded that it does not indicate a flaw in the IA. Task 6 contains one participant that struggled with completing the task. After watching this participant complet-

ing task 6 again, it seems like the participants misunderstood the task. This participant also complaint about tasks not always being clear, so this would be a plausible explanation. To successfully complete task 7, participants had to use the search bar. However, not everyone noticed the bar, indicating a design flaw or misunderstanding of the task. Task 10 asked about changing the model to see-through mode. Some participants were trying to accomplish this via the default menu bar of the 3D model. Again, this does not refer to flaws in the IA.

7.4.2 SUS

Brooke et al. [21] who developed SUS, explains that the individual results of SUS are not meaningful. Meaning is related to the overall usability of the system and can be deducted from its SUS score [21]. The SUS scores range from 0 to 100 [21]. Therefore, each item's score has to range from 0 to 4. To do this, formula 2 has to be used [21]. Odd numbered questions (q_o) are positively worded, while even numbered questions (q_e) are negatively worded. A high score for a positively worded questions means the opposite compared to a negatively worded question and this is why there is a distinction made in formula 2 between even and odd questions. The SUS score that is calculated using formula 2, only refers to a participant. To get the SUS score that gives meaning to the usability of the system, the average SUS scores by participants has to be taken, like in formula 4.

The SUS score can also be obtained by calculating the average score for each question. Formula 3 calculates the average question score (aq) by summing all the answers to a question (a_p) and dividing it by the amount of participants (n). The found average questions scores can be put in formula 2 to find the SUS score for the system.

$$SUS\ score_p = 2.5 \left(\sum (q_o - 1) + \sum (5 - q_e) \right) \tag{2}$$

$$aq = \sum (a_p)/n \tag{3}$$

$$SUS\ score = \sum (SUS\ score_p)/n \tag{4}$$

Bangor et al. [15] developed the ranking in figure 16 to interpreted the SUS scores. A SUS score around 68 is considered to have an okay usability [15]. SUS scores that are below 51 indicate the usability of a system definitely needs to be improved [15].

An overview of the collected SUS results can be seen in figure 17. Each score is color coded, resulting in a heat map matrix. The green color refers to a good score, while red refers to a bad score. The intensity of the color relates to how good or bad the result is. What a good or bad score is depends on the type of question. For positively worded questions, this would be a high score and the opposite for a negatively worded question. Neutral is being marked as white.

When looking at figure 17, questions 6, 7, 8 and 9 have bad results. This means that participants think that the system is inconsistent, cumbersome, has a

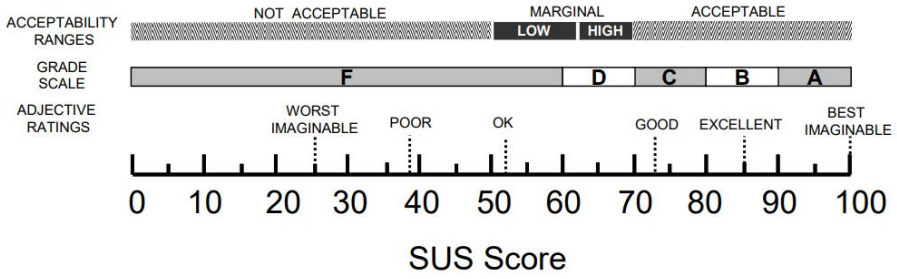


Figure 16: SUS grade ranking of SUS scores [15]

steep learning curve, and makes the user feel insecure during use. On the other hand, the other questions have good results. Most importantly, participants rated the question about frequently using the system with a score above 4. So the concept of the DT seems to be of the participants interests.

The rounded average SUS score for the tested prototype is 56. When looking at the scale in figure 16, a score of 56 would be considered OK. However, it would also be scored as an F which is not acceptable. The SUS scores by participants all have the same categorization. Therefore, it can be concluded that the usability of the current system needs to be improved.

Question	Participant 1	Participant 2	Participant 3	Participant 4	Participant 5	Participant 6	Participant 7	Participant 8	Participant 9	Participant 10	Participant 11	Participant 12	Participant 13	Participant 14	Participant 15	Average
1	5	4	4	4	4	4	4	4	3	4	5	4	4	5	4	4.133333333
2	2	2	2	3	1	2	1	2	2	2	1	2	1	2	2	1.8
3	4	4	3	3	4	3	4	3	3	3	3	4	3	5	4	3.533333333
4	2	1	3	3	3	2	3	2	2	2	1	2	5	4	2	2.466666667
5	4	4	3	5	4	4	4	3	3	4	3	4	4	4	4	3.8
6	4	4	3	4	3	2	4	4	3	4	3	4	4	5	4	3.666666667
7	2	2	2	4	1	2	2	3	4	2	1	4	3	2	2	2.4
8	4	5	4	5	4	4	4	3	4	4	3	4	4	5	3	4
9	4	3	3	2	1	3	2	4	3	2	1	2	4	3	2	2.6
10	2	1	4	2	1	2	1	2	2	2	2	2	2	2	3	2
	62.5	60	47.5	52.5	55	60	57.5	60	57.5	52.5	57.5	60	55	52.5	55	56.33333333

Figure 17: Detailed view of SUS calculations by question, by participant, a heat map matrix, and the SUS score

7.4.3 Closed-ended questions

The only module of preference that has been chosen by every profile, according to the bar chart in figure 15, is the maintenance module. This is an interesting outcome, since this topic has not been mentioned during the interviews. Also the circularity module has been chosen by the asset manager and risk analyst profile which was unexpected. The rest of the chosen modules by the asset manager and risk analyst profiles seem to be inline with the IA. The operator, inspector, and external stakeholder profiles are only chosen once or twice. So it is difficult to obtain meaning from the outcomes of these profiles.

The answers to the experience survey in Appendix G indicate that participants are positive about a flexible UI for the DT that is based on turning modules on or off. The current system was not confusing to participants, and the majority felt no negative emotions while using the system. However, the

participants seem not completely happy with the content of the system. Some functionalities are missing, and the organization and labeling of content could be improved. To get a better understanding of how this can be improved, the answers to the open questions should be studied.

The usability study itself seems to be an okay representation for the reality, since 87% scored the question *The tasks I just completed correlate to the tasks I face during my job* with a 3 or 4 on the Likert scale. However, the confidence level of participants about how well they completed the tasks is quite low since 54% scored this question with a 3. Since participants could do the usability study on their own, there is no possibility to ask about the cause of the low confidence score. The cause could be related to the IA, or to the setup of the usability study itself.

7.4.4 Open-ended questions

Ten participants answered the open questions, while fifteen people completed the tasks. It was probably not clear to some of the participants that there still were some questions after exploring the prototype, or they deliberately made the decision to skip these questions. None the less, the collected answers provide qualitative information about the usability of the system.

Half of the participants answered that there is nothing that can be left out. A participant mentioned that maybe not everything in the system is useful for him/her, but that it can be useful to someone else. Therefore, the profiles and modules would be a good addition. Another participant expresses his/her concern about the feasibility of some functionalities that are related to organizational processes that are hosted at external sources.

There were some comments about including more information. An asset manager mentioned that information related to the optimization of values and costs is incomplete. The addition of risk profiles, asset performance and costs should be integrated in the asset manager profile. Another asset manager could not find information about performed maintenance. It would be useful to know when an object was maintained, and when maintenance is scheduled. A risk analyst proposed to include the product information of parts.

Some participants were not impressed with the quality of the prototype to test IA content. A participant missed the possibility of navigating in the 3D model. Someone else complained about the organisation of functionalities on pages, they should have been in alphabetical or functional order. However, these comments are not related to the content of the IA. Moreover, multiple participants mentioned that they liked the DT and its flexibility by the use of profiles and modules. As improvement, three participants propose an introductory session or tutorial, to get familiar with the system.

Overall, the IA seems to be complete and useful for users that fit the profiles. A couple of functionalities could be added to the asset manager and risk analyst profile, and therefore the IA and requirements should be updated. Furthermore, a tutorial or introductory session needs to be developed for the final DT application.

7.5 Recommendations

The goal of this usability study is to understand possibilities and conditions for sensible use of a modular UI for a DT in O&M. The objectives (focused on effectiveness, efficiency, and satisfaction) help to determine how capacity can be increased to solve identifies problems. Based on the average success rate of 80.1%, it can be concluded that the current IA forms a good base for users to effectively complete their goal. The most useful functionality for all users, which is not inline with the current IA, is the maintenance module. The functionalities in the IA for the asset manager and risk analyst profiles seem to support the users to work effectively. The other profiles need more extensive testing to determine which functionalities are useful for them.

The results show that users can efficiently use the current IA. A recommendation would be to place the functionality for assigning a risk score in the monitor page, underneath the condition score functionality. The users could not always accomplish the goal of the tasks efficiently, since the average amount of clicks for most of the tasks is higher than the minimum amount of clicks necessary. A request was made for a tutorial, this would be a valuable addition to the DT in order to increase efficiency. However, this is only interesting to develop when the IA is fixed and the design is finalized.

The tasks correlate to the reality of the participants jobs, since 87% scored that question with a 3 or 4 on the Likert scale. The results of the closed-ended questions indicate that users are satisfied about the idea of a modular UI for a DT in O&M. However, users made some recommendations to extend the IA. All user profiles showed interest in a maintenance functionality in the monitor page of the basic UI. It is also recommended to add object specific documentation to the object menu in the decomposition and documentation page. Just as the functionality to watch the work orders history of the selected object, which is a completely new function that the participants requested. The asset manager profile requests the addition of risk profiles, asset performance, costs, and performed maintenance. A risk analyst proposed to include the product information of parts, which could be added in the documentation page or in the object menu. Moreover, the organization and labeling of content could be improved.

Since a participant expressed concerns about the feasibility of some functionalities, a DT developer of Arcadis has been asked to review the IA. Together we went over all functionalities of the IA, in order to get an even better understanding of potential chances, design space, issues and limits. Indeed, the DT developer mentioned that a couple of things are difficult to realize. For example the *recent changes* mode in the explore page, this has to be made manually by adding labels to those objects. This is the same issue for the visualization in the maintenance page, which can easily lead to mistakes and problems, making the DT less intelligent. A more complex challenge is the realization of an account based task list. The DT developer did not want to say if this was possible or not without looking into it. Furthermore, a suggestion was made by the DT developer to use an external application (like Fulcrum or BIM360 checklist) for

registering data during an inspection. It would be possible to do it with the DT, but offline use would cause some difficulties. However, the use of a QR-code would offer some possibilities, since a form can be assigned to an object and can be uploaded to the DT when there is an internet connection.

For future work, it is recommended to change the session of the usability study since it is not an effective method. The problem is that the email gets lost in inboxes, or people read the mail and forget about it, or people get distracted while doing the usability study. As a result, a low number of participants finished the whole usability study. A solution would be to not have an external link that requires to request access. Preferably the link to the study is private, or participants can login on the study itself. Furthermore, it is recommended to make the usability study less independent. It would be advised to schedule a video call, so the researcher has more control. This will prevent the participant from getting distracted, and it is less likely that participants will forget a scheduled session. Another advantage of a live session is that the researcher can ask the participant to explain themselves. This helps to develop a greater understanding of why participants did what they did. Moreover, in a further developed stage of the modular UI for a DT, it will be important to include participants that cover all user profiles. The target group should eventually get the chance to reflect on a prototype that forms a realistic representation for a modular UI design for a DT in O&M. Lastly, it is recommended to do a card sorting to check the organization and labeling of the IA in a later stage. This could be combined with the current usability study.

8 Immersive technology prototype to test interaction with Digital Twin

As stated in the introduction, the usability of the DT depends on the IA and the interaction technology. These factors together influence the design of a modular UI that results in an user friendly DT. The prototype created to test the content of the IA has been tested on a 2D web page, while it was recommended in preparatory research [25] to use an immersive technology. it is important to also let users experience an immersive prototype by completing tasks that relate to their job, in order to get a better feeling for the usability of such a DT [17].

To extend the IA to an immersive prototype based on a fitting interaction technology, relevant use cases are needed. Preferably these use cases cover both synchronous and asynchronous remote collaboration scenarios, since the research question about the influence of a modular UI on remote collaboration cannot be answered yet. The asset manager of the Waterwolftunnel introduced two current issues that form interesting and realistic use cases.

The first use case is related to asynchronous remote collaboration. In the Waterwolftunnel are many doors with electrical key locks that have to be inspected regularly. The inspector is usually not familiar with the Waterwolftunnel. Therefore, the asset manager has to prepare an inspection route for the

inspector to follow. The second use case is related to synchronous remote collaboration. The visibility meters and nitrogen dioxide sensors that are placed in the waterwolftunnel have to be inspected annually by an inspector from the manufacturer. However, the manufacturer is located in England. Due to the COVID-19 pandemic there were strict quarantine regulations to prevent traveling, making it too difficult for an inspector to visit the Waterwolftunnel. As a workaround, the sensors were removed and sent to the manufacturer. The inspector returns the sensors after inspection. It would have been more durable, efficient, and cheap if the inspector from the manufacturer could guide a local inspector via remote collaboration.

Consequently, the focus of the immersive technology prototype will be on the inspector profile. Using a see-through HMD as interaction technology for a DT on-site. Section 8.1 explains the chosen software and hardware that has been used for realizing the prototype. Section 8.2 includes the resulting prototype.

8.1 Software and hardware

The immersive technology prototype that is developed to test interaction with a DT, is created for a Microsoft Hololens 1 (see figure 18)[6]. The Hololens 1 has a FoV of around 30x17 degrees [40]. Based on the literature research in [25], it would have been better to use the Microsoft Hololens 2 [7] since the limited FoV of the Hololens 1 has a negative effect on the interaction. However, it was not possible to get my hands on a Hololens 2 for the whole development process. Therefore, the prototype has to be created for a Hololens 1.

Two types of applications were needed to fulfill both use cases. One application for the inspection route on-site, and one for synchronous remote collaboration. Microsoft 365 Remote Assist [8] is an existing Hololens 1 application that can be downloaded from the Microsoft store on the device. Allowing the Hololens 1 device to connect via an internet connection with a remote mobile device that can run Microsoft Teams [10]. The inspection route application is created in the Unity game engine [9]. In Unity version 2019.4.10f to be exact, since the Hololens 1 is not able to run applications that are build with newer versions. To accelerate MR app development in Unity, the Mixed Reality ToolKit (MRTK) was implemented in the project [11]. MRTK provides essential building blocks for MR apps. For the Unity app to get an understanding of the world, World Locking Tools is used to provide a stable world-locked coordinate system that binds the physical with the holographic world [12]. The DT data of an object can be obtained by gazing at a QR-code that comes from a database in the Vuforia Engine[2]. Vuforia Engine has to be implemented in the project in order to use a camera of the Hololens 1 as a QR-code scanner. Remainder functionalities like creating holographic inspection points and navigating along them in order, had to be realized using scripts written in C++.

The Unity engine runs on a HP Spectre 13-3010eg Ultrabook laptop with an Intel Core i7-4500U CPU. The active platform needed to build a Unity application for Hololens 1 should be Universal Windows Platform. The build Unity app can be uploaded to the Hololens 1 using a stable internet connection

and Visual Studio 2019 [3]. In Visual Studio the solution configuration should be set to *release*, the solution platform to *x86* and the emulator to *remote machine*. To build the project on the Hololens 1, its IP-address has to be entered as *Machine Name* in the debugging settings in the configuration properties. By pressing *Start without debugging* the build process will start.

Figure 18: The Microsoft Hololens 1

8.2 Visualization and interaction

This section will provide information about the UI and interaction possibilities in the used Hololens applications. The Hololens 1 is capable of gaze tracking, voice support and gesture input [6, 42]. The gestures that can be made are *air tap* to select, and *bloom* to open the main menu. In figure 19 a visualization of the gestures can be found. By holding the *air tap* gesture it becomes possible to scroll, or move objects in space.

8.2.1 Microsoft 365 Remote Assist for synchronous remote collaboration

The dashboard that appears when opening the app can be seen in figure 20. The top menu contains interaction possibilities for drawing or reposition the app in space. The left menu has functionalities for starting a video call, accessing files, or capture assets conditions. The user can select items using the air tap gesture.

During a video call, the Hololens 1 and the mobile device have a different UI (see figure 21a). The UI of the Hololens 1 stays the same as the dashboard in figure 20, but a sub menu is added to the bottom of the screen. This sub

(a) Air tap (b) Bloom

Figure 19: Visualization of Hololens 1 gesture input

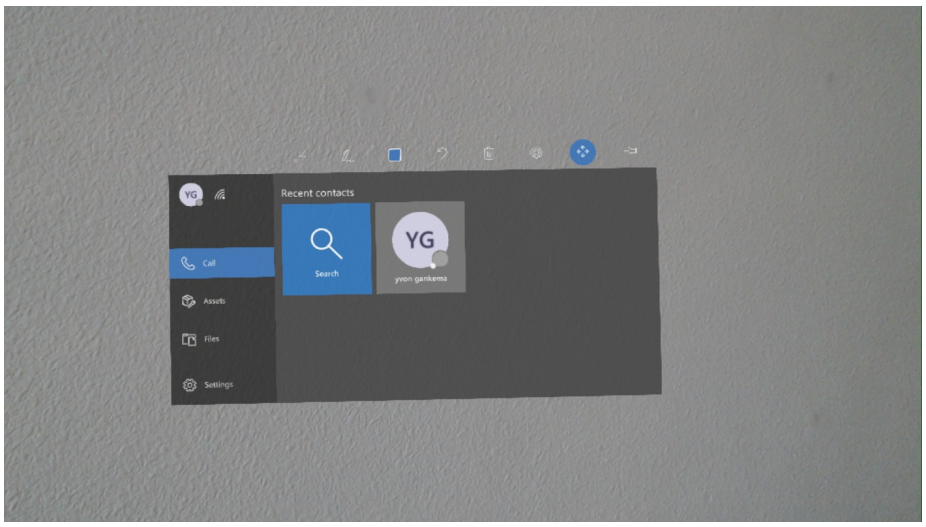
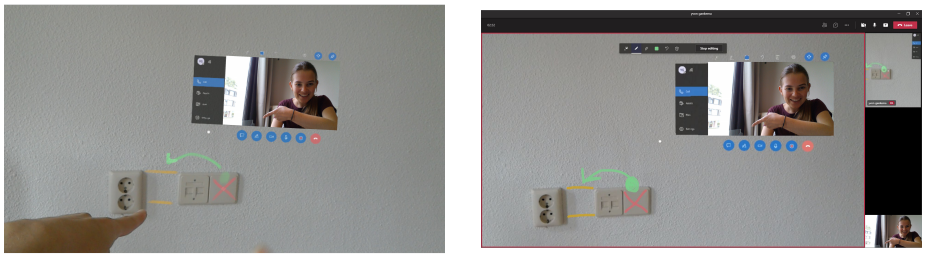


Figure 20: Dashboard in Microsoft 365 Remote Assist on Hololens 1

menu contains functionalities that are related to the video call, like camera, microphone, or record settings. The remote user joins the video call on a mobile device using Teams [12], having its standard UI with the little sub menu that can be seen in figure 21b. This sub menu allows the remote user to take a screenshot of what the Hololens wearing user is watching. At the top right, the view of the Hololens wearing user can be seen, and the bottom shows the remote users' own video feed. The large screen in the middle shows the taken screenshot. It is possible to place arrows or sketch on this screenshot. The Hololens wearing user will see the result placed in the real world, at the same location as where the screenshot was taken by the remote user. This way the drawing created by the remote user will be aligned with what the Hololens wearing user is seeing, even when moving around.

The interaction possibilities for the remote user on Teams [12] depend on the type of mobile device that is being used. On a mobile phone or tablet, the

touchscreen can be used. On a computer it is possible to use a mouse or drawing tablet. In this study a laptop is used, so the touchpad or mouse can be used for interacting with the application.



(a) UI in Hololens 1

(b) UI on a mobile device

Figure 21: UI of Microsoft 365 Remote Assist during a video call

8.2.2 Unity inspection route app for asynchronous remote collaboration

The Unity inspection route app is a prototype for setting up and following an inspection route. When you open the app, three items can be seen; the reset button, main menu and first target point. The inspection route will consist of multiple target points that need to be positioned manually. By holding the *air tap* gesture, the target points can be moved around and placed in space. A new target point can be added by pressing the *Add target* button, the most left button of the main menu in figure 22, using the *air tap* gesture. An unchecked target point exist of a green circular object and a checkbox, as can be seen in figure 23a. The checkbox can be checked by selecting it using the *air tap* gesture. The target point will turn pink and the checkbox will be checked when the action is performed correctly.

Figure 22: Main menu of Unity inspection route app for Hololens 1

(a) An unchecked target point (b) A checked target point

Figure 23: Target points and navigator to form inspection route in the Unity inspection route app for Hololens 1

The *Navigator* button, the middle option of the main menu as can be seen in figure 22, can be selected when the inspection route is prepared. A blue arrow will become visible, as can be seen in figure 23. This arrow points in the direction of the next unchecked target point. The size of the arrow is related to the distance to the next target point; the greater the distance, the greater the arrow. When the user found the target point, the user can inspect the object of interest. After completing the inspection, the checkbox of the target point should be checked in order for the navigator arrow to point to the next unchecked target point. At the moment, the app does not indicate when the last target point has been checked. The navigator does not know what is actual walking space. It does not take into accounts walls for example, which can lead to confusing visualizations.

The right button of the main menu in figure 22 opens a screen that contains information about the current work order. An example can be seen in figure 24

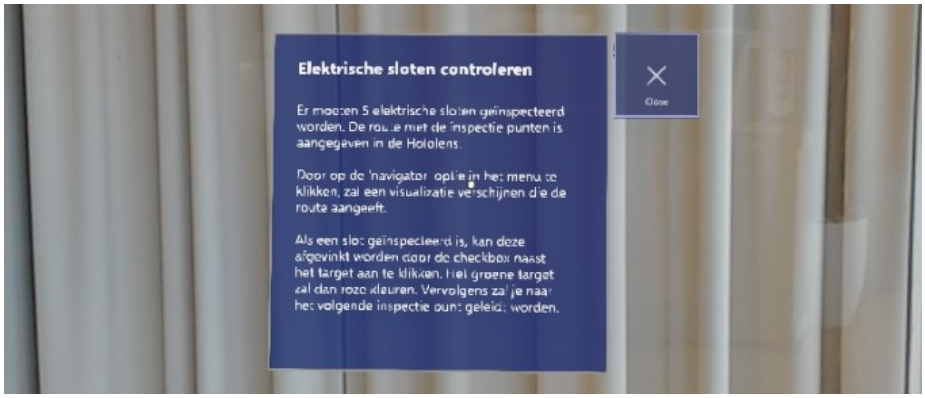


Figure 24: Information screen about the current work order in the Unity inspection route app for Hololens 1

.

A reset button is located at the starting position of where the app is opened.

The reset button, in figure 25, is actually a toggle button. Meaning that it has a state; on or off. The off state of the reset button turns off the Vuforia camera. The on state turns the Vuforia camera on, unchecks all target points, and resets the navigator. The original state of the reset button is on. To activate a full reset of the app, the reset button needs to be selected twice.

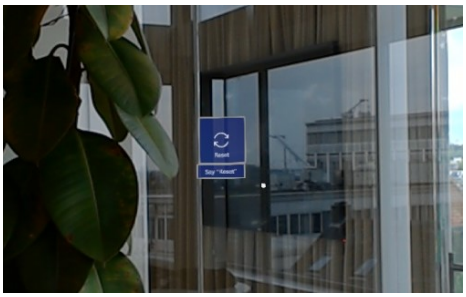


Figure 25: Reset button in the Unity inspection route app for Hololens 1

To obtain object related information, QR-codes are used. The QR-codes are physical and placed next to its related physical object. By gazing at a QR-code, the screen in figure 26 will appear. The idea is that in the future these QR-codes are linked to the DT. However, in this prototype the scanned QR-code shows a display with static information. The information is partly from actual object related data. It is possible to select the buttons in figure 26, but they will also show a static UI.

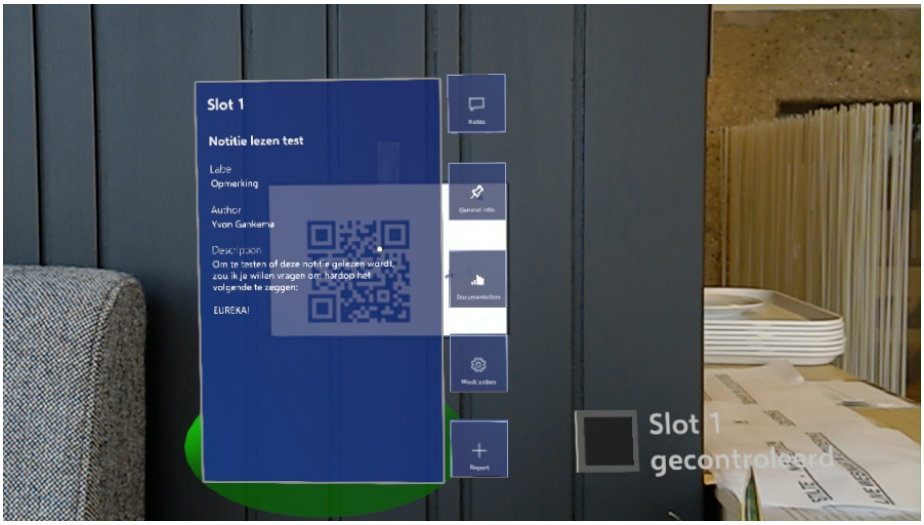


Figure 26: Scanned QR-code in the Unity inspection route app for Hololens 1

9 Validation of immersive technology prototype

The immersive applications are tested in a user study based on the use cases, to get a better understanding of the integration of HMI and DT, remote collaboration with a modular UI, and the user profiles. This chapter describes the goals and objectives of the user study, the used methodology, and the obtained results. The results are discussed to form recommendations for Arcadis about using MR as interaction technology for a DT on-site.

9.1 Goals and objectives

The goal of the user study is to understand if and what the added value would be of using immersive technology as interaction technology for a DT. The use cases on which the user study is based is limited to DT use on-site, and thus to only using MR as interaction technology.

The objectives can be divided into three categories; potential, inspection, and remote collaboration. To measure the potential of using MR as interaction technology for a DT, a couple of questions need to be answered. First of all, how could MR be used in combination with a DT? Referring to opportunities, also for other immersive technologies. What are the requirements for using MR, and does this have an influence on the current requirements in Appendix C? Moreover, does the implementation of MR lead to potential issues? The objective related to inspection refers to what the added value would be of using MR during inspections. The objective for remote collaboration is divided into synchronous and asynchronous remote collaboration. It is important to understand what the influence of using MR is for both types of remote collaboration.

9.2 Methodology

According to the UCSD methodology the immersive applications should be evaluated using heuristic evaluation or a user testing method [38]. In order to achieve the stated goals and objectives, the participants have to get a feeling for the technology and how this can potentially solve the use cases. Both the applications are not fully developed yet, and should therefore be seen as a way to give the participants the experience and inspiration of how it could be used. For that reason a user testing method is more suitable, so a user study is designed to show the potential of MR. The participants will be able to try the applications in order to form an opinion about future implementation. The data on users and their needs that will be collected during the user study supports the development of requirements for useful and usable products [32].

This section explains the methodology, that consists of information about participants, tasks, the discussion with participants, and how everything is combined in the final session.

9.2.1 Participants

The participants of the user study should fit the defined target group for on-site users, such as inspectors, operators, and asset managers. A qualitative representation of the target group is more important than quantity, because this will result in more valuable information. Moreover, a low number of participants is more realistic due to restricted access of the study's location (the Waterwolftunnel).

Three to four participants are recruited by the asset manager of the Waterwolftunnel. Half of the participants are inspectors from Engie, half are asset managers of the Waterwolftunnel from Arcadis. Also asset owners of the Waterwolftunnels are asked to participate. On forehand will the participants receive the information brochure in Appendix H by email from the asset manager.

Participation is voluntarily. No incentives are given to participants after completing the user study.

9.2.2 Tasks

The goal of the user study is to provide an experience for participants that gives them an impression of how MR could be used in combination with the DT. To achieve this, two different tasks are prepared for the participants to try using the Hololens 1.

The first task is meant to illustrate an asynchronous remote collaboration scenario using the Unity inspection route app that is explained in section 8.2.2. The task is based on the use case related to visualizing an inspection route for an inspector that is unfamiliar with the asset, to inspect electrical key locks. The participant has to inspect five electrical key locks using the Unity inspection route app. The location and relevant information about objects of interest can be found in the app. By providing little information, the participant has to rely on the technology. This way the participant can experience how to operate independent, effective and efficient using such a technology that contains prepared instructions.

The second task is based on the use case about the remote inspection of sensors. An inexperienced inspector is on-site, while the expert is not. The expert should provide clear instructions to the inspector on-site to successfully complete the inspection of, in this scenario, complicated signs. This task should illustrate what the influence is of using MR for synchronous remote collaboration. To allow the participant to make a better comparison between a remote collaborative experience that is immersive and one that is not, two similar sessions will be done. During one session the researcher that plays the expert can only give instructions using the video stream and audio. Mimicking the current situation. During the second session, the researcher is allowed to use immersive tools like placing arrows and drawing in 3D space that correlates to the world coordinate system of the Hololens. The user receives a paper that is filled with Japanese signs, as can be seen in Appendix L. Two of these signs are incorrect. The idea is that the participant has no idea what the problem is, and has to

rely completely on the instructions of the remote expert. To also test the feeling of spatial awareness, the drawing tools that are needed to repair the signs are placed somewhere in the room the study takes place.

9.2.3 Discussion with participants

To collect as much information as possible about the experience, thoughts and feelings of the participants about using an immersive technology as interaction technology for a DT, the user study ends with a discussion. The idea is that the participant gets the chance to speak his/her mind. The discussion has no interview structure. The conversation is lead by the participant, or participants, while the researcher just listens and takes minutes. However, that does not mean that the researcher should complete give away the control of the conversation. The researcher has to make sure that the topic of conversation stays within limits, and the discussion keeps going. By preparing questions, that can be found in Appendix K, the researcher can intervene to hold a grip on the flow and topic of conversation.

9.2.4 Session

The ethics committee that is assigned to Interaction Technology at the University of Twente approved the assessment for the user study. Before the participant starts the user study, (s)he is asked to give consent for using the obtained data in this thesis report. The consent form can be found in Appendix I.

The complete user study will take between 45 and 60 minutes. The session is divided into five parts. A detailed overview of the whole user study can be found in Appendix J. To assure consistency and prevent the researcher from forgetting to tell any important information, a script is prepared (Appendix K).

The first part of the user study is the introduction and takes about five minutes. To safe time, this part can be done with multiple participants simultaneously. The researcher will give information about the thesis research and this user study, and explain how the session will look. The participants will explicitly be told what their rights are and be asked whether they have any questions. If a participant did not receive the information brochure, it will be handed out after the introduction. Accordingly, the participant is asked to sign the consent form. When signed, the researcher can continue with the session.

The second part of the user study gives participants the opportunity to follow a Hololens 1 gestures tutorial. It is recommended to follow the tutorial when the participant has no experience with the Hololens. Completing the tutorial takes about five minutes. If the participant feels comfortable using the Hololens 1, and there are no further questions, the researcher can move on to the next part.

During the third part of the user study the participant gets the chance to experience the Unity inspection route app. The researcher will first setup the inspection route using the Hololens. Afterwards the researcher will explain the task as described in section 9.2.2, and gives the participant the disinfected device

to experiment. The researcher will walk with the participant to observe. If the participant has a question, the researcher is allowed to answer. The researcher can also stimulate and support the participant during the experience. This part should take about ten minutes.

The fourth part of the user study is meant to experience synchronous remote collaboration using the Microsoft 365 Remote Assist app [10]. A little task that will take about 10 minutes has been prepared, as described in section 9.2.2. The participant is placed in a room, while wearing the Hololens, with a sheet of complicated signs and two drawing tools. The researcher is in another room with a laptop. During a video call on Teams [12], the researcher has to explain to the participant how (s)he can restore the incorrect signs. There are two signs that are incorrect. One has to be explained using a classic video call and the other using the MR tools available in the Microsoft 365 Remote Assist app [10].

The last part of the user study is a discussion about the experience of the participant(s). To safe time and to stimulate the discussion, it would be preferred to involve multiple participants simultaneously. A discussion should be interrupted after 20 minutes. Section 9.2.3 provides more information about the goal of the discussion and potential questions for the researcher to keep the conversation going and on topic.

Safety is the number one priority throughout the whole user study. The Hololens will always be disinfected before someone puts it on. The researcher will try to keep the 1.5m distance as much as possible. When close contact can not be avoided, the researcher will ask the participant for permission. When preferred by the participant, the researcher will wear a mask.

9.3 Results

This chapter contains a summary of the obtained results of the user study with the immersive technology prototype. An overview of the detailed observations and discussions can be found in Appendix M.

In total seven participants started the user study. One asset manager, four asset owners, and two inspectors. However, not all four asset owners completed the user study. Due to limited time, one participants dropped out after trying the inspection route app. Another participant could not try the Hololens applications due to the limited time slot, but did participate in the discussion. So only two asset owners completed the user study.

Five QR-codes were used to form the inspection route. Three were placed inside the service building on different doors, at the same height as the locks. Two were placed outside, one on a fence and on on the ground.

The setup of the synchronous remote collaboration test involved a laptop and the Hololens. The expert, played by the researcher, was sitting in one room, while the participant wearing the Hololens stayed in the meeting room. In the meeting room some black and white markers were hidden in the windowsill and on a desk. The paper with signs was taped to a flipchart. During the user study with the asset owners, the meeting room was occupied, so the paper with signs was placed on a table in the hallway.

9.3.1 Observations

Every participant did the tutorial. What stood out was that the older generation struggled more with completing the tutorial than the younger generation. The younger generation, the inspectors in this case, completed the tutorial quicker than the other participants. Moreover, they did not need the help of the researcher to complete the tutorial. The older generation on the other hand often got stuck at a particular part of the tutorial, where they had to try the *hold air tap* gesture. The researcher had to intervene to help some of the participant complete the rest of the tutorial. Furthermore, a participant made a comment about the use of speech commands. During the tutorial the participants had to say *select* in order to select. However, the letter *s* was sometimes difficult for this participant to pronounce due to stuttering. So saying that word clearly was seen as a challenge.

After the tutorial the participants could try the inspection route app. During the first user study this setup showed some bugs. First of all, since it was a sunny day, it was too bright outside to properly see the Holograms. Secondly, the Holograms of the QR-codes seemed to be misplaced in space. They appeared quite far away form the user which made it difficult to read because it was so small. After a reset the Holograms appeared on the correct place again when the QR-codes were scanned. However, they were still difficult to read because of their too low placement. The QR-code that was placed on the ground mainly caused issues, because when the user looks down, the main menu will block the view of the checkbox and the QR-codes' Hologram. The QR-codes should be placed at the eye level of the user in order to properly read its Hologram.

Due to the bugs that appeared in the first user study, the decision was made to change the inspection route to the inside. Also the QR-codes were placed at a higher position on the doors to meet the eye level of the participants. During the other user studies some other bugs appeared. The Hololens seemed to have some issues with keeping the coordinate system in place. Participants could not always see the targets anymore, which made it impossible for them to check them and continue to the next inspection point. The researcher tried to solve this bug by resetting the application. For this reason, the inspection route was cut short for multiple participants. Some participants complained during their interaction with the inspection route app. A participant mentioned for example that it would be preferred to have something tangible instead of just gestures, to have some kind of feedback. Another issue is related to the small FoV. Since the target points are not placed at the eye level of participants, some participants struggled to find them due to the target points being outside of their FoV. In combination with the unstable coordinate system, participants could get confused about whether the app was actually broken or not. Moreover, the participant mentioned some suggestions. Like being able to scale the size of the text in figure 26, or swapping the colors of checked and unchecked targets. A couple of participants tried the voice command to select a button. They would have liked to use this functionality.

A couple of issues appeared during the synchronous remote collaboration

test using the remote assist app [10]. First of all, the view of the remote and the local user was sometimes misalignment. When the Hololens wearing user looks down without moving the head down as well, the remote users' view will be misaligned from the local users' view because the cameras of the Hololens are placed above the eyes. This was only an issue during the user study where the paper with signs was placed on a table instead of on the flipchart. Moreover, the placement of Holograms in space seem to be misaligned sometimes for both users. Secondly, the screen in figure 20 got lost in space a couple of times. Since it is then outside of the users' FoV, it can be quite difficult to find again. Lastly, the accuracy of the drawing tool is too low for detailed tasks like in this experiment. The software automatically transforms a small line to a dot. This made it impossible to draw on the sign itself. The remote user had to draw the sign separately and use colors to identify correct or incorrect parts of the sign.

9.3.2 Discussion with participants

First of all, all participants enjoyed participating in this user study. They unanimously mentioned that both applications in combination with a see-through HMD have potential. All participants found the Hololens in combination with gestures intuitive to use. Even though, they think it would cost some time to adjust and get completely comfortable with this type of interaction technology. The main advantage of the Hololens was found to be the hands free interaction. This would help the user to be more efficient and it is considered to be safe. Wearing the Hololens in the time frame of the user study was considered to be comfortable. However, some participants mentioned that they thought it could get uncomfortable when wearing it for a longer period of time. Furthermore, according to the participants using MR adds value during synchronous remote collaboration. The drawing and placing of objects in space was appreciated, since it helps the local user to quickly understand what the remote user means. An inspector even mentions that he would dare to inspect the sensors this way. Also the inspection route was seen as a way to help inspectors and operators, as well as improve the quality of maintenance. This application would support the user in not forgetting inspection points, making them more efficient. The QR-codes in the app also make it easier and quicker for the user to find the needed documentation. Moreover, the app allows the user to directly report which results in direct feedback for others. Which not only speeds up the maintenance process, but also generates complete and accurate data. Additionally, participants thought the navigation in the app was helpful and clear. However, the visualization should be changed. Preferably the visualization should be more immersed in the environment. For example the route could be visualized by the use of arrows on the walls and floors.

The participants also expressed some concerns about their experience. A UI related issue corresponds to handling large documents. An inspector said that he would prefer to use his mobile instead of scrolling his way through a large or complex document. A more technical issue is caused by bright sunlight, resulting in disappearing holograms. Another technical limitation that raised

concern among the participants is the short battery life of the Hololens. An inspection this size takes two to three days to complete. The inspectors work shifts of about four hours with half an hour break. The battery should be able to survive such long days. Moreover, the inspectors mentioned the lack of internet and gps in the tunnel. The applications have to work without it, or there should be invested in assuring internet connection through the whole asset. Furthermore, when the participants were asked about their thoughts on the size of the FoV, they said that it was not too bad but it could be better. The problem of this size FoV is that you can only focus on one task at a time. It would be preferred to have an increased FoV that would fit the problem at hand, and the helping tool. Participants also said that when something was outside of their FoV, it made them doubt about whether or not the application was still working properly. The Microsoft 365 remote assist app [10] resulted in some more specific issues related remote collaboration. When working together it would be preferred to also show your own video feed, so you are aware of what the other person is seeing. The drawing function of [10] is inaccurate. To deal with detailed problems, the accuracy needs to be improved.

The conversation with the asset owners took an interesting turn towards the ethical side of using such a technology. They wondered about what the user and outsiders on-site would think when someone would walk around with a Hololens like device, since it contains multiple cameras and a microphone. People should not feel afraid of being recorded. It will be important to explain what is being recorded and when. Additionally, the asset owners raised the question what happens with the data. Inspectors and operators should not be afraid about being called out on something they did or said while wearing the Hololens. Furthermore, another topic that was discussed it the implementation of different user profiles. They said that at the moment people are afraid to say something that is considered to be out of their job description. Which is a shame, because it very useful to share information about something that you think is out of the ordinary. Therefore, the suggestion was made to include some kind of functionality to share any kind of information and notify the asset manager.

Overall, all participants would like to see the tested applications being developed further. As of right now, the applications are not ready for implementation. When all data sources of interest can be combined in the application, the inspectors would like to use it. The participants came up with some suggestions for further development. A feature they would love to see is speech to text. Being able to talk to the technology, instead of typing, would be highly appreciated since it would be another feature that would not require the need of hands. The asset manager was thinking about realizing a system that is able to determine routes by itself within the asset. For example, if a malfunction appears, the user could just select it in the Hololens and the route towards it will be automatically visualized. Depending on your profile, the route can exclude areas that you do not have access to. Another request of the asset manager involves safety notifications. It would be useful to notify the user when entering a room about its PBMs and safety-plan. The inspectors as well had a safety suggestions

related to the navigation visualization. They wondered if it would be possible to combine it with visual warnings for risk zones. For example, if there would be a hole in the floor, and you are focusing on following the navigation, it would be handy if the application could warn you for it. Moreover, the inspectors also asked which level of the decomposition would be used for the creation of QR-codes. Because a component level for example would be too overwhelming.

9.4 Discussion

The results of the user study are rather positive, in contrast to what was expected. The expectation was that participants would think the Hololens is cool and fun, but not necessarily more useful than their mobile phone for example. However, the results indicate that the use of the Microsoft Hololens 1 [6] creates added value as interaction technology for a DT that is used on-site. The added value is based on hands free and intuitive interaction, the support it provides the user during inspections, and improved synchronous remote collaboration.

The inspection route app was seen as a way to improve the quality of maintenance, since it helps users becoming more efficient. This application makes sure no inspection points are forgotten, documentation can easily and quickly be found, and higher quality data is collected. The use of check boxes allow automatic data collection like exact time of inspection and whether or not an object is inspected, which lead to complete and exact data. Furthermore, the use of MR saves time throughout the inspection process. The inspector can directly report, resulting in generating direct feedback and real time data. The results also show that during synchronous remote collaboration, a better understanding between remote users can be formed when MR is used. The fact that you do not have to hold the camera, but the remote user can always see what you see, allowing you to have your hands free and just work on the task, is liberating. Participants also liked the drawing and placing arrows in space functionality.

However, for actual implementation, the accuracy of the drawing and localization needs to be improved. When you work with electronics for example, you need to be able to work precisely. Moreover, the biggest concern is that the user wearing the see-through HMD is distracted by the holograms, not being aware of the physical world anymore. Furthermore, it is unsure whether the saved time during inspections using MR, weights up to the time it costs the asset manager to prepare. Another important issue that was raised during the user study is the ethical aspect of using a MR device, like the Microsoft Hololens 1 [6], in combination with a DT on-site. Because this device contains a microphone and cameras that record continuously, it needs to be clear for users what happens with this data.

Overall, the results of the user study correspond with the previously formed requirements in Appendix C. Nevertheless, the user study also resulted in a new requirement. The battery life of the device needs to be able to survive a working day of eight hours, with a maximum charging time during breaks of 30 minutes.

The results of the user study show that the developed inspection route app and Microsoft 365 remote assist app [8] can be used to solve the use cases. Since the applications are not based on a specific asset, it is rather easy to use them for other assets. The only requirement is to have a see-through HMD that can run comparable applications. A DT that has a high reproduction value is valuable for such a large multinational as Arcadis. It can be used to mobilize knowledge for greater expertise. Coming to the conclusion that MR as interaction technology for a DT used on-site is a feasible solution to potentially solve similar use cases.

When a fitting interaction technology is being used for a DT, even on a low level (also referred to as a digital model or digital shadow [13]), it can improve the quality of maintenance. Meaning that the integration of HMI and DT is important to create a good UX. Therefore, it should be included in the continuation of DT development. With that being said, all participants would like to see the tested applications being developed further, because the apps help them to be more efficient and effective in their work. Thus, the topic of the user study would be important enough to repeat.

10 Future research

The focus in existing scientific discussions that relate to DT development, lays on developing and optimizing the DT back-end. They always use a single UI and different types of interaction technologies. However, true added value of DT use cases are not driven by the technology itself, but by the understanding of clients' problems [14]. Currently, there is a lack of HMI integration which is why this research aims to bring the human factor back in DT development [36]. The goal of a DT in O&M needs to be to support its user in knowledge, skills and efficiency. By understanding what users need, the DT back-end can be used to its full potential, and that is how maintenance will be improved.

The objective of this thesis research is to achieve design and implementation of a novel use case for a DT that offers a good UX. The novelty comes from the implementation of a modular UI that is based on identified user profiles. The formed requirements and IA offer a complete and structured overview of the desired data and functionalities that each user profile desire from a DT with a modular UI. This research found that added value is created when a modular UI is used for a DT in O&M. However, another iteration cycle is needed to implement the recommendations in section 7.5, to optimize the current requirements and IA.

Furthermore, it was found that a DT with MR as interaction technology creates added value during remote collaboration. However, Gankema [25] recommended to use MR as interaction technology only when the user is on-site. For office use it is recommended to use VR as interaction technology, which this work does not cover. Future work should research the influence of using VR as interaction technology for a DT in O&M.

The next steps that have to be taken to achieve a user friendly, accessible

DT for O&M are related to generalization, safety, and ethics. Future research has to focus on generalizing the identified user profiles, IA, and recommended interaction technologies. This is necessary to say something about the reproduction value of this research. Furthermore, extended research should be done about using a see-through HMD device on-site. A better understanding needs to be created about the effect on the spatial awareness of users when using an MR app, to prevent and support in dangerous situations. In addition, the effect on bystanders when someone on-site is wearing such a device needs to be studied in order to be conscious of the ethical issues.

Recommendations to improve the MR applications used in the user study, are based on the creation of smart navigation, and a better UI design for MR. To create smart navigation, future research needs to focus on creating a stable world coordinate system that works throughout the whole asset, that can be saved and loaded. This functionality could also be used to automatically calculate a route to an object of interest based on profile based access restrictions. The issue related to losing objects because they are out of FoV, should be solved by improving the UI design. More research has to be done to understand what the best way is to help users deal with a UI that is not always in their FoV.

11 Conclusion

This work opens up new directions in the development of DTs in O&M with a modular UI and complementing interaction technologies to offer true added value. The modular UI is based on user profiles that have been identified in the preparatory literature research [25]. This thesis research focuses on how to design a modular UI that is based on these user profiles and what its added value would be to support its users.

First of all, research had to be done to understand *"which data to include for each profile?"* By interviewing and observing users that fit the user profiles, qualitative data could be collected. It was found that each user profile has similar and unique wishes, expectations and needs for a DT.

Accordingly, the collected data is analyzed using RTA to understand *"how the modular UI of the DT should be designed to support its users"*. The results of the RTA in combination with the literature research performed in [25] form the foundation for requirements to design a user friendly DT in O&M. The usability of the DT mainly depends on its architecture. Therefore, an IA was created based on the formed requirements and user profiles. The asset manager and risk analyst profile (Full overview UI type) should have a modular UI, allowing the user to adapt the UI to the current need of the user by switching modules on/off. For the other user profiles it would be recommended to have a static, personalized UI that is based on the requirements and IA. A usability study revealed that the current IA should be improved. Therefore, another UCSD iteration should be executed that is based on the formed recommendation in section 7.5.

Furthermore, the design of a user friendly, modular UI for the DT depends

on the interaction technology. A user study with the Microsoft Hololens 1 [6] based on use cases for inspections on-site, show that MR creates added value for a DT used on-site. The main advantage was found to be intuitive and the hands free interaction, which increases efficiency.

Lastly, research focused on *"how to prevent hindering remote collaboration when using different UIs?"* The results of the user study with the Microsoft Hololens 1 [6] also indicate that MR adds value during (a)synchronous remote collaboration. The technology provides functionalities that support the communication between local and remote users, like direct video feed of the local users' view and the possibility to virtually interact with the real world.

To conclude, the answer to the research question *"what is the added value of a DT with a personalized/modular UI to support the user in comparison to a DT with a single UI?"* can be given. The quality of maintenance can be improved by the implementation of a modular UI in combination with a complementary interaction technology for a DT in O&M. Added value comes from supporting its users to be more efficient. The DT will only show what is of interest to the user. Inspections will be completed faster and with less mistakes, which increases the quality of data. Remote collaboration becomes more effective due to the possibility to directly share data of interest, and more intuitive because of the appropriate choice of immersive technology. Therefore, it is recommended to focus on developing not just one DT, but rather a DT that is flexible and can adapt to the needs of its user. Meaning that the UI should be modular and the interaction technology not fixed.

This research contributed to understanding what a good UX for DTs in O&M should consist of to offer efficient interaction design, a user friendly UI for all users, intuitive remote collaboration, and a complimenting choice of interaction technology. By bringing the human factor back in DTs, Arcadis will be able to create the most value for its DT users. Helping Arcadis to fulfil their mission to not only improve the quality of maintenance, but also the quality of life.

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Appendices

A Interviews

A day in the life of an Asset Manager (large asset)

Date: 07-05-2021
Time: 10:00 - 11:00

1. **What is your role within Arcadis?**
    a. Specialist, maar projectafhankelijk
    b. Beheerder van de tunneltechnische installaties
    c. Asset manager (binnen management agent) → beheer tunnel installatie, assets onderhouden worden, juiste onderhoud krijgen, storingen opgelost worden, juiste inspecties ingevoerd worden, dat dit gebeurt door gecertificeerde personen (dat alles ook gecertificeerd is), onderhoudsplanning voor onderhoud en vervanging en bijhouden van kritische voorraad (op peil houden van voorraad van onderdelen die snel vervangen moeten worden).
    d. Onderhoudsplannen vastgesteld op risico analyse. Wat heeft het voor invloed op doorstroming van verkeer.
        i. FMECA (overlap met risico analyst)
2. **Which tasks do you perform?**
    a. Hangt van het jaar af
    b. Voornamelijk bewaken van preventief onderhoud process. Detailplanning inzichtelijk is voor aannemer, dat hij kan inplannen en uitvoeren, zij rapporteren, die checkt asset manager en dan kan daar weer de FMECA aangepast worden. Aan de hand hiervan onderhoudsplan aanpassen.
    c. Iterative process. Kwaliteit onderhoud verhogen, kosten verlagen en veiligheid garantie bieden
    d. Correctief onderhoud, herstellen storingen (Sander), eigenlijk andersom. Er is een storing geregistreerd. Score 1 is echt niet meer veilig, 4 is laagste, maakt niet zoveel uit.
        i. Wij maken storing inschatting, gaat naar aannemer, moeten binnen bepaalde tijd aan de hand van score reageren. Zij controleren of het binnen deze tijd wordt gehaald. Voor die tijd gerepareerd zijn. Deze rapportages checken wij ook, is het naar wens gerepareerd. Proberen we ook van te leren, moeten onderhoudsplannen worden aangepast
    e. Inspectie processen. Schouw

f. Wettelijke processen, vanuit de wet zijn er bepaalde inspecties vereist. Bijvoorbeeld elk jaar checken trappen, brandblusser etc. Moet ook rekening mee gehouden worden.
g. Daarnaast, op lange termijn, tunnel moet 100 jaar meegaan, bijv. Onderdelen vervangen zoals camera's. Dit inplannen en budget voor reserveren. Documentatie moet weer op orde gebracht worden. Want er komen dan andere datasheets, onderdelen, etc. Aantonen dat nieuwe systeem aan eisen voldoet.
    i. Vaak allemaal beetje tegelijkertijd dat dingen vervangen moeten worden.

3. Could you describe a typical workday?

a. Verschilt
    i. Op locatie
        1. Begeleiden van aannemers, ze komen aan, weten niet precies wat ze moeten doen (zouden ze wel moeten weten)
        2. Aanspreek punt voor inspecteurs
        3. Af en toe ook zelf inspecteren
    ii. Kantoor
        1. Controleren op rapportage
        2. Aannemers doen wat ze altijd doen, wij willen meer data, een trend kunnen herkennen. Willen de juiste informatie van aannemers krijgen
        3. Vergaderingen met aannemers
        4. Financiën van aannemer controleren.
        5. Maken aantekeningen in onderhoudsplanning. Controleer rapport en maakt notities, zodat ik die aan eind jaar kan verwerken
b. Elke dag anders, een verrassing
c. Veel vrijheid om zelf invulling te geven

4. Are there any problems you experienced during your work?

a. Veel werk om alles inzichtelijk te houden. Arcadis niet echt beheerder, eerder bouw. Niet echt tools om het process asset management te beheren.
    i. Doe bijna alles in excel. Alle info zelf gekoppeld in excel. Niet handig en veel werk. Als ik analyses wil doen, kan ik dat doen omdat ik de enige ben die daar mee bezig is. Maar iemand anders kan dat zo snel niet zien. Flinke klus.

ii. BIM 360 waar alles in staat, maar moet net weten waar je moet zijn. Ik wil weten wat voor onderhoud op welk tijdstip op een camera is uitgevoerd. Moet ik snel kunnen zien, en niet zo moet zoeken.
iii. Kan DT wel echt helpen. Kan info handig en overzichtelijk in opslaan.

5. **Which tools do you use to perform the tasks you need to do? (Both digital and analogue)**
    a. Excel, BIM360
    b. Informatie systeem management agent (IMA)
        i. Eigen systeem, web interface
        ii. Storingen
        iii. Werkvergunning
        iv. Bediening, verkeer etc. Voor nu niet interessant
        v. Gebruiken we alleen in Arcadis als management agent
6. **Could you describe the positive aspects of your work?**
    a. In alles kan DT wel meerwaarde bieden.
    b. Risico DT → je moet iedereen meekrijgen en gestructureerd mee werken
        i. Aannemers moeten op goede manier gebruiken, goede data gebruiken
        ii. Provincie uitleggen hoe ze DT moeten gebruiken
        iii. Toegankelijk vanuit meerdere locaties moet veilig → cybersecurity
        iv. Gebruikersprofielen → niet iedereen toegang tot alle data.
    c. Could you describe a workday that you remember as good?
        i.
7. **Could you describe the negative aspects of your work?**
    a.
    b. Could you describe a workday that you remember as bad?
        i.
8. **Who do you collaborate with?**
    a. Management agent staat tussen aannemer en asset owner
        i. Werkvoorbereiders aannemer
        ii. Tunnel inspecteurs en operators ()
        iii. Provincie → programmamanager tunnels en beheerders gelijke objecten
            1. Cybersecurity (installaties moeten hieraan voldoen)
            2. Veiligheidsmensen van provincie

iv. Projecten die om ons heen spelen, Schiphol bijv. Aangepaste wegen en Alle gebieden om ons heen, weg naar en van tunnel is in beheer van iemand anders. Soms hebben die dingen gemeen natuurlijk.
v. veel nieuwe gebouwen. Komt bijv. Een kraan op de weg te staan.
vi. Hulpdiensten die in de tunnel oefeningen willen doen

b. How does the communication go?

i. Meeste via overleg en email
ii. Of het goed gaat ligt aan partij
    1. Soms natuurlijk miscommunicatie
iii. Meeste met onder aannemers en provincie
    1. Gaat over algemeen wel goed
    2. Meestal overleggen

9. What is the connection between your work and the DT?

a.

10. Do you already use a DT in your work?

a. Imke is er mee bezig, dit jaar proof of concept leveren aan provincie.
    i. Als provincie akkoord gaat, DT gebruik voor opleveren voor documentatie aan eind van contract in 2 jaar.
    ii. Hopelijk dit jaar toestemming
b. Nu nog niet.

c. If yes, where do you use the DT for?

i.

d. If yes, what is your experience with this DT?

i.

e. If yes, could you describe the positive features of this DT?

i.

f. If yes, could you describe the negative features of this DT?

i.

11. Where would you use a DT?

a. Voor alles, dus zowel op kantoor als op locatie

12. Could you describe how your ultimate DT would look?

a. Beheer documentatie, niet in mappen maar aan DT hangen
b. Onderhoudsplanning, wanneer welk onderhoud en waar dit impact op heeft

c. Preventief onderhoud, is er storing en waar? Directe link met relevante documentatie
d. Toegangsprotocol; nu sleutels die geprogrammeerd worden per persoon, zou er aan DT willen verbinden
e. Analyses; object gerelateerd iets willen aanklikken. Wanneer storing geweest etc.
f. FMECA aan DT
g. De DT moet weten waar in de asset je bent zodat je de juiste info kan krijgen.
h. Veiligheid / gebruik
    i. Wanneer tunnel gesloten
    ii. Live verkeersmaatregelen

13. Observations

a.

14. Other notes

a. Werk processen die in de DT moeten voor technisch beheer
    i. Onderhoud standaard
    ii. Voorraadbeheersing
    iii. Documentatie beheer
    iv. Afhandelen storing meldingen
    v. Monitoren
    vi. Gegevens beheer (DT)
    vii. Configuratie beheer (software)
    viii. Storingen downgraden, naar planbaar onderhoud
b. Hi-fi prototype graag bij de waterwolftunnel testen :)

A day in the life of an Asset Manager (small asset)

Date: 28-05-2021

1. **What is your role within Arcadis?**
    a.
2. **Which tasks do you perform?**
    a. Day2Day → alles wat je kan plannen rondom een asset.
    b. Irregularities → dingen op een gestructureerde manier herstellen. Irregularity in kaart brengen, hoe heeft het kunnen gebeuren.
    c. Quality → Borgen op uitvoeren en meten van conditie. Via checklists. Inspecties om de zoveel jaar. Gestandaardiseerde rapportering.
    d. KPI → Targets. Concrete meetpunten. Checken of je target gehaald hebt. Als niet gehaald krijg je een boete van finance, als je niet kan uitleggen waarom niet gehaald.
    e. Het is een process wat door elkaar loopt.
3. **Could you describe a typical workday?**
    a. Gemiddelde asset manager; 70% volgeboekt met taken die gedaan moeten worden. Als 40% gehaald, goed gedaan. Er komen veel dingen tussendoor.
    b. Irregularities → kan meer tijd kosten dan je denkt.
    c. Opeens nieuwe wet, die hebben opeens data nodig en moet je overleggen. Moet je alles aan de kant zetten.
4. **Are there any problems you experienced during your work?**
    a. Plots een prioriteit toegewezen krijgt.
    b. Onderscheid kritiek en niet kritiek; moet aan de hand daarvan alles laten vallen.
    c. Asset manager heeft verantwoordelijkheid, ligt wel aan type organisatie. Hoe groter organisatie hoe gefragmenteerder de verantwoordelijkheid wordt.
        i. Maakt grote asset uit? Nee, heeft meer te maken met specialisatie richting. Ligt aan discipline. Ligt ook aan type asset.
5. **Which tools do you use to perform the tasks you need to do? (Both digital and analogue)**
    a. BRAIN → eigen ontworpen software
        i. Database met AI, waarbij data uit verschillende bronnen omgetoverd wordt naar informatie

ii. Er zijn dus heel veel verschillende systemen op het moment
iii. FIS → Facility Information System (voor gebouwen)
1. Statische data
iv. IoT (real-time data), Cloud data (data over onderwerpen buiten asset, zoals weer en verkeer bijv.)
v. BRAIN is slimmere asset manager, zodat je kan plannen voor over 20 jaar.

b. BIM
c. Power Bi
i. Plan (komende 20 jaar)
ii. Type kosten
1. Aan de hand van decompositie
iii. Conditie metingen
1. Risico matrix
2. Wordt budget aan gekoppeld
3. Assesment is de naam van kopje in menu voor dit onderwerp
iv. Afwegingsmatrix
1. Overzicht rendement maatregelen
2. Return of Investment (ROI)
3. Wat is de invloed op het uitvoeren van bepaalde maatregelen zoals dubbel glas bijv. (CO_2 vermindering, verbruik, etc.)
4. Scenarios maken
d. Deze software komt al overeen met DT

6. Could you describe the positive aspects of your work?

a. Organisatie breed overzicht krijgt
b. Strategisch beleid, aansturing
c. Could you describe a workday that you remember as good?
i.

7. Could you describe the negative aspects of your work?

a. Asset manager is nog in volle ontwikkeling
i. Lange termijn visie (over 20 jaar)
ii. Rekening houden met externe factoren zoals verkeer, corona leefstijl, etc.
iii. Wordt expertise domein

b. Wordt nog gezien als onderhoudsmanager, kosten plaats visie, maar gaat richting strategisch beleid om core business.

c. Could you describe a workday that you remember as bad?

i.

8. Who do you collaborate with?

a. Onderscheid tussen intern en extern

i. Intern: operation manager (klant, moet ervoor zorgen dat alles blijft draaien), health safety & environment, HR, werknemers vertegenwoordiging

ii. Extern: leveranciers, andere bedrijven die in het ecosysteem van de asset vallen, onderhoudspartijen,

b. How does the communication go?

i. Je moet zelf je communicatielijnen goed organiseren.

ii. Men denkt vaak nog ouderwets, dit heeft geen prio. Dus als asset manager moet je soms je voet tussen de deur zetten

9. What is the connection between your work and the DT?

a. Bewust maken van wat een DT is. Bestaan veel interpretaties, en misvattingen. Duidelijk maken wat een DT is en hoe we hieraan kunnen bijdragen

b. Men denkt nog in design&engineering. Voor de meeste is het klaar wanneer iets gebouwd is. Echter begint dan pas het echte asset management. → missionaris werk

10. Do you already use a DT in your work?

a. Ja (bijv. BRAIN)

b. If yes, where do you use the DT for?

i. Wordt gebruikt om alle stakeholders en assets in kaart te brengen

1. Inventaris, Decompositie etc.

ii. BRAIN wordt gebruikt om processen in kaart te brengen

1. Onderhouden van bepaalde objecten

c. If yes, what is your experience with this DT?

i. Leerproces tussen ontwikkelaars en beheerders (asset managers). Lastig soms om elkaar te begrijpen

1. Gebrek aan kennis bij andere partijen → communicatie

d. If yes, could you describe the positive features of this DT?

i. In de cloud

ii. Heel gebruiksvriendelijke tools om alles samen te brengen

e. If yes, could you describe the negative features of this DT?

i. Nog in ontwikkeling

ii. IT verhaal, waarin je zelf niet altijd de kennis hebt die miss handig is.

1. Uploaden data kan makkelijk via excel, kunnen veel mensen.
2. Info. uit DT halen, dan moet je een query kunnen schrijven nu.

11. Where would you use a DT?

a. Gebruik het altijd, DT is synoniem voor altijd toegang hebben tot data

b. Op mobiel en op computer

12. Could you describe how your ultimate DT would look?

a. Een hologram,

i. Door Middel van mobile device tevoorschijn toveren en interactief op kan klikken

ii. Geen device in je hand

iii. Virtueel doorheen kunnen lopen

b. Functionaliteiten

i. Data uploaden

ii. Data opschonen

iii. Real-time data

iv. Data in verschillende dimensies bij elkaar kunnen brengen

v. Alles samenbrengen en vertalen in informatie

c. Overal mee naartoe kunnen nemen

d. Vanuit rol toegang tot bepaalde functionaliteiten

13. Observations

a.

14. Other notes

a.

A day in the life of a Risk Analyst

Date: 06-05-2021
Time: 13:00 - 14:00

1. **What is your role within Arcadis?**
    a. Kunstwerk/asset is een systeem die een bepaalde functie vervuld. De functie kan je terugkoppelen aan systemen. Hieronder zitten weer subsystemen om het hoofdsysteem te ondersteunen.
        i. Bijv. Van A naar B gaan, brug is dan hoofdsysteem. Hier vallen subsystemen onder die samen het hoofdsysteem vormen. Alle onderdelen die voor ondersteuning van brug dienen zijn substemen. Ander subsysteem zijn signalering zoals stoplichten of vluchtroutes bijv.
        ii. Hele systeem moet veilig zijn tijdens hele life cycle.
        iii. Hier kijk je allemaal naar als je risico analyseert.
        iv. Hoofdsysteem moet blijven werken. Een bouwdeel/element kan in slechte conditie zijn, maar als dit niet gelinkt is aan hoofdsysteem, maakt het niet uit. Geen risico voor het vervullen van hoofd functie.
        v. Redeneren vanuit systeem, gebruik elementen voor verliezen van functie in asset.
        vi. Bepaald budget, alleen geld uitgeven aan dingen die echt nodig zijn.
        vii. Veel verschillende risico's, horen onder een categorie. Hiervoor gebruiken we RAMS categorie → Reliability/Ability/Maintainability/Safety
            1. RAMSSH*EEP* → Environment/Euros/Politics (aan de hand van belangen, je risico's bepalen. Bijv. in de stad is graffiti een gevaar voor environment, omdat mensen zich dan onveilig kunnen voelen)
            2. Welke punten belangrijk zijn hangt af van asset owner. RWS → Reliability & safety.
        viii. Risico = kans * effect (kans dat iets kan gebeuren)
2. **Which tasks do you perform?**
    a. Er is een bepaalde structuur om te doen, anders kan iedereen het doen.
    b. Risico kan op verschillende manieren en levels

i. Failure mode and criticality analysis.(FMECA) → Hoe belangrijk systeem is voor hoofdsysteem.
    1. Is er iets mis, dan schrijf je dit op en bepaal je het risico

3. **Could you describe a typical workday?**
    a. Ik hou me met verschillende dingen bezig. Veel verschillende projecten. Geen scheiding tussen de rollen, iemand kan verschillende rollen op zich nemen.
    b. Inspectie → risico analyse.
        i. Inspecties doen we niet altijd zelf
4. **Are there any problems you experienced during your work?**
    a. Onvoldoende informatie om risico goed in kaart te brengen.
        i. Verschilt per keer wat er mist
        ii. Inspectie doen om alsnog deze data te verzamelen
        iii. Als je zelf niet de missende data kan verzamelen, is dat een risico op zichzelf
5. **Which tools do you use to perform the tasks you need to do? (Both digital and analogue)**
    a. Word
    b. pen/papier
    c. Fulcrom → app voor inspectie data verzamelen
    d. (software) Excel,
    e. (software) Relaitics → simulaties modelleren
        i. Info. aan elkaar linken
        ii. Niet heel gebruiksvriendelijk, komt een nieuwe tool voor, zelf ontwikkelen of een bestaande gebruiken
6. **Could you describe the positive aspects of your work?**
    a. In geheel, Afwisselend
    b. Could you describe a workday that you remember as good?
        i.
7. **Could you describe the negative aspects of your work?**
    a. Altijd te veel werk. Niet nee zeggen. Opdrachtgever niet snel reageert. Planning misschien, houd je niet aan de planning omdat je het zelf of de klant zich niet aan de planning houd. Kan er niet altijd zelf wat aan doen.
    b. Could you describe a workday that you remember as bad?
        i.

8. **Who do you collaborate with?**
    a. Inspecteurs, collega's, opdrachtgevers, projectleiders, business developers, specialisten, af en toe stagiaires.
    b. **How does the communication go?**
        i. Taal ;p Gaat goed via mail. Voorkeur voor mail, is mail ook beetje to do lijst, kan ik zien wat ik nog moet doen
9. **What is the connection between your work and the DT?**
    a. Momenteel geen. Idealiter risico's kunnen laten zien in DT, zijn ze goed zichtbaar en kan je ze goed bespreken. Bespreken met opdrachtgever en specialist
10. **Do you already use a DT in your work?**
    a. Nee
    b. **If yes, where do you use the DT for?**
        i.
    c. **If yes, what is your experience with this DT?**
        i.
    d. **If yes, could you describe the positive features of this DT?**
        i.
    e. **If yes, could you describe the negative features of this DT?**
        i.
11. **Where would you use a DT?**
    a. Ik weet niet, afhankelijk van hoe groot object is en hoe goed DT opgebouwd en hoe makkelijk het is om aan info te komen. Zou er een hele goede UI moeten zijn.
    b. Track app → voor LMRA, erg onhandig. Voorkeur voor pen en papier. Was langer bezig met invullen app dan wanneer ik het zelf zou opschrijven.
12. **Could you describe how your ultimate DT would look?**
    a. Tijdens inspectie met hulp van DT , ik zou willen dat DT meeloopt. De DT moet weten waar ik ben, zodat ik niet hoef te zoeken waar in the asset ik ben.
    b. Moet een goede decompositie hebben
    c. Niet traag
    d. Info. makkelijk terug kunnen zien
    e. Visualisatie van risico's per element.
13. **Observations**
    a.

Interview after observing inspectors (Arcadis)

1. **Waar vul je informatie in? Eerst papier, dan software systeem?**
2. **Hoe lang duurt het uitvoeren van een bepaalde inspectie?**

   1 object duurt een dag om te inspecteren, dus zo'n 8 uur. Ze gebruiken dus vaak die app, daarom gaan er vaak 3 mobieltjes per duo mee. Om er zeker van te zijn dat ze lang genoeg meegaan, nemen ze ook een powerbank mee en een cameratoestel. Het verwerken van de verkregen data duurt zo'n 2 dagen.
3. **Wat gaat meestal wel goed bij inspecties?**

   Veiligheid is altijd nr. 1 bij Arcadis. Bij andere bedrijven schijnt dat nog wel eens minder te zijn.

   a. **Waar worden vaak fouten gemaakt/vind je lastig om te doen?**

      GTI → De voorbereidingen gaan vaak moeizaam. Het regelen en coördineren van een inspectie kan veel tijd kosten. Er moeten vergunningen aangevraagd worden, met onder aannemers overlegd worden, de beschikbaarheid moet gecheckt worden, etc.
4. **Hoe zit het inspectie process in elkaar?**

   a. **Welke stappen?**

      1. Voorbereiding (praktische dingen)
      2. Inspectieplan en veiligheidsplan opstellen en TRA maken
      3. Afstemmen
      4. Uitvoeren inspectie
      5. Uitwerken bevindingen
      6. Projectleider controleert het verslag
      7. Goedgekeurd, opsturen naar de klant

    b. **Welke software?**

5. **Wat kunnen jullie makkelijk visueel inspecteren?**
6. **Waar kunnen jullie niet bij en is dus lastig om visueel te inspecteren?**

   Dat gebeurt nog wel eens, dan worden er duikers, drones, multibeams of hoogwerkers ingezet. (multibeam is iets waarmee je het bodemverloop kan zien) Echter doen ze dit niet zelf, er is vaak wel een inspecteur aanwezig om aan te wijzen waar foto's gemaakt van moeten worden.

    a. **Ontstaan tijdens de inspecties van lastig te bereiken delen gevaarlijke situaties? Zo ja, wat voor situaties kunnen dit zijn?**

7. **Is het handig om handsfree te kunnen werken, of kan je prima iets vasthouden?**

   Kan prima iets vasthouden

    a. **Is het in bepaalde situaties wel handig om handsfree te kunnen werken?**

       Tijdens het traplopen of op een ladder is handsfree echter wel handig.

8. **Wat voor PBMs zijn gebruikelijk om te dragen op locatie?**

   Meestal een helm, veiligheidsjas, veiligheidsschoenen. Bij water ook een reddingsvest. Soms ook oordoppen, wanneer er veel lawaai is. Some een veiligheidsbril. Aan de weg werken moet met een veiligheidsbroek. Op hoogte moet met een harnas. En soms dragen ze nog handschoenen, hier kan je wel makkelijk mee schrijven.

9. **Enig idee of inspecties overal hetzelfde gaan, of dat hier verschil in zit? Bijv. per regio of land.**

   Geen idee. Ze hebben het idee dat alleen hun afdeling in Arcadis inspecties uitvoert. Van andere bedrijven weten ze ook niet, ze denken alleen dat Arcadis meer op de veiligheid gericht is (met al die veilig- en risico analyses etc.)

10. **Hoe ziet je ultieme DT eruit?**

    - Risico gebieden visualiseren
    - Hoeveelheden en kosten kunnen zien

- In het model kijken (mechaniek etc. denk ik dan, wat niet direct zichtbaar is)
- Schades → up to date houden van het model!
- Maatregelen om risico's op te lossen samen met hoeveel dat kan gaan kosten
- Uitdraai kunnen maken van de top risico's ipv steeds op locatie moeten controleren.

11. Verder nog vragen? / overige notities

Communicatie blijft altijd een dingetje, kan nog wel eens mis gaan.

Biesboschsluis observatie inspectie Arcadis

Waar: Biesboschsluis
Wanneer: Donderdag 15 april, 09:00 - 10:00
Wie: 2 inspecteurs van Arcadis
Wat: Schouw
PBM's: helm, veiligheidsjas, veiligheidsschoenen en een reddingsvest.

Observaties

- Voordat we beginnen met de schouw moeten we ons eerst melden bij de brugwachter. Echter is deze niet aanwezig. Daarom wordt Rudolph Jauregui gebeld, die gaat er achteraan. We mogen gewoon beginnen.
- Voor de schouw wordt er eerst een LMRA gedaan (Last Minute Risk Analyse). Hiervoor wordt een app gebruikt. Alle gegevens worden in de app ingevuld, zoals aanwezige, etc.
- App
    - Deze app is speciaal ontwikkeld voor hun afdeling om alles tijdens inspecties te kunnen noteren.
- Normaal gesproken zouden er ook notities in de app of op papier gemaakt worden. Echter is deze schouw bedoeld om te checken of er schade is aan de sluis na windkracht 7, en zijn ze er een maand geleden nog geweest, dus worden er alleen foto's gemaakt.
- Van bijna alle bouwdelen worden foto's gemaakt.
    - Op deze manier kan je altijd nog makkelijk terugkijken of dingen nog een keer controleren. Als iemand een vraag heeft over een specifiek bouwdeel, kan je op deze manier altijd antwoord geven.
    - Ook is het handig om zoveel foto's te hebben om te kunnen vergelijken met eerder genomen foto's. Hierdoor kan worden gezien of/en hoe snel een bouwobject achteruit gaat.
- Sommige risicovolle bevindingen die als advies gegeven worden aan de asset owner, wordt niks mee gedaan. Hierdoor komt dit advies regelmatig terug.
    - Ik vraag me nu af: Waarom wordt er niks mee gedaan? Is dit een communicatie issue? Kan dit niet in een DT aangegeven worden, zodat dit soort punten zichtbaar worden?
    - In dit geval ging het om een betonnen uitsteeksel waar aarde onder moet komen. (Waarom dat moet weet ik zelf eigenlijk ook niet, misschien heeft de asset owner dit ook?)
        - Krijgt de asset owner wel eens advies wat ze niet goed begrijpen?
- Inspecties worden altijd met 2 man gedaan. Vanwege de veiligheid.
- Voor de elektra/werktuigbouwkundig objecten worden andere inspecteurs ingezet. Of van Arcadis, of van een extern bedrijf.

Vragen

1. **Wat voor type inspecties voeren jullie uit?**
    a. Conditiemeting
        i. Aan de hand van decompositie (nen2676)
        ii. Elk bouwdeel wordt gecontroleerd
        iii. Conditie bouwdeel wordt vergeleken ten opzichte van de conditie die genoteerd is tijdens vorige inspectie
        iv. Elk bouwdeel krijgt een conditiescore (1 laag risico - 5 hoog risico)
    b. Nulmeting
        i. Vergelijkbaar met conditiemeting, maar dan kan je het niet vergelijken met voorgaande metingen.
    c. GTI
        i. Gericht kijken naar een specifiek bouwdeel
    d. Toestand inspectie
        i. Welke onderdelen zijn gevoelig om snel stuk te gaan? Daar kijk je tijdens deze inspectie naar.
        ii. Wordt een risico score gegeven van 1 - 5.
    e. Schouw
        i. Doen ze bijna niet eigenlijk
        ii. Controle, zijn er erge dingen aan de hand?
2. **Wat is het doel van de app die jullie gebruiken om notities te noteren?**
    a. Door digitaal te noteren, gaat het veel sneller. Je hoeft het niet over te typen oid. Je vult alles in 1x in.
    b. Bij Arcadis Amerika doen ze dit al jaren.
        i. Toch eens kijken of ik contact kan zoeken met Arcadis Amerika?
    c. Ze zijn de eerste adviesgroep die zo'n app/digitalisering toepassen
    d. Oudere mensen zijn er niet zo'n fan van, die vinden het lastig om iets anders te doen dan ze gewend zijn. Het werkte altijd prima, waarom moet het anders?
    e. Bespaart veel tijd en dus ook geld.
    f. Het invullen van de bevindingen van een inspectie kost tijd. Handmatig kan het zelfs dagen duren.

Interview after observing inspector (external)

1. **Waar vul je informatie in? Eerst papier, dan software systeem?**

   Notities tijdens een inspectie worden gemaakt aan de hand van een foto nemen. Arcadis wil namelijk dat er van alles foto's gemaakt wordt. Om een gedetailleerde notitie te kunnen maken.

   Daarna wordt de informatie op kantoor in expert desk, een OMS, gezet. Hierin kan je ook makkelijk voorgaande taken terughalen. Er komt een nieuwe systeem, Maximo. Echter bouwt het bedrijf wel zijn eigen UI voor het platform, zodat iedereen er makkelijk mee om kan gaan.

   In dit nieuwe systeem kan/willen ze op afstand kunnen controleren aan de hand van sensoren.

2. **Hoe lang duurt het uitvoeren van een bepaalde inspectie?**

   Deze schouw duurt gemiddeld zo'n 2 dagen. Hierin worden 3 locaties geïnspecteerd door 2 man. (2 man is nodig vanwege de besloten ruimtes, er moet altijd een mangatwacht zijn)

   Er is ook nog nachtelijk onderhoud. Dit gebeurt 3/4x per jaar. Ze beginnen om 18:00 uur en zijn klaar rond 06:00. Hierna moeten de bevindingen zo snel mogelijk omgezet worden in tickets. Het verwerken van zoveel tickets duurt gemiddeld zo'n 3 uur. Het duurt zo lang omdat echt alles genoteerd moet worden. Zowel dingen die goed als niet goed zijn. Per bouwdeel dat geïnspecteerd is moet er een ticket gemaakt worden. Als er ergens 20 camera's hangen en ze zijn allemaal goed, dan moeten er alsnog 20 individuele tickets gemaakt worden. Dit kost erg veel tijd.

3. **Wat gaat meestal wel goed bij inspecties?**

   Kent het systeem uit het hoofd

a. **Waar worden vaak fouten gemaakt/vind je lastig om te doen?**

   Er zijn niet perse dingen die lastig zijn. Wat wel vaak niet goed gaat of irritant is, is een onrealistische planning wanneer er meerdere partijen betrokken zijn. Als inspecteur moet je soms aanwezig zijn bij reparaties, of als je als mangatwacht staat, dan kan je niet weg en moet je wachten totdat ze klaar zijn. In deze tijd kan je dus niet je eigen ding doen.

4. **Hoe zit het inspectie process in elkaar?**

   a. **Welke stappen?**

      1. Taak een week van tevoren voorbereiden
      2. Op locatie de werkvergunningen checken, klopt dit met de werkzaamheden?
      3. Uitvoeren inspecties (foto's en notities maken)
      4. Ticket uitschrijven
      5. Het kantoor checkt de tickets, om te kijken of er nog nieuwe werk orders gemaakt moeten worden/ dingen gekocht worden, dat soort dingen. Die regelen dat wat stuk is gemaakt wordt. Het kantoor plant een reparatie in en maakt hiervoor een nieuw ticket aan.

   b. **Welke software?**

      OMS (expert desk, Maximo)

      Sommige objecten moeten via simulatie gecheckt worden

5. **Wat kunnen jullie makkelijk visueel inspecteren?**

   Over het algemeen kan alles makkelijk visueel geïnspecteerd worden.

   Langs de weg is dat wel lastiger. Voor sommige dingen heb je dus 2 man nodig, mocht er iets mis gaan dan ben je niet alleen. Dat is ook iets waar rekening mee gehouden moet worden natuurlijk.

6. **Waar kunnen jullie niet bij en is dus lastig om een visueel te inspecteren?**

    a. **Ontstaan tijdens de inspecties van lastig te bereiken delen gevaarlijke situaties? Zo ja, wat voor situaties kunnen dit zijn?**

7. **Is het handig om handsfree te kunnen werken, of kan je prima iets vasthouden?**

   Maakt niet uit. Kan prima een hand missen, voor bijvoorbeeld een mobieltje.

    a. **Is het in bepaalde situaties wel handig om handsfree te kunnen werken?**

       In een hoogwerker bijv. omdat je dan contact moet houden met iemand anders en dat ding moet besturen. Daarvoor is handsfree wel handig. Of in de auto natuurlijk. We worden veel gebeld en zijn veel onderweg. Soms hebben ze wel 3 mobieltjes bij zich; persoonlijk, werk en nog iets werkgerelateerd.

8. **Wat voor PBMs zijn gebruikelijk om te dragen op locatie?**

   Werkschoenen, hesje, helm en soms ook een broek wanneer je bij de weg werkt.

9. **Enig idee of inspecties overal hetzelfde gaan, of dat hier verschil in zit? Bijv. per regio of land.**

   Hoe een inspectie gaat/ genoteerd wordt verschilt per contract. De ene opdrachtgever vraagt veel meer details dan de ander.

   Het is ook lastig om te bepalen wat precies van wie is tijdens een inspectie.

10. **Hoe ziet je ultieme DT eruit?**

    - Een DT zou handig zijn om nieuwe werknemers te trainen. Waar zitten bepaalde dingen, het verkrijgen van een stukje vertrouwen, bekendheid en kennis.
    - Het zou ook makkelijk zijn als we sommige componenten of objecten gewoon via de DT zouden kunnen controleren en daarvoor niet helemaal naar de asset toe moeten.
    - Het zou fijn zijn als we in de DT zouden kunnen zien van welke partij bepaalde objecten zijn. Dit is nu niet altijd duidelijk
    - Van afstand kunnen zien of er ergens storingen zijn, en wat voor storing er gegeven wordt. Dit scheelt super veel tijd, omdat we zodra we dit op de computer

zijn dan meteen kunnen regelen dat er iemand komt om het te maken. Anders moeten we daar eerst heen rijden, op locatie regelen dat er iemand komt en dan nog heel lang wachten totdat ze er zijn om het te maken. Dat kan efficienter met de DT.

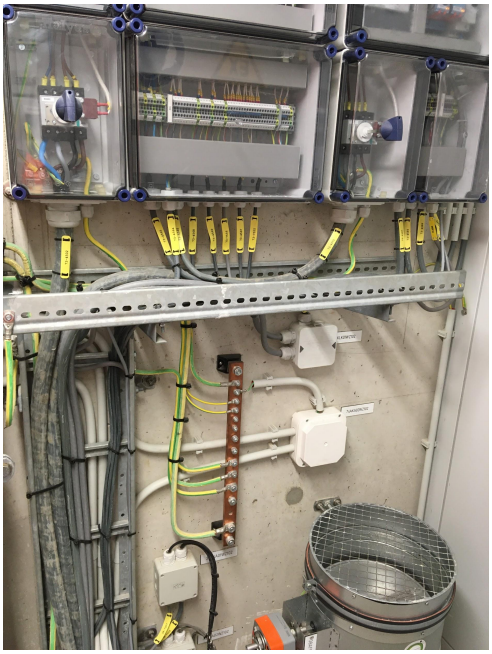
11. Verder nog vragen? / overige notities

Waterwolftunnel observatie inspectie extern bedrijf

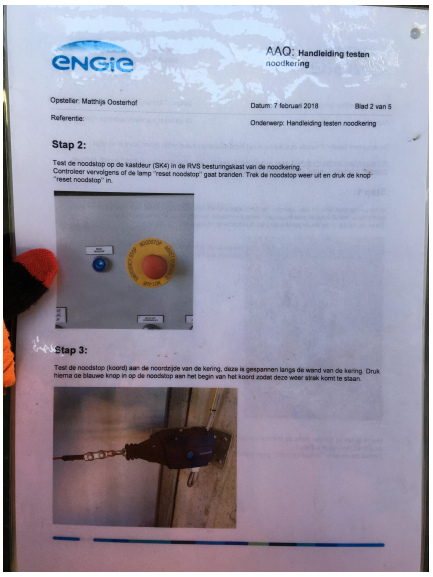
Waar: Waterwolftunnel
Wanneer: Maandag 12 april, 08:00 - 15:00
Wie: 2 inspecteurs van extern bedrijf
Wat: Maandelijkse schouw
PBM's: helm, veiligheidsjas, veiligheidsschoenen

- De maandelijkse schouw is een visuele inspectie
- De dag begint met het aanmelden van werkvergunningen bij de opzichter van de brug. Een administratieve controle van de taken die uitgevoerd gaan worden.
- Wanneer er een storing afgelezen wordt door 1 van de inspecteurs op het schermpje van een kast met apparatuur, wordt er een foto gemaakt van de melding.
- De inspecteurs zelf mogen geen reparaties oid uitvoeren als ze iets tegenkomen tijdens de schouw. Als er iets gerepareerd moet worden, dan moet dit eerste gemeld worden bij de opzichter. Die kan een vergunning aanvragen. Daarna mag het wel uitgevoerd worden.
    - Tijdens de schouw mogen ze wel een lampje vervangen.
- Alles moet worden genoteerd. Dit geldt natuurlijk voor objecten die gerepareerd moeten worden, maar ook wanneer er niks aan de hand is moet dit gemeld worden. Dit kan nog wel eens lastig zijn, aangezien elk bedrijf een ander OMS gebruikt.
    - Ook kleine dingen moeten genoteerd worden, echter gebeurt dit niet altijd verteld de opzichter, omdat daar het nut niet van wordt gezien.
- Het vinden van bepaalde dingen is lastig voor een externe werknemer. Denk hierbij bij kleine dingen zoals een toilet.
    - Zowel de externe inspecteur als monteur die de locatie niet kent ervaren hier moeilijkheden.
    - Dit is iets wat ik overhoord heb tijdens een gesprek tussen inspecteur en monteur.

- Als iets vervangen of aangepast wordt/is, moet dit gemeld en doorgegeven worden.
    - De tekeningen moeten dan namelijk met de hand aangepast worden. Als dit niet gebeurt ontstaan er problemen in de toekomst. De tekeningen moeten actueel zijn om nuttig te zijn.
- Alle bouwobjecten zijn gelabeld met een bordje waarop de bijbehorende code staat. Deze code is of een referentie naar de decompositie of naar de bouwtekening.
    - Bijv. K50326 → K = relais, 503 = pagina nr., 26 = specifiek object
        - Ik weet niet meer precies wat wat is, maar iets wat hierop lijkt. Het helpt om makkelijk iets terug te vinden in de fysieke documenten die aanwezig zijn.

- 
- Bij sommige objecten liggen papieren boekjes die de bijbehorenden documentatie bevatten (bouwtekeningen, instructies etc.)
    - Wanneer er iets aangepast wordt aan het object, moet de tekening ook aangepast worden. Deze moet dan ook nog geprint en in het boekje gedaan worden. Zodat het boekje weer up to date is.
- Het is niet altijd duidelijk of werkorders al gemeld of uitgevoerd zijn.
    - Is dit probleem al gemeld, maar nog niet gemaakt?
    - Is het wel al gemaakt?
    - Veel onduidelijkheid
- Er is ook onduidelijkheid over bepaalde acties; de verwarming stond ergens uit, maar waarom staat de verwarming uit? Is deze stuk? Is dit express gedaan?
    - Om dit te controleren moet er naar de PLC gekeken worden. Maar dat kan alleen op een computer en niet hier. Daarom maar een foto maken van de melding die het scherm aangeeft en later controleren op kantoor.
    - Waar wordt de temperatuur eigenlijk gemeten?
- Normaal gesproken worden er labels gebruikt om bepaalde acties uit te leggen. De mededeling wordt op het label geschreven en gehangen aan desbetreffende object.
    - Op deze manier communiceren ze met elkaar.
- De papieren map met documentatie valt uit elkaar, er zit teveel in denk ik.
    - Muizen eten het papier ook op. Daarom staan er echt overal muizenvallen.

- 

- Bij sommige objecten moeten wat dingen aangezet worden. Hiervoor is een stappenplan aanwezig.
  - 

Overige notities

- Ze hebben niet altijd overal bereik of internet. Over het algemeen wel, maar met al die betonnen constructies om je heen wordt het wel lastig.

    - Ik probeerde op mijn mobiel een weer app te laden terwijl we binnen in een besloten ruimte waren. Echter was dit erg traag. Toen we boven kwamen deed'ie het wel direct.
- Tijdens een inspectie ben je niet altijd binnen. We zijn ook een paar keer buiten geweest om te inspecteren. Echter was het koud, sneeuwde/hagel/regende het. De interactie technologie die aan de DT komt te hangen moet hier wel tegen kunnen.
    - Ook zijn de dagen lang. De accu moet dus ook wel een tijdje mee gaan.
- Het trainen van nieuwe inspecteurs en tunnel operators is erg belangrijk. Wanneer ze niet bekend zijn met de tunnel missen ze vertrouwen, kunnen ze dingen niet snel regelen. Dit vertraagd de overige inspecteurs. Erg vervelend, want tijd is kostbaar.

Op een paar punten kan de DT denk ik ondersteunen:

- Op het moment hangen er overal papieren boekjes met documentatie over het betreffende object. Dat is natuurlijk veel handiger om digitaal te hebben. Kan niet opgegeten worden door beesten en is altijd up to date
- Als er nu iets gevonden was wat stuk was, wisten ze nooit zeker of dit al gemeld was/er al een reparateur langs geweest was. Het is denk ik ook handig om de werkorders aan een bouwobject te hangen, zodat je dit kan zien
- Sommige objecten zijn eigenlijk nooit echt stuk maar moeten toch altijd gecontroleerd worden. Voor dit soort objecten is het makkelijk om er een sensor/camera oid aan te hangen, zodat je het van afstand in de DT kan zien en niet helemaal naar de locatie hoeft. Scheelt veel tijd!
- Wat ook veel tijd kost zijn nieuwe mensen. Het zou voor hun vertrouwen en efficiëntie erg nuttig zijn om in de DT alvast bekend te worden met een asset; er doorheen kunnen lopen, kijken waar bepaalde dingen zitten etc.
- Ik hoorde ze ook klagen over dat (zowel monteurs als inspecteurs) ze niet goed weten waar wat is. Het zou makkelijk zijn als ze DT kunnen gebruiken om snel te zien waar bijv. een toilet oid
- Het aanmaken van tickets (werk orders) kost nu veel tijd en kan pas na het afronden van de inspectie gestart worden op de computer. Het zou veel tijd schelen en het een stuk makkelijker maken als dit ter plekke gedaan kan worden doormiddel van de DT.
- Het is niet altijd duidelijk wat van welke asset owner is en dus geïnspecteerd moet worden. Het zou handig zijn om dat te kunnen controleren in de DT.

B Asset owner requirements

Overzicht mogelijkheden Digital Twin

Nr.	Instantie	Functie	belangrijk in model
1	RWS, Onderhouds aannemer	Beheerder, projectleider en technisch coördinator	Risico's tav de functie van het object, hierbij is de toestandindicatie van cruciale onderdelen belangrijk. Bijvoorbeeld: - Het brugdek is zodanig versleten dat het wegverkeer er doorheen kan zakken of - De aandrijving van een beweegbare brug is in slechte staat, slijtage in de lagers van een draaipunt.
2	RWS, Onderhouds aannemer	Beheerder, projectleider en technisch coördinator	Overzicht en lokatie van de storingen, daarnaast kunnen de storingsmeldingen worden geanalyseerd, waar dan weer predictive maintenance kan worden toegepast.
3	RWS, Onderhouds aannemer	Beheerder, projectleider en technisch coördinator	De fasering van de werkzaamheden in bijvoorbeeld een weekend dat de brug is afgesloten. Door middel van kleuren die corresponderen met tijden geeft dit een goed overzicht van de fasering.
4	RWS, Onderhouds aannemer	Beheerder, projectleider en technisch coördinator	In hoeverre is het object circulair opgebouwd. Materialenpaspoort, aan de kleur is te zien in hoeverre de materialen te hergebruiken zijn (circulair).
5	RWS, Onderhouds aannemer	Beheerder, projectleider en technisch coördinator	Energieverbruik zowel dasboards als in detail per onderdeel.
6	RWS, Onderhouds aannemer	Beheerder, projectleider en technisch coördinator	Op welke lokaties zijn er gevarenzones ten aanzien van machineveiligheid. Op basis van deze informatie kan een instructie worden gegeven aan personen die het object gaan bezoeken (soort safety walk).
7	RWS	Projectmanager of hoofdbeheerder district	Per intem kan een dasbord worden weergegeven: - de risico's tav de functie van het object - het energieverbruik - de storingen - het aantal brugprocessen - mate van circulariteit
8	RWS	Projectmanager of hoofdbeheerder district	Realtime informatie t.a.v. bijvoorbeeld uitzetten brugdek, scheefstand toren en landhoofden, trillingen in de constructie.
9			

C Requirements

3.1 Final requirements

These requirements apply to all users.

- The DT should be up-to-date, identical to the physical asset
- The DT needs a connection with OMS
    - Also connection model of asset with OMS
- There should be a detailed and complete decomposition
    - Incorporate linking and brushing technique (when an object in decomposition is selected, visualize the according object in the digital model)
- Monitoring: Allow for data analysis for predictive maintenance (Overview of multiple data sources like condition scores, sensor data, malfunctions, new working orders, historic data)
- Personalization:
    - Flexible UI design, allow turning off/on modules
    - Personalized restricted access
- Functionalities:
    - Search
        - Search for (a) specific object(s)
        - Search for a specific document
        - Filter objects with certain risk / condition score
    - Notifications
        - Be able to create a personal message/notification for another user using tags
        - Of malfunctions
    - Visualization
        - Highlight objects
            - That contain an important note
            - That need to be inspected
            - That lack data
        - Of real time data (sensor data)
            - Overall level (Be able to compare data sources by combining them in a graph)
            - Object level
        - Of malfunctions and the type of malfunction
        - Of condition /risk scores of objects
        - Of risks and danger zones
        - Work orders
        - Be able to visualize parts and mechanics that are covered (see-through mode)
    - Add note to object
        - Label note
    - Creation of personal task list
        - Add a priority level parameter to task
        - Filter / order tasks based on priority level

Interaction Technology

- Should contain a model/visualization of asset
- Be able to virtually ‘walk through’ asset
- Performance of the DT itself should be ‘quick’
- Wide camera viewing angle
- Technology should be portable
- Enable communication between multiple stakeholders
    - Visualize head- and/or eye-gaze of user
    - Share perspectives by aligning views, while still remaining an independent head orientation (independent and shared FoV)

DT on-site use

- Camera
    - To take and save pictures
    - To scan markers from objects
- Be capable of tracking physical location in asset
- A DT that is used on-site needs to be safe to use in this environment
- The DT should be able to deal with
    - Harsh weather conditions
    - Loud noises
    - Bad connectivity
    - Bright light (overcome visibility issues)
- Offline use of DT ?

DT office use

- The DT should enable looking at the asset from all sides.
- A remote expert should be able to highlight points of interest for other users
- Obtain quick insights about state asset

UI

- Should be user friendly and easy to use
- Instructions should be visualized as static models
    - user should be able to turn visual instructions on/off
- Modular UI
    - Turn UI modules on/off
- Transparent overlays of task-relevant material
- Indicate which objects could be interacted with
    - Color change when object is selected
- Indicate off-screen objects or events (via tactile or auditory feedback?)

Interaction

- Pointing ray
- Be able to interact with objects in the scene

- Integrate dynamic gestures that are in line with people's usual way of interacting
- Intuitive remote collaboration
- Be able to 'select' an object
    - Obtain its code
    - Inclusion of instruction manuals, connected to the related object
    - Related documentation

3.2 Profile based requirements

These requirements only apply to one or multiple profiles.

1. Inspector (external)
2. Inspector (Arcadis)
3. Asset manager (small asset)
4. Asset manager (large asset)
5. Risk analyst
6. Asset owner

Requirement	1	2	3	4	5	6
Work permit: - Check work permits - Request work permit						
Inspection: - Data registration should be consistent and as detailed and structured as possible. (ordered steps to register observations in a structured manner) - Register data in OMS for a single or multiple objects - Visualize objects that need to be tested for inspection ? - Give notification when changes/additions are made in the DT during use - Visualize only objects that are related to relevant asset owner - Register LMRA - Register that you are on-site - Sign off when you leave the on-site location						
Changes in asset - Give notification when a change in the digital model is made - Visualize changed objects						
Document management - Obtain documents that correspond to a selected object - Make changes in documents - Version control of documents - A structured and complete document management system						

Working order: - Visualize objects that got a new working order assigned to - Give notification when a new working order is created - Filter on type of work order ?						
Assign risk/condition score to object						
Connection with IMA						
Access to: - Maintenance planning - External documents - Inventory management - Critical parts document						
FMECA						
Overview of people that are on-site						
Visualize the different phases of maintenance						
Circular: - Visualize for each object state of material - Filter on a certain state / material						
Amount of (bridge)processes						

D Information Architecture

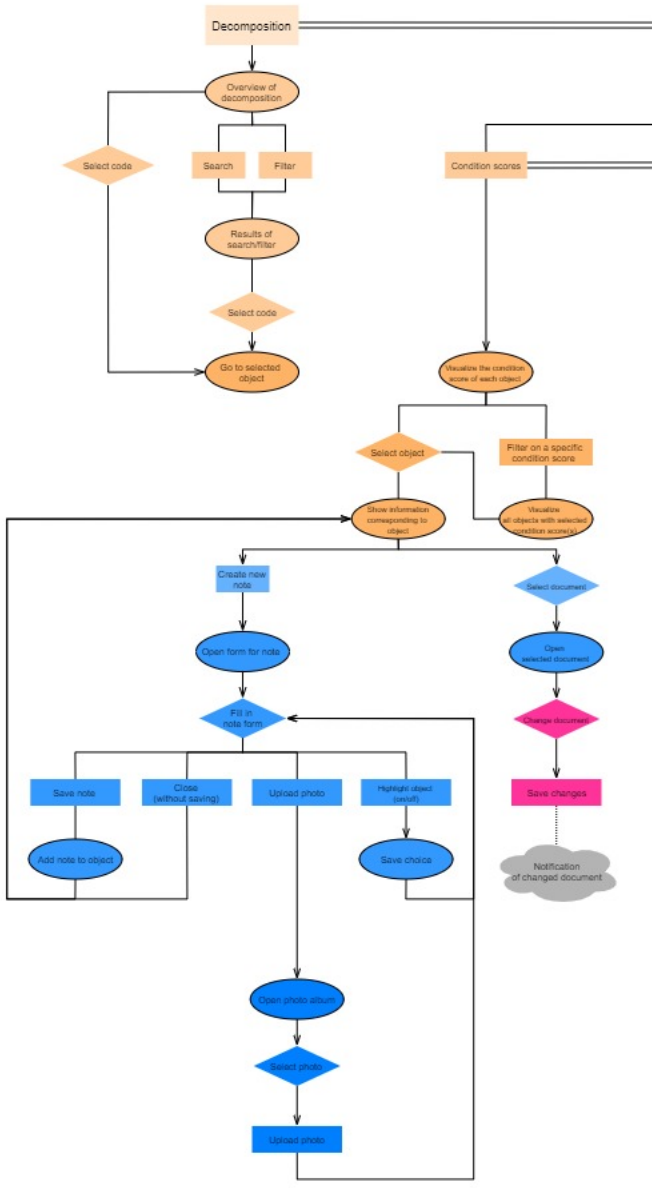
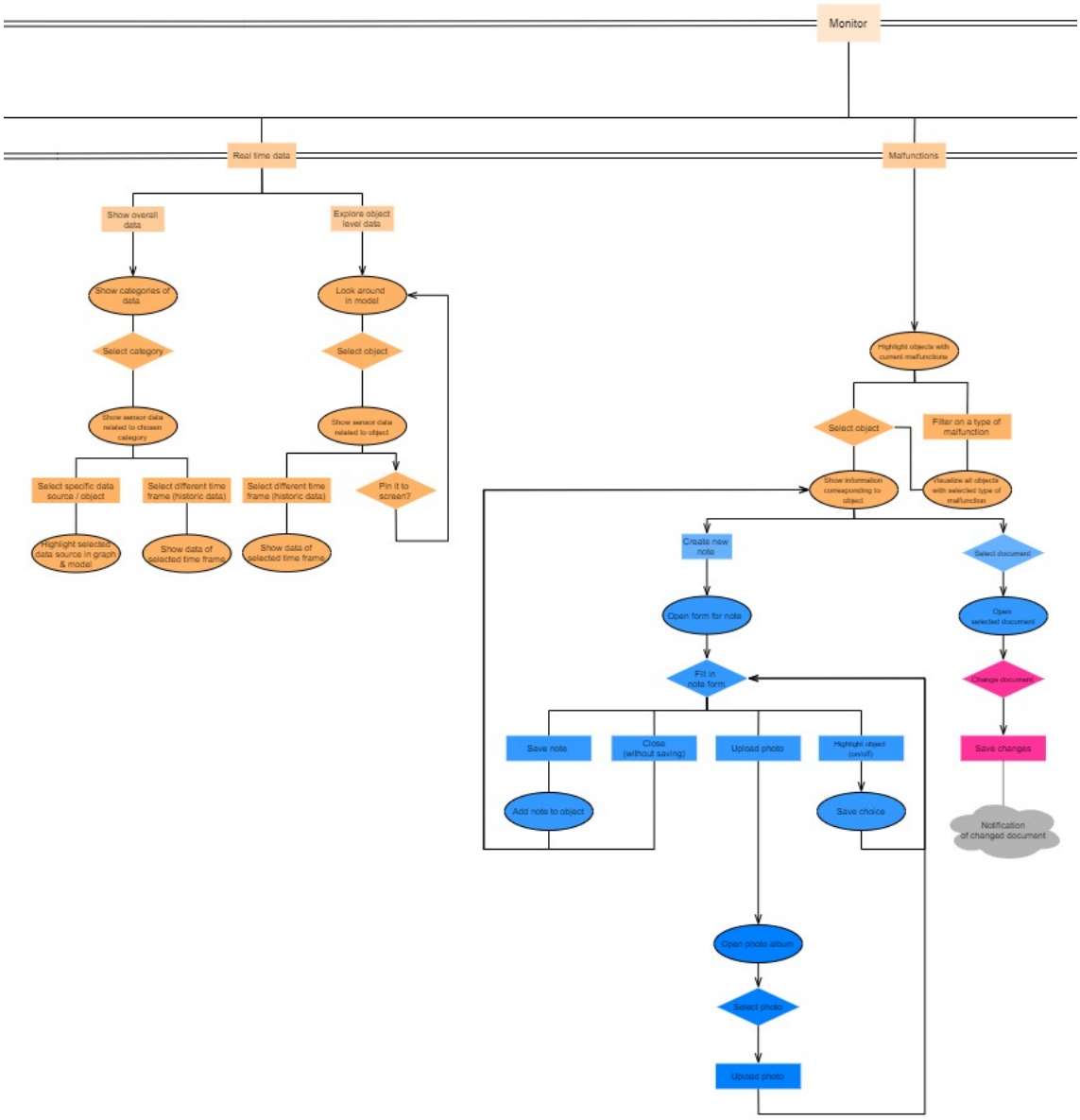
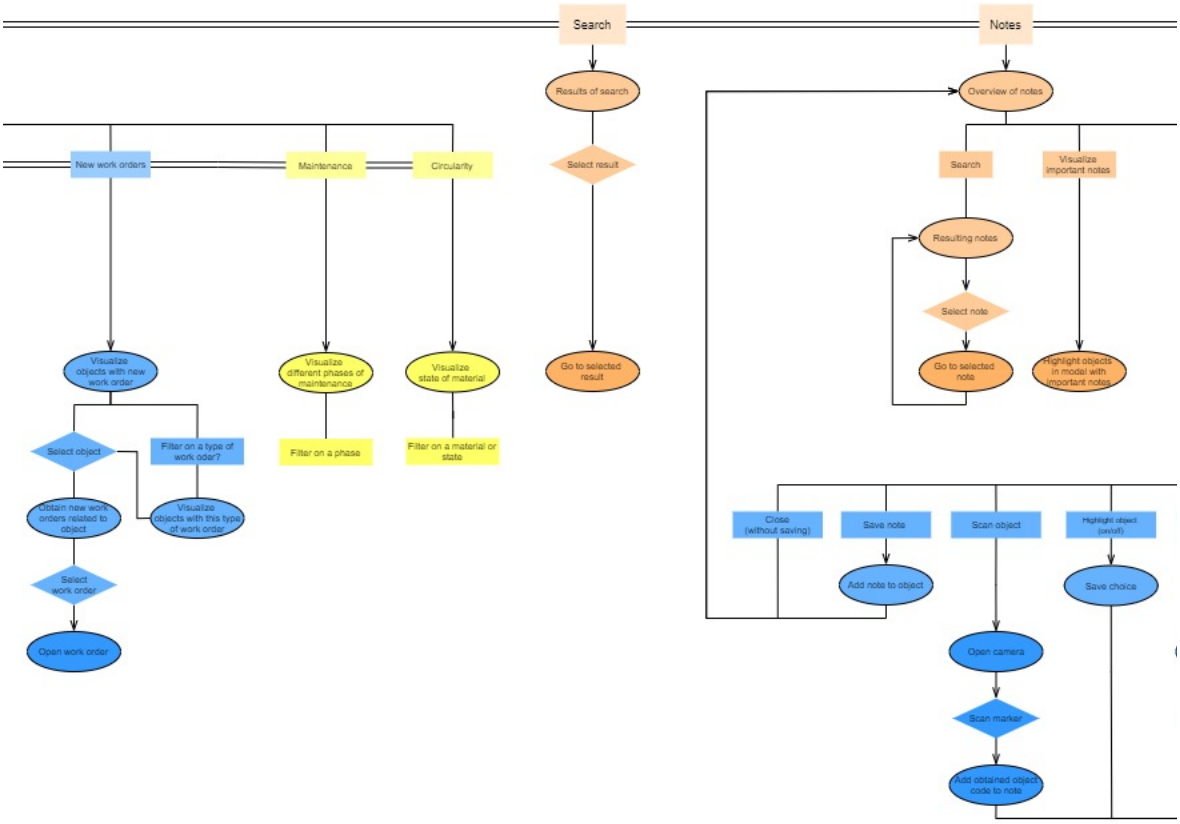
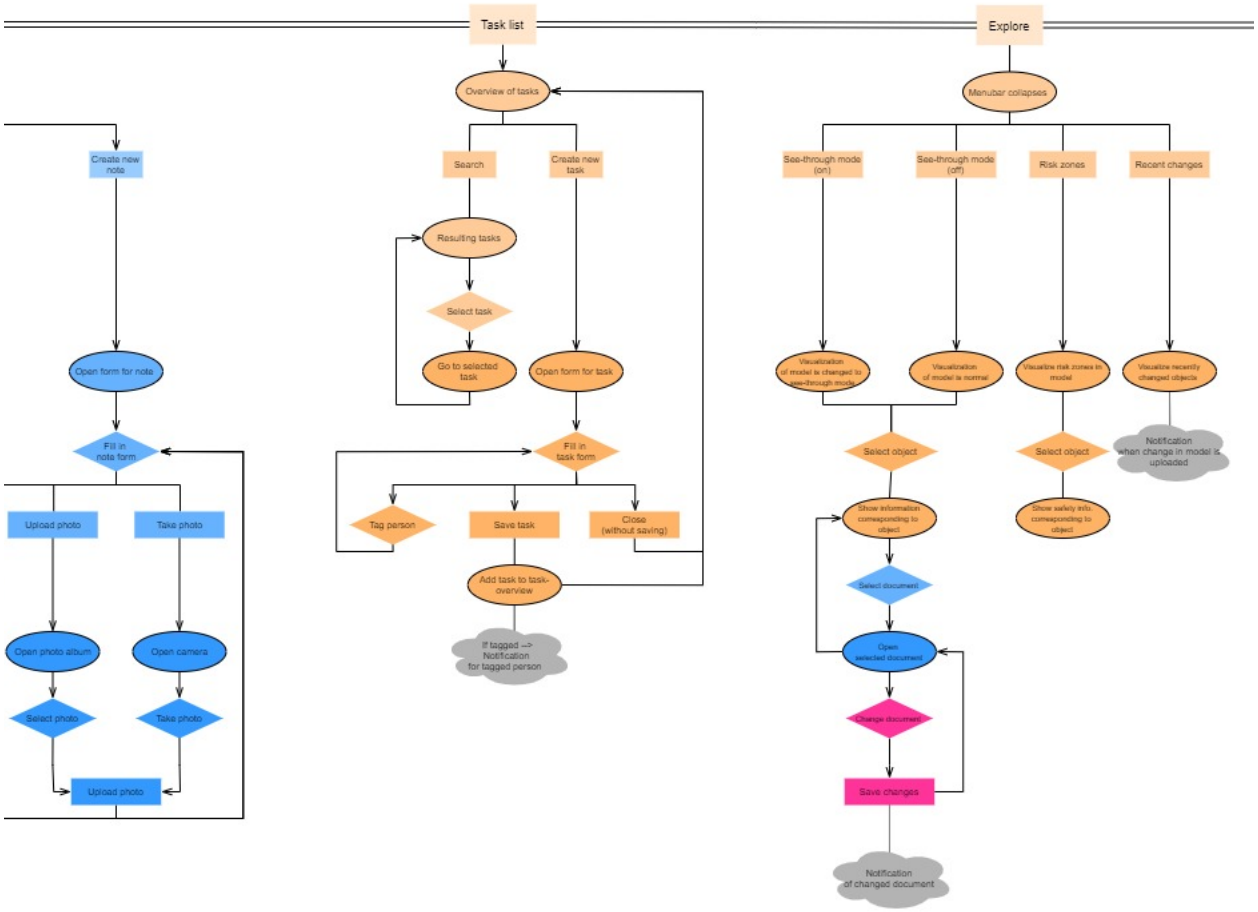
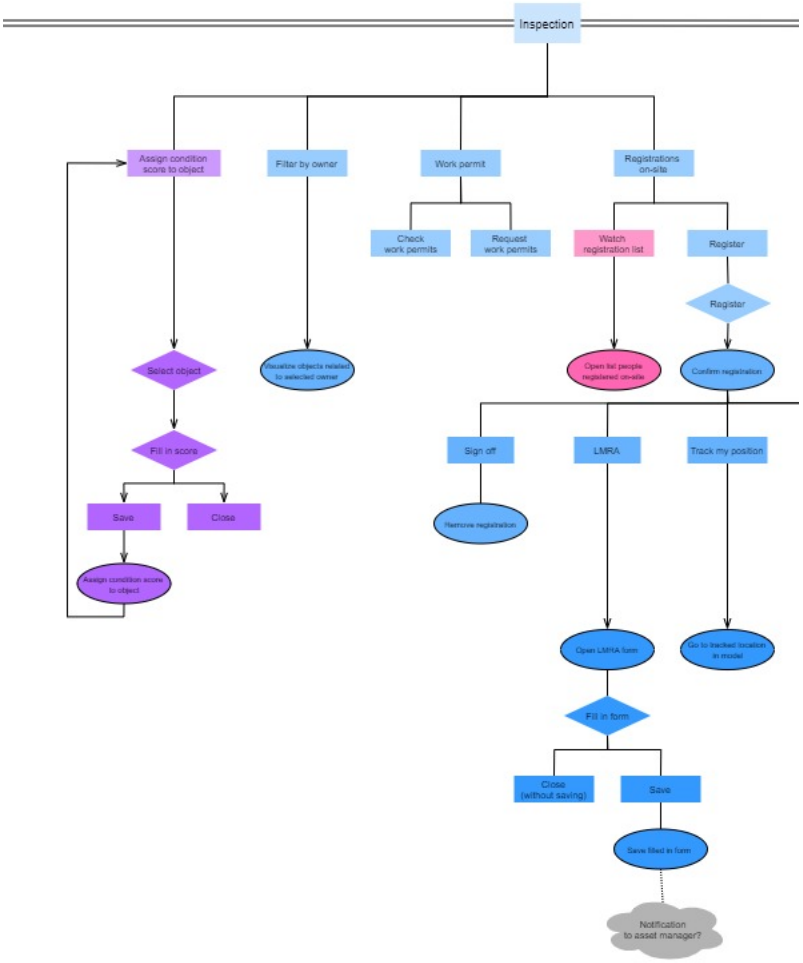


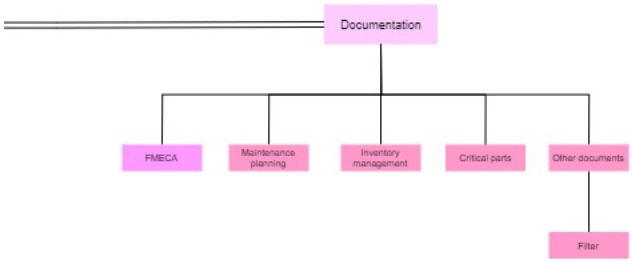
Figure 27: Information Architecture of the project. Continues in next pages.

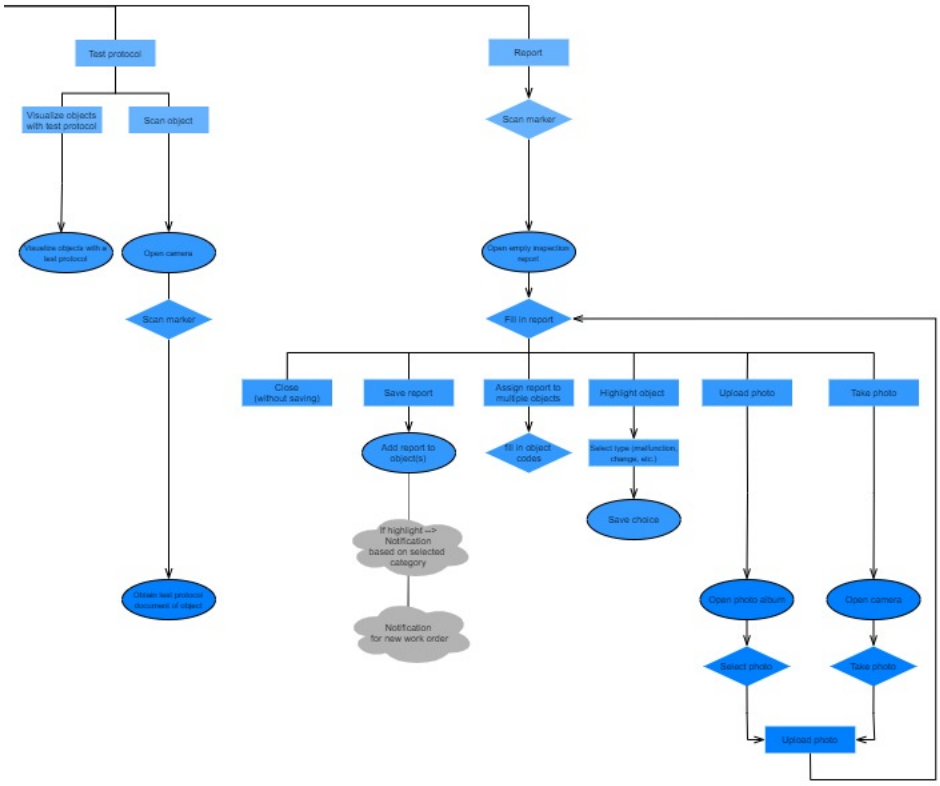

Monitor
Real time data
Malfunctions
Show overall data
Explore object level data
Show categories of data
Select category
Show sensor data related to chosen category
Select specific data source / object
Select different time frame (historic data)
Highlight selected data source in graph & model
Show data of selected time frame
Look around in model
Select object
Show sensor data related to object
Select different time frame (historic data)
Pin it to screen?
Show data of selected time frame
Highlight objects with current malfunctions
Select object
Filter on a type of malfunction
Show information corresponding to object
Visualize all objects with selected type of malfunction
Create new note
Open form for note
Fill in note form
Save note
Close (without saving)
Upload photo
Highlight object (on/off)
Add note to object
Save choice
Open photo album
Select photo
Upload photo
Select document
Open selected document
Change document
Save changes
Notification of changed document


Search
Notes
Results of search
Overview of notes
New work orders
Maintenance
Circularity
Select result
Search
Visualize important notes
Resulting notes
Select note
Visualize objects with new work order
Visualize different phases of maintenance
Visualize state of material
Go to selected result
Go to selected note
Highlight objects in model with important notes
Select object
Filter on a type of work order?
Filter on a phase
Filter on a material or state
Obtain new work orders related to object
Visualize objects with this type of work order
Close (without saving)
Save note
Scan object
Highlight object (result)
Select work order
Add note to object
Save choice
Open work order
Open camera
Scan marker
Add obtained object code to note


Task list
Explore
Overview of tasks
Menubar collapses
Create new note
Search
Create new task
See-through mode (on)
See-through mode (off)
Risk zones
Recent changes
Resulting tasks
Select task
Go to selected task
Open form for task
Open form for note
Fill in note form
Fill in task form
Upload photo
Take photo
Tag person
Save task
Close (without saving)
Add task to task-overview
If tagged --> Notification for tagged person
Select object
Show information corresponding to object
Select document
Open selected document
Change document
Save changes
Notification of changed document
Notification when change in model is uploaded
Open photo album
Open camera
Select photo
Take photo
Upload photo


Inspection
Assign condition score to object
Filter by owner
Work permit
Registrations on-site
Check work permits
Request work permits
Watch registration list
Register
Register
Select object
Open list people registered on-site
Confirm registration
Fill in score
Sign off
LMRA
Track my position
Save
Close
Remove registration
Open LMRA form
Fill in form
Close (without saving)
Save
Save filled in form
Notification to asset manager?


Documentation
FMECA
Maintenance planning
Inventory management
Critical parts
Other documents
Filter


Test protocol
Visualize objects with test protocol
Scan object
Visualize objects with t test protocol
Open camera
Scan marker
Obtain test protocol document of object
Report
Scan marker
Open empty inspection report
Fill in report
Close (without saving)
Save report
Assign report to multiple objects
Highlight object
Upload photo
Take photo
Add report to object(s)
If highlight -> Notification based on selected category
Notification for new work order
fill in object codes
Select type (malfunction change, etc.)
Save choice
Open photo album
Open camera
Select photo
Take photo
Upload photo

E Information brochure for usability study

Informatie over onderzoek

Arcadis is op het moment bezig met het ontwikkelen van een Digital Twin (DT). Deze is echter op het moment nog niet gebruikersvriendelijk en daarom gaat mijn afstudeeropdracht over hoe de DT dit wil kan worden. Aan de hand van mijn vooronderzoek heb ik gebruikersprofielen gedefinieerd. Ik wil gaan onderzoeken of het opsplitsen van de interface van de DT, op basis van deze profielen, ervoor zorgt dat de DT gebruiker beter ondersteund kan worden.

Om te controleren of de ontworpen interfaces compleet zijn en goed aansluiten bij de profielen in kwestie, heb ik een prototype gemaakt. Deze krijgt u zo te zien. U mag straks door het prototype heen klikken, aan de hand van taken en vragen. Aan het eind krijgt u de kans om vrij rond te klikken en feedback te geven.

Zodra er op ‘verder’ geklikt wordt, krijgt u de vraag of u toestemming geeft om uw verkregen data te gebruiken voor dit onderzoek. Wanneer u geen toestemming geeft kan u dit tabblad sluiten. Met toestemming zal vervolgens automatisch een schermopname starten van alleen deze applicatie, zodat ik terug kan kijken of en waar problemen ontstaan. Alleen deze applicatie wordt opgenomen, alles wat u buiten dit tabblad doet wordt niet opgenomen. Dus audio wordt niet opgenomen en ook aangesloten camera's aan je computer zullen niks opnemen. Zodra u de vragen heeft afgerond of het tabblad wegklikt stopt de opname automatisch.

De data die wordt verzameld is volledig anoniem. Tijdens het onderzoek mag u zich altijd terugtrekken van uw deelname. In dat geval zal ik de data verwijderen. Ook na het beëindigen van het onderzoek kan u aangeven dat u liever niet meer deel neemt en de data zal worden verwijdert.

Contact

Onderzoeker

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Onafhankelijk contact

Wanneer u vragen hebt over uw rechten als deelnemer aan dit onderzoek, meer informatie wilt, of uw zorgen over dit onderzoek wilt bespreken met iemand anders dan de onderzoeker, kunt u contact opnemen met het secretariaat van de ethiek commissie “Elektrotechniek, Wiskunde en Informatica” van de Universiteit Twente.

Mail: ethicscommittee-cis@utwente.nl

F Session usability study

F.1 Introduction questions

- Hereby I give permission to use my required data for this research. Moreover, I hereby state that I will not share the link to this usability test with anyone else.
  - *Yes*
  - *No*
- Give yourself a nickname (If you want to delete your data after completion, I am able find your data again)
- Which of the following profiles best describes your job description?
  - Asset manager
  - Risk analyst
  - Inspector
  - Asset owner
  - Operator
  - External stakeholder
- Which modules seem interesting to you to include in your Digital Twin? *(You can select more than one)*
  - Document management
  - Inspection
  - Note creation
  - New work orders
  - Maintenance
  - Circularity

F.2 Tasks

1. Select the profile for operator or external stakeholder.
2. Navigate to a specific object in the decomposition.
3. Filter the asset on objects with a good condition.
4. Find out what is wrong with 'wegdek A16'.

5. Navigate to the real-time vibration values of the asset.
6. Select the yellow line in Group B to show its related object.
7. Search for ‘wood fender’ with type ‘wrijfstijl’.
8. Find out if there are any importants notes attached to objects in the asset.
9. Check out which tasks you still have to do.
10. Switch the model of the asset to see-through mode, to see hidden and dynamic objects.
11. Find out what protection gear you have to wear in the low risks zones of the asset.
12. Select the profile for asset owner.
13. Navigate to monitor to see which extra modules are added.
14. Select the inspector profile.
15. Check your work permits.
16. The inspection is commissioned by the ’gemeente Nissewaard’. Check out which parts of the asset they own.
17. Almost ready to start the inspection, first register that you will be on-site.
18. We can start inspecting now. Navigate to the test protocol of the boom barriers (slagbomen).
19. Hmm, it looks like something is broken here. Report it.
20. Select the risk analyst profile.
21. Navigate to the FMECA file.
22. Based on our previous inspection, we found that a boom barrier was broken. Thus, change its condition score.
23. Select the asset manager profile.
24. Check out the documentation management.
25. One of the documents needs some changes. Edit a document.
26. Documents can also be attached to an object. Select an object to see which documents are attached.
27. Before you end your work day, do a quick check to see if everyone left the asset.

F.3 System Usability Scale (SUS)

The questions can be answered using a 5 point Likert-scale, in which 1 responds to *Strongly disagree* and 5 to *Strongly agree*.

1. I think that I would like to use this system frequently.
2. I found the system unnecessarily complex.
3. I thought the system was easy to use.
4. I think that I would need the support of a technical person to be able to use this system.
5. I found the various functions in this system were well integrated.
6. I felt very confident using the system.
7. I thought there was too much inconsistency in this system.
8. I would imagine that most people would learn to use this system very quickly.
9. I found the system very cumbersome to use.
10. I needed to learn a lot of things before I could get going with this system.

F.4 Experience survey

The questions can be answered using a 5 point Likert-scale, in which 1 responds to *Strongly disagree* and 5 to *Strongly agree*.

1. The naming of the items in the system were clear to me.
2. I feel like the content of my profile is complete.
3. I feel like the content of my profile is well organized.
4. I think that being able to turn on/off modules in the interface is useful.
5. I would adapt the interface based on my task by turning on/off modules.
6. I feel like I completed the tasks perfectly.
7. The tasks I just completed correlate to the task I face during my job.
8. I feel like the system contains the data and functionalities I need to do my job efficiently and effectively.
9. Using the system was confusing to me.
10. While using the system I felt insecure, discouraged, irritated, stressed, or annoyed.

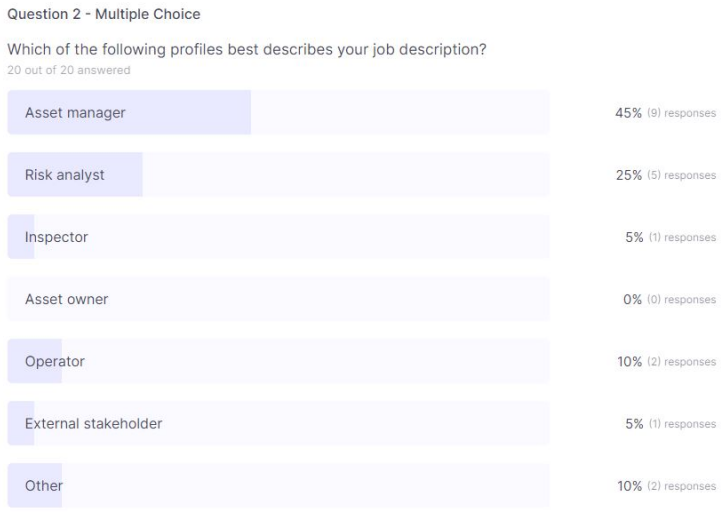
F.5 Feedback

The following questions are open-ended questions.

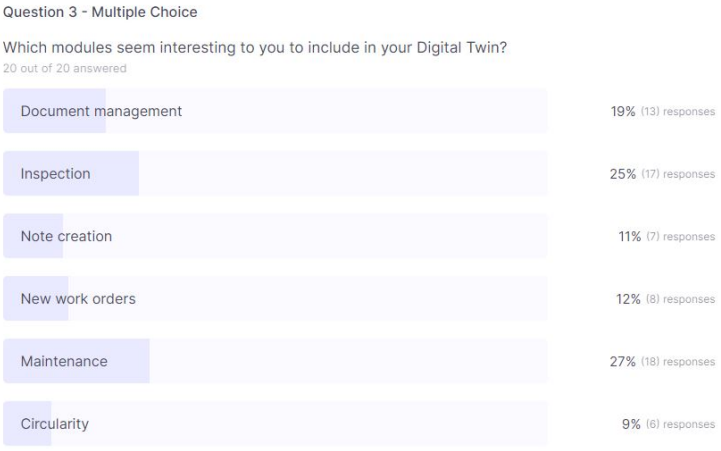
1. Is there anything that can be left out? If yes, please shortly explain why.
2. Is there something that should be included? If yes, please shortly explain why.
3. Do you have any other comments?

G Usability study results

G.1 Introduction questions

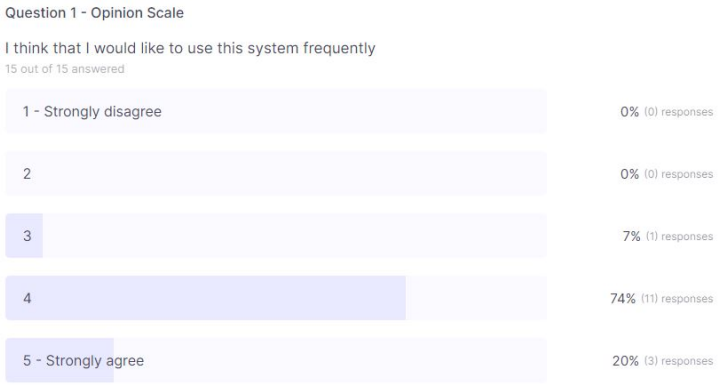


(a) Participants job description results



(b) Modules of interest results

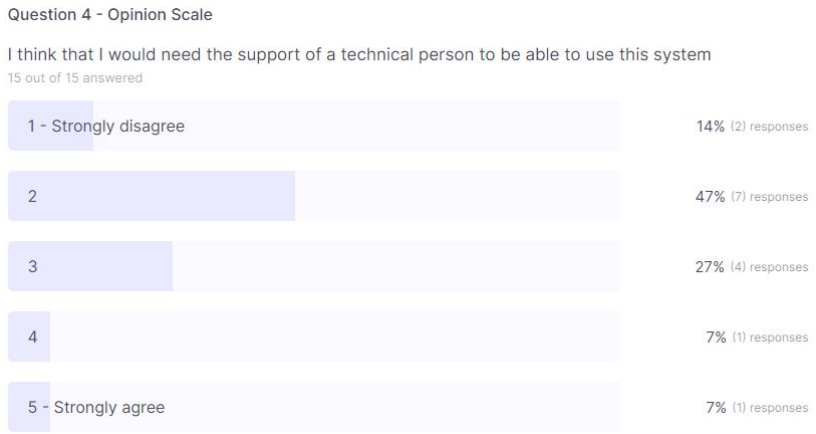
G.2 SUS



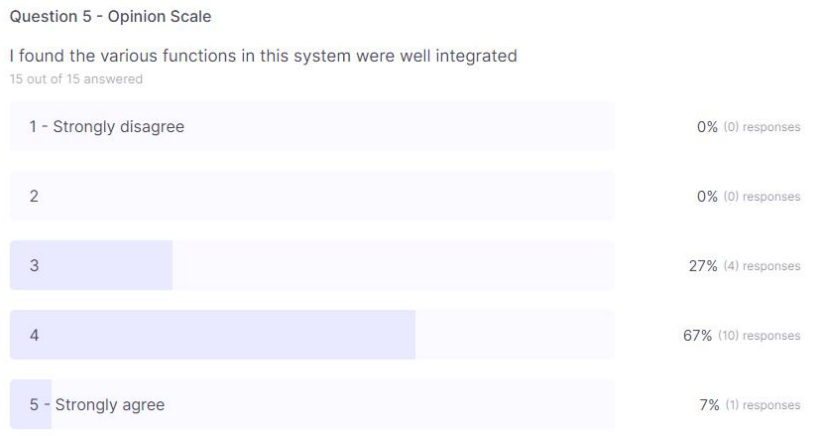
(a) SUS Question 1

(b) SUS Question 2

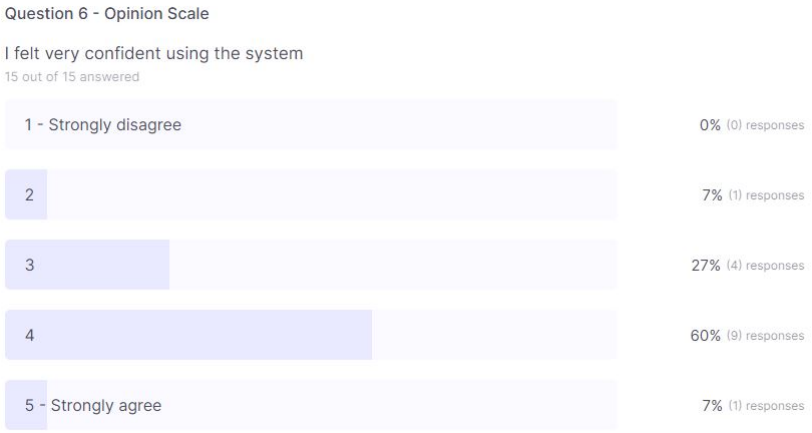
(a) SUS Question 3



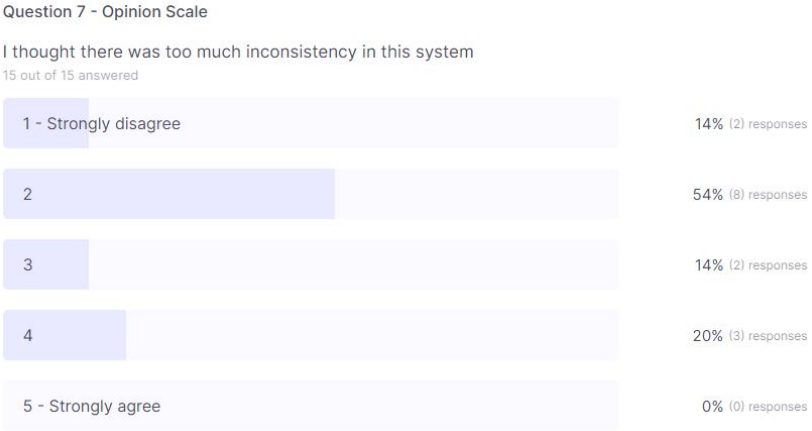
(b) SUS Question 4



(c) SUS Question 5



(a) SUS Question 6



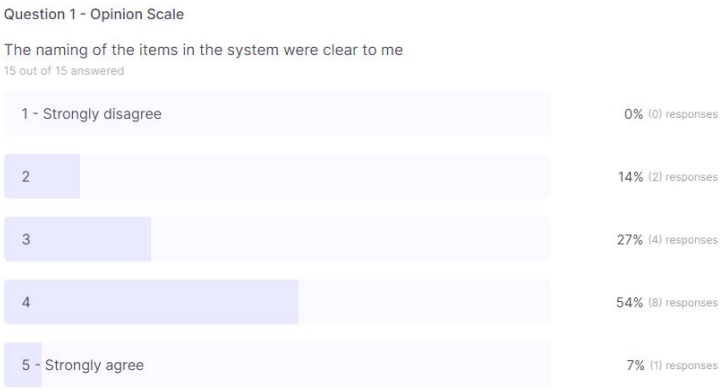
(b) SUS Question 7

(c) SUS Question 8

(a) SUS Question 9

(b) SUS Question 10

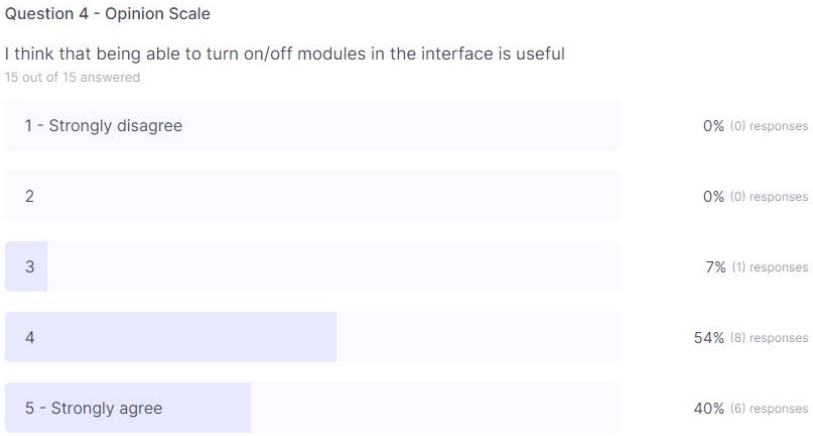
G.3 Experience survey



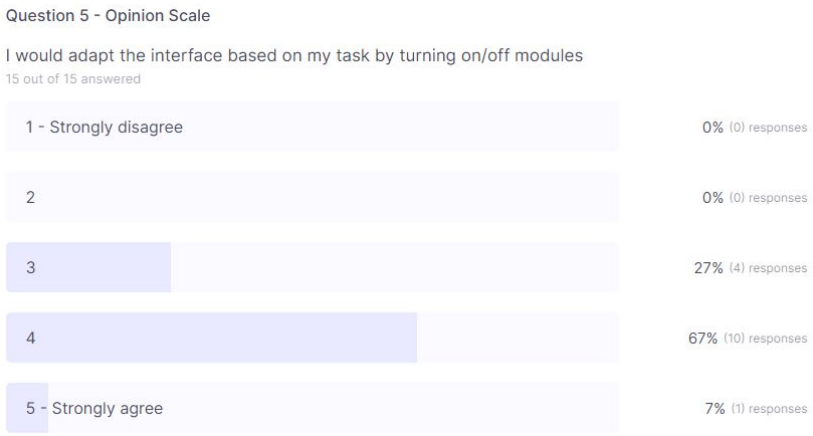
(a) Experience Question 1

(b) Experience Question 2

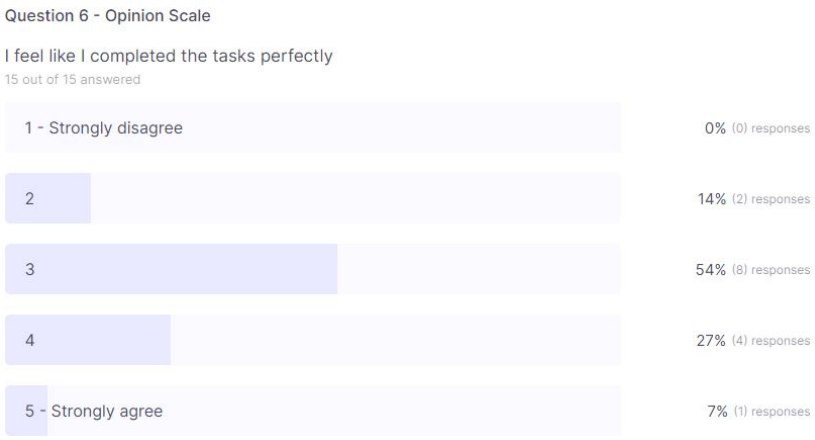
(a) Experience Question 3



(b) Experience Question 4



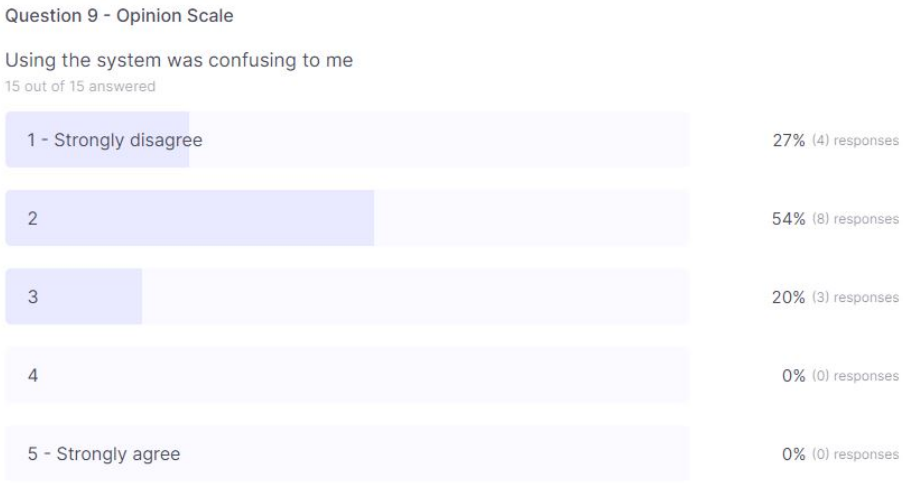
(c) Experience Question 5



(a) Experience Question 6

(b) Experience Question 7

(c) Experience Question 8



(a) Experience Question 9

(b) Experience Question 10

G.4 Feedback

Question 1: Is there anything that can be left out? If yes, please shortly explain why.

- I would like to add the information need of an Asset Manager to optimize value an costs. I saw more relevant information for execution of inspections. I would like to add risk profiles, performance of assets and costs
- what is not usefull for mee could be usefull for someone else
- Not that Ive seen
- 5465
- no
- No
- No
- The interface itself works good, think it's more user friendly then some of the digital twin platforms we've developed so far. Do have some questions about the feasibility, since many of the functionalities are related to organizational processes that are hosted in source systems at clients. And connected to internal and execution policies.
- Nee, volgens mij is alles relevant.
- Advies; is om een korte introductie te geven, zou een video kunnen zijn maar denk beter is een real time sessie met iemand met kennis van zake.

Question 2: Is there something that should be included? If yes, please shortly explain why.

- Looks like not all functions were working, for example navigating through the 3D visualisation. I would like to have that function.
- The options should pop up in an orderly manner. In the current situation you have boxes next to each other, there are randomly positioned in the screen. I would order them in alphabetical order or functional order
- Informatie over uitgevoerd onderhoud kon ik niet direct terugvinden. Alleen de storingen. Het zou handig zijn om te weten wanneer iets is onderhouden, en wanneer het weer op de planning staat om onderhouden te worden.
- Maybe a button that links to a complete manual or instruction video

- yes, helpfile within the system
- I would like to add the information need of an Asset Manager to optimize value an costs. I saw more relevant information for execution of inspections. I would like to add risk profiles, performance of assets and costs
- Dit is hele goede visualisatie wat allemaal mogelijk is, afhankelijk van de rol van de persoon bij OG kunnen tools worden uitgebreid.
- productinformation of parts
- No
- Looks project specific, think making it work generic (not having to do project specific development) would be of great added value.

Question 3: Do you have any other comments?

- Nice DT! The system should be flexible to change to client needs ore business oportunities
- It is good to do this survey. Pleas continue with this.
- Hou goed contact met de daadwerkelijke gebruiker tav verschillende wensen, ook te aanzien van presentatie.
- I really liked the experience, Well done!
- testing with a real dynamic model will give some extra experiance

Informatie over onderzoek

Arcadis is op het moment bezig met het ontwikkelen van een Digital Twin (DT). Deze is echter op het moment nog niet gebruikersvriendelijk en daarom gaat mijn afstudeeropdracht over hoe de DT dit wel kan worden. Aan de hand van mijn vooronderzoek heb ik gebruikersprofielen gedefinieerd. Ik wil gaan onderzoeken of het opsplitsen van de interface van de DT, op basis van deze profielen, ervoor zorgt dat de DT-gebruiker beter ondersteund kan worden.

Daarnaast wil ik weten wat voor technologie het best ingezet kan worden om zo goed mogelijk met de DT te kunnen werken. Daarom heb ik een prototype gemaak op de Hololens die een onderhouds route visualiseert. Ook wil ik een bestaande app (Microsoft 365 Remote Assist) testen om het samenwerken op afstand te ervaren met de Hololens. Het is de bedoeling dat het prototype en de Remote Assist app straks geprobeerd worden, terwijl ik zal observeren hoe het gaat. Deze observaties schrijf ik op en gebruik ik in mijn onderzoek om te bepalen hoe de digital twin het best ingezet kan worden om uiteindelijk bij inspecties te ondersteunen. Om er zeker van te zijn dat ik alles heb begrepen en een compleet beeld verkregen heb, zou ik ook graag wat vragen willen stellen in een interview. De verkregen informatie zal anoniem gebruikt worden in het verslag. De complete sessie zal ongeveer 45-60 min. duren.

De data is volledig anoniem. Tijdens het onderzoek mag u zich altijd terugtrekken van uw deelname. In dat geval zal ik de data verwijderen. Ook na het beëindigen van het onderzoek kan u aangeven dat u liever niet meer deel neemt en de data zal worden verwijdert.

Contact

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Onafhankelijk contact

Wanneer u vragen hebt over uw rechten als deelnemer aan dit onderzoek, meer informatie wilt, of uw zorgen over dit onderzoek wilt bespreken met iemand anders dan de onderzoeker, kunt u contact opnemen met het secretariaat van de ethiek commissie “Elektrotechniek, Wiskunde en Informatica” van de Universiteit Twente.

Mail: ethicscommittee-cis@utwente.nl

I Consent form for user study

Toestemmingsformulier deelname studie

Ik begrijp de informatie over de studie waar ik vandaag aan deelneem. Ik heb vragen kunnen stellen en mijn vragen zijn naar mijn tevredenheid beantwoord.

O Ja **O** Nee

Ik geef vrijwillig toestemming om deel te nemen in dit onderzoek en ik begrijp dat ik vragen niet hoef te beantwoorden, en dat ik elk moment mijn deelname kan intrekken zonder reden aan te hoeven geven.

O Ja **O** Nee

Toestemming

Hierbij geef ik _____, op ___-___-2021, toestemming om de

verkregen data van deze user study te gebruiken voor dit onderzoek.

Handtekening onderzoeker

_____

Handtekening deelnemer

_____

Contact

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J Protocol of user study

Protocol of user study

Testing the Hololens at the WWT

Preparation (before session)

Materials

- Hololens (**charged**!)
- Laptop(s) (**charged!**)
- Chargers (Laptops + Hololens + *powerbank*)
- Printed QR codes
- Printed sync remote collaboration documents (2 for researcher + 6 participant)
- 4 Drawing tools (2 color black + 2 color white)
- Notebook + pen
- Printed information brochures
- Printed consent forms
- Printed questions for discussion
- Printed script for the researcher
- Disinfection wipes
- Mask
- Stable wi-fi connection
- Tape
- This printed document (the protocol of the user study)

Setup inspection route

CHECK THE BATTERY OF THE HOLOLENS!! This battery should be fully charged.
Also check the brightness of the hololens, this should be put to its maximum value.

The researcher has to set up the Inspection route manually in the Hololens app. When the app is opened, the researcher has to wear the hololens, and take the printed QR codes and some tape. When the researcher places a virtual target point, a physical QR code should be placed at the same location. This should be repeated for each target point until the researcher covered all inspection points (Electrical locks in this use case). Then, the Hololoens should be disinfected and preferably be connected to a charger/powerbank until use.

Setup synchronized remote collaboration

To be able to do the synchronized remote collaboration test, it is important that there is a stable wi-fi connection. Also, the Hololens needs to be connected to a charger or powerbank, because otherwise the connection will fail.
The laptop needs to be connected to the internet. There is a special account that is needed to log into Teams.
The researcher and the participant should not be able to hear or see each other during the test. Preferably they are in separate rooms. The room for the participant needs to have 2 black and 2 white pens (or something similar) in it. It would be best to place the pencils in such a way that the participant can not directly see it. For example, a pen can be placed in a drawer or behind a cup of tea. Every pen should be in a different place (which the researcher needs to remember!) Also, a printed sheet with incorrect signs should be placed in the room of the participant.

Session itself

Introduction (5 min.)

1. Read the introduction outloud to the participant(s) (explain the thesis research and this session)
2. Give the participant(s) the information brochure. (No new info. should be in here). Explain to them that they are allowed to take it home, or rather should take it with them.
3. Give the participant(s) the consent form and a (clean) pen to sign it.
    a. If a participant decides not to sign the consent form, thank them for their time and end the session.

Tutorial Hololens (5 min.)

4. Ask the participant if (s)he has experience with the Hololens, and if they would like to first do a short tutorial to practice the use of the Hololens.
    a. If they would like to do the tutorial, the participant can wear the Hololens and adjust its settings until it feels comfortable. The researcher should explain which app to open, to start the tutorial. (make sure the Hololens is disinfected!)
    b. Wait until the participant finishes the tutorial.
    c. Ask the participant if everything is clear and if (s)he is ready to start the user study.

Inspection route with Hololens (10 min.)

5. The researcher should explain what the goal is of the inspection route app, and how it works. To do this, the researcher will give the participant the printed script about the inspection route. The participant can read it for him-/herself.

6. In the meantime, the researcher will put on the Hololens (disinfect it first) to set out the inspection route. When all inspection points are set, go back to the participant.
7. Ask the participant if (s)he has any questions.
8. The researcher can now take off the Hololens, disinfect it and give it to the participant.
9. Let the participant do their thing. The researcher observes them, while making notes.
    a. When there are multiple participants, the participant should be asked to select the Reset button twice before starting the inspection route.
10. When the participant feels like (s)he is done, move on to the next part.

Synchronized remote collaboration (10 min.)

11. Go to the location where the synchronized remote collaboration will take place.
12. Ask the participant for the Hololens back (disinfect it ofcourse)
13. Connect it to a charger/powerbank
14. Setup the call between Hololens and laptop.
15. Disinfect the Hololens again, and give it to the participant. Ask participant to wear the Hololens and wait until the researcher is seated.
16. The researcher should take the laptop and go to another room. When seated, the researcher should explain (again) what will happen and what the purpose is of this test.
17. Do the experiment without using the drawing function.
18. Do the experiment while using the drawing function.
19. When completed, thank the participant and explain that you will be right there. Hang up, go back to the participant and tell them to take off the Hololens.
20. Turn off the Hololens and move on to the last part of the user study.

Discussion (20 min.)

21. Ask if the participant needs a short break, something to drink or going to the toilet before the user study continuous.
22. Go to a place where the participant(s) and the researcher can comfortably talk.
23. Start the discussion.
24. Try to keep it within 20-30 min.
25. Thank the participant

K Script for user study

Script for user study

The participants of this study are busy and have limited time. Therefore, it is important to make efficient use of their time. The explanation parts of this study will be scripted, to avoid unnecessary rambling of the researcher and prevent giving incomplete instructions. Moreover, this will assure continuity between the user studies. Since the participants are Dutch, this information is written in Dutch as well.

Introduction

Introduction thesis research

Arcadis is op het moment bezig met het ontwikkelen van een Digital Twin. Deze is echter op het moment nog niet gebruikersvriendelijk en daarom gaat mijn afstudeeropdracht over hoe de DT dit wel kan worden voor al haar gebruikers. Aan de hand van mijn vooronderzoek heb ik gebruikersprofielen gedefinieerd. Ik wil gaan onderzoeken of het opsplitsen van de interface van de DT, op basis van deze profielen, ervoor zorgt dat de DT-gebruiker beter ondersteund kan worden.

Introduction user study

Daarnaast wil ik weten wat voor technologie het best ingezet kan worden om zo goed mogelijk met de DT te kunnen werken. Daarom heb ik een prototype gemaak op de Hololens die een onderhouds route visualiseert. Ook wil ik een bestaande app (Microsoft 365 Remote Assist) testen om het samenwerken op afstand te ervaren met de Hololens. Het is de bedoeling dat het prototype en de Remote Assist app straks geprobeerd worden door jou, terwijl ik zal observeren hoe het gaat. Deze observaties schrijf ik op en gebruik ik in mijn onderzoek om te bepalen hoe de digital twin het best ingezet kan worden om uiteindelijk bij inspecties te ondersteunen. Om er zeker van te zijn dat ik alles heb begrepen en een compleet beeld verkregen heb, zou ik ook graag wat vragen willen stellen in een interview. De verkregen informatie zal anoniem gebruikt worden in het verslag. De complete sessie zal ongeveer 45-60 min. duren

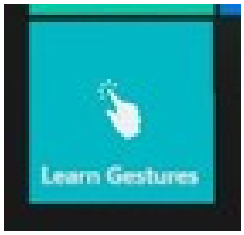
Ethical information

De data is volledig anoniem. Tijdens het onderzoek mag je je altijd terugtrekken van je deelname. In dat geval zal ik de data verwijderen. Ook na het beëindigen van het onderzoek kan je aangeven dat je liever niet meer deel neemt en de data zal worden verwijdert.

Duidelijk? Heb je nu nog vragen? Je mag me anders altijd nog vragen stellen.

Tutorial

Learn gestures



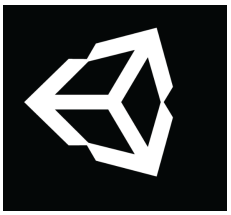
Zoek het blauw groenige tegeltje waar ‘Learn Gestures’ op staat.
Je ziet ook een wit puntje in het midden van je scherm. Probeer het witte puntje op het ‘learn gestures’ tegeltje te plaatsen door je hoofd te bewegen.
Gelukt? Houdt dan je vinger voor je, zo (doe voor), en beweeg je vinger naar beneden. Zo kan je selecteren. Als het goed is heb je nu de app geopend, gebeurt er wat?

Klaar met de tutorial? Maak het bloom gesture en klik op het huisje.

Inspection route with Hololens

Zometeen ga je een inspectie route lopen die op de Hololens is aangegeven. Er zijn 5 punten die geïnspecteerd moeten worden. Deze punten zijn te herkennen aan een groene punt met daarnaast een checkbox. In de echte wereld kan je ze herkennen aan een QR code. Als je met de Hololens naar zo’n QR code kijkt, dan zal er automatisch een scherm openen met knoppen waar je op kan klikken. Dit komt overeen met de informatie die je in de DT zal aantreffen over het desbetreffende object. Probeer ze uit, kijk rond, maar houdt in gedachte dat het een mock-up is, dus dat veel dingen er nu statisch in staan en je dus niet op alles kan klikken. Om naar een volgend inspectie punt geleid te worden, moet je de checkbox aanvinken. Dit kan je doen door de pinch gesture te maken (voordoen). De groene cirkel zal roze kleuren wanneer het gelukt is. Dit betekent dat je het punt geïnspecteerd hebt.
Om de visualisatie van de route indicator te starten, moet je naar beneden kijken. Daar vind je een menu. Door op de middelste knop, navigation, te klikken activeer je een pijl die wijst in de richting die je moet lopen om het inspectie punt te vinden.
Wil je meer informatie over je work order, klik dan op de meest rechter knop in het menu.

Open inspection guide app on Hololens



In het menu wat je nu voor je ziet gaan we zo, nu nog niet, het tegeltje rechts onderin openen. Hier staat een wit icoon op in de vorm van een kubus. Ik zou je willen vragen om zo meteen de app te selecteren, nu nog niet! Als je dat gedaan hebt, moet je de Hololens even hier neerleggen met de glazen deze kant op. Duidelijk? Oke, dan mag je op het tegeltje klikken en vervolgens de Hololens afzetten en neerleggen.

Synchronous remote collaboration

Wat we nu gaan uitproberen is het samenwerken op afstand. Als je nu wilt dat er iemand met je meekijkt, pak je waarschijnlijk je telefoon om te bellen, of video bellen. Dit is het scenario wat we zo eerst ook gaan testen met de Hololens. Echter biedt de Hololens nog een andere manier om op afstand samen te werken. De persoon op afstand (ik nu dus) kan visuele aanwijzingen maken, zoals tekeningen, die jij door je Hololens in de echte wereld kan zien. Dit is iets wat alleen met de Hololens kan, dus dat gaan we straks ook proberen.

Oh nog 1 praktisch dingetje, je kan het scherm waarin je mij nu ziet verplaatsen door het pinch gesture te maken en vast te houden. (Doe voor)

Voor je ligt een papier waar allemaal ingewikkelde tekens op staan. We gaan zo samen inspecteren of deze tekens kloppen. Als we een fout vinden, zal ik je proberen uit te leggen hoe deze opgelost moet worden. Duidelijk, nog vragen?

Video call

1. Laat ze goed naar het papier kijken, beweeg er een beetje overheen, vertel je een fout hebt gevonden. Probeer uit te leggen welk teken dat is.
    a. Vraag of ze het fouten teken willen aanwijzen.
2. Teken gevonden → Probeer duidelijk te maken wat er mis is met het teken door uit te leggen.
    a. Mocht dit echt lastig worden, laat dan een voorbeeld zien over de camera.
3. Probleem begrepen → Nu moet je het natuurlijk verbeteren, we kunnen het niet zo achter laten. Hiervoor hebben we een zwarte/witte pen nodig. Leg uit waar in de ruimte de juiste pen gevonden kan worden.
4. Pen gevonden → Begeleid de deelnemer in het verbeteren van het teken.

Klaar? Top! Heel goed. Laten we kijken of er nog een fout in zit.

MR call

1. Laat ze het hele papier in beeld krijgen.
    a. Wanneer dat het geval is, open de teken tool!
    b. Vertel dat je een fout hebt gevonden, en dat je deze zal markeren. (Markeer het teken wat fout is)
    c. Vraag of ze het foute teken kunnen aanwijzen.
2. Teken gevonden → Probeer duidelijk te maken wat er mis is met het teken door te tekenen.
3. Probleem begrepen → Nu gaan we het weer proberen te verbeteren. Hiervoor hebben we een zwarte/witte pen nodig. Leg uit waar in de ruimte de juiste pen gevonden kan worden.
4. Pen gevonden → Begeleid de deelnemer in het verbeteren van het teken.

Questions

1. Wat vind je van de ervaring die je net hebt gehad?
2. Waarom deed je … ?
3. Als je deze technologie vergelijkt met de huidige situatie, wat zijn dan de voor- en/of nadelen van zowel de huidige situatie en de Hololens?
4. Wat is volgens jou de toegevoegde waarde van deze technologie?
5. Hoe zou je deze technologie willen gebruiken?
6. Voorzie je problemen?
7. Wat zijn voorwaarden om met deze technologie te werken?
8. Wat zijn de mogelijkheden van deze technologie die je niet met huidige 2D technologieën kan oplossen?
9. Denk je dat deze technologie het samenwerken of communiceren op afstand verbeterd?
10. Wat vind je ervan als deze technologie gebruikt zou worden om met de DT te werken wanneer je op locatie bent?

L Synchronous remote collaboration test

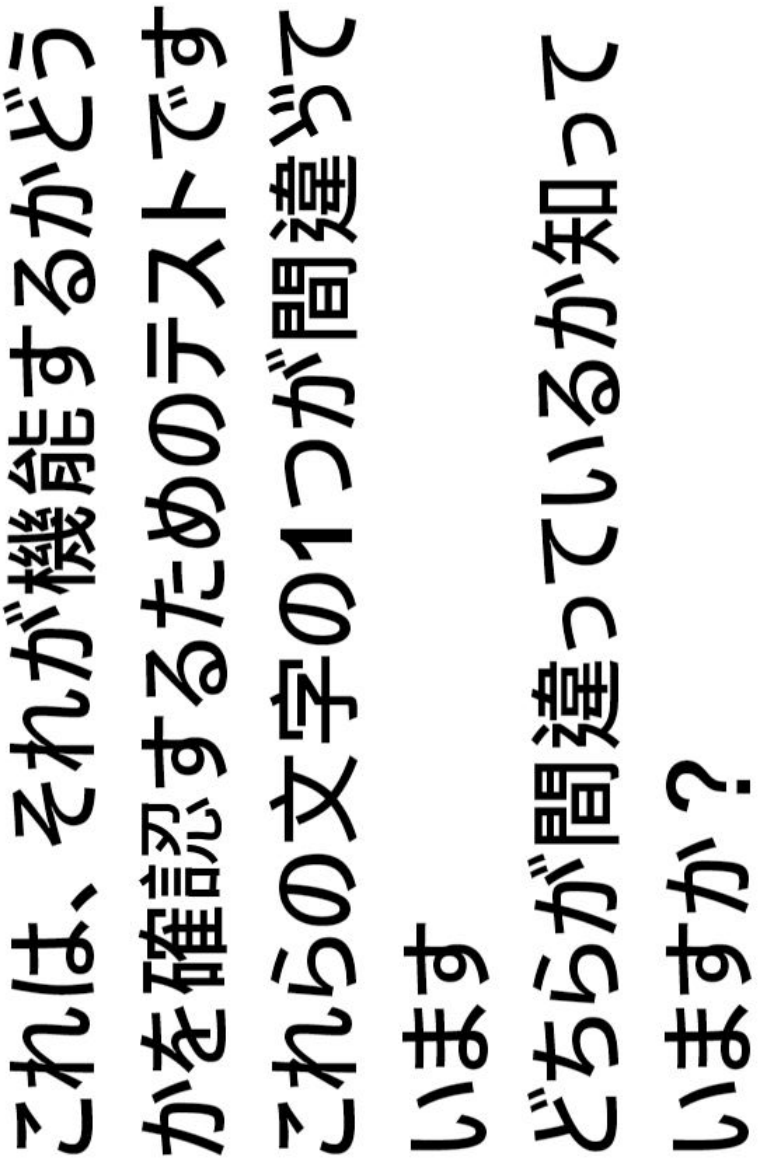


Figure 37

M Results user study

M.1 Asset manager

Results user study Asset Manager

Time: 9:35 - 10:45
Nr. of participants: 1
Company: Arcadis
Hololens experience?: No

Observations

Tutorial

- Loopt vast bij het ‘hold air tap’ gedeelte van de tutorial. Ik moest helpen om door te gaan naar volgende onderdeel.

Inspection route

- Kan de Hologram die verschijnt wanneer je naar de QR-code kijkt niet goed zien. Deze is te ver weg waardoor de tekst niet gelezen kan worden. De tekst lijkt op witte lijntjes.
    - Dit blijkt een fout te zijn in de app. Na opnieuw opstarten gaat het wel goed.
- De QR-code kan niet goed gescand worden door de Hololens omdat deze te laag hangen. (de QR-code hangt op ongeveer deurklink hoogte en de deelnemer is vrij lang)
    - Dit is snel opgelost door de QR-codes op ooghoogte te hangen van de deelnemer.
- Tijdens deze test hingen er 2 QR-codes buiten; 1tje aan een hek en 1tje op de grond.
    - De zon scheen behoorlijk deze dag, hierdoor waren de Hologrammen maar moeilijk te zien.
        - Uiteindelijk zijn deze QR-codes naar binnen verplaatst
    - De QR-code op de grond was irritant, want het hoofdmenu komt voor de QR-code en checkbox te staan als je naar beneden kijkt. Hierdoor kan je de Hologram die verschijnt door naar de QR-code te kijken en de checkbox niet meer goed zien en is interactie maar moeilijk.
- De deelnemer maakt de opmerking “Zou het niet handig zijn als je de tekst van de QR-code hologrammen zou kunnen schalen?”

Sync remote collaboration

- De fout in het teken is vrij gedetailleerd. Echter kan de remote user niet zo klein tekenen. Dit veranderd automatisch in een grote stip. Daardoor kon er niet op het teken zelf worden getekend. Als vervanging kon het teken na getekend worden, en met kleurtjes kon worden aangegeven wat weg moest of moest blijven.

Discussion

- *Wat vind je van de ervaring die je net hebt gehad?*
    - Leuke ervaring.
    - De menutjes die verschenen als je naar een QR code kijkt werken niet goed.
        - (Dit was een bug in het systeem)

    - Het aangeven van de richting werkt wel fijn. Het is ook handig dat de route object voor object aangegeven wordt.
    - Ik vind het intuitief, ook al is het wel iets wat je even moet leren om er goed mee te kunnen werken.
    - Buiten waren de Hologrammen niet goed zichtbaar, daar werkt het wel minder.
- *Denk je dat deze technologie het samenwerken of communiceren op afstand verbeterd?*
    - Het tekenen en de pijlen die je in de ruimte kan zetten creëren wel toegevoegde waarde voor de Hololens.
    - Echter werkt het nog niet helemaal lekker. De resolutie en nauwkeurigheid van de app zouden wel verbeterd moeten worden. Nu kon je bijvoorbeeld niet op het teken zelf tekenen omdat het te klein was. Dat is niet handig als je met kabels of elektrische circuits werkt. Dan heb je die nauwkeurigheid wel nodig.
    - Ik denk dat het gebruik van de Hololens een goede manier is om iemand bij te staan vanaf een afstand.
    - Een voordeel is dat je wanneer je de Hololens draagt je handen vrij hebt, dus de inspecteur kan gewoon z'n ding doen terwijl de expert aan het tekenen is.
    - Het zou het zeker waard zijn als dit verder ontwikkeld zou worden. Dan zouden we het hier prima kunnen gebruiken.
- *Hoe lang moet de batterij mee kunnen tijdens een inspectie?*
    - Een inspectie duurt zo'n 2 à 3 dagen. Meestal wordt er eerst 4 uur geïnspecteerd, een half uur pauze en dan weer 4 uur. Dus het apparaat zou wel 4 uur mee moeten gaan, in een half uur moeten kunnen opladen, en dan weer 4 uur meegaan.
- *Field of View*
    - Ik was onder de indruk van hoe goed de Hololens de omgeving begrijpt, de spatial awereness is echt goed.
    - Je leert super snel hoe je met de Hololens moet omgaan en het is makkelijk in gebruik.
    - Tijdens het samenwerken op afstand was de FoV echter wel te klein. Het liefst zou je en het video beeld van de expert en het probleem zelf in beeld willen hebben. Nu moest je steeds kiezen.
- *Inspection route app*
    - Je moet wel even waar alles is, aangezien een groot deel van de objecten niet altijd in je FoV zit. Dit maakt het lastig om te weten waar alles zit als je het niet kan zien.
    - Ik mis ook dat je geen bevestiging krijgt of iets gelukt is ja of nee, zoals bij de QR code bijvoorbeeld.
    - De navigatiepijl werkte voor links en rechts wel prima, maar diepte was lastig te volgen.
    - De navigatie was nu nog vrij dom natuurlijk ook, maar daardoor was het wel lastig om QR codes die achter een hoekje geplaatst waren te vinden bijvoorbeeld.

    - De navigatiepijl in het midden van het zicht is op zich prima. Echter zou het wel mooier zijn om de visualisatie voor de route te embedden in de omgeving, zoals op de vloer of op de muur.
        - (Dit is ook een kenmerk voor MR. De pijl in het midden is meer AR)
    - Kan het systeem ook zelf routes verzinnen? Bijvoorbeeld, ik sta nu hier in de asset en ik wil naar dit object. Kan'ie dan zelf de route bepalen en visualiseren? Het zou wel heel makkelijk zijn als de Hololens zou kunnen zeggen: hier is een storing, via deze route kan je er komen.
        - Op het moment als een operator of inspecteur ergens moet zijn gaan ze naar Wouter en die legt het ze dan uit.
    - Het zou ook erg tof zijn dat wanneer je een ruimte binnenkort er een melding in beeld komt over de PBMs (Persoonlijke BeschermMiddelen) en het veiligheidsplan.
        - Het scannen van een QR-code zou hier ook al heel handig voor zijn ipv automatische melding.
    - Het voordeel van een voorgeprogrammeerde inspectie route is ook dat ik beperkingen kan opleggen. Ze mogen niet altijd door alle ruimtes heen. Door de route van te voren in te stellen kan je ze om de ruimtes heen leiden waar ze geen toegang tot hebben.
    - De navigatie zou gerealiseerd kunnen worden met behulp van het BIM model(?)
- *Wat is volgens jou de toegevoegde waarde van deze technologie?*
    - Ik verwacht dat de kwaliteit van het onderhoud beter zal worden, omdat onderdelen minder snel vergeten zullen worden.
    - Ook zal de informatie van de inspecteurs veel sneller beschikbaar worden voor ons. Als ze het ter plaatse al kunnen invullen ipv achteraf.
    - In de toekomst zal het mensen helpen om makkelijker en efficiënter dingen te vinden in de tunnel.
    - Ook het helpen op afstand heeft meerwaarde. Zoals het vrij hebben van je handen, dat is beter dan dat je de hele tijd met zo'n tablet zit.
    - Echter staat deze technologie nog wel in de kinderschoenen, het kan wel gebruiksvriendelijker.
        - Het moet nauwkeuriger
        - Het is niet handig als de Hololens drager stil moet staan als de remote expert iets wil tekenen. Het zou efficiënter zijn als de Hololens drager gewoon door kan gaan met zijn activiteit.
        - Ook is de accuduur nu nog te laag. De Hololens moet wel een paar uur mee kunnen op een dag.
- *Voorzie je problemen?*
    - Voor hier in het dienstgebouw werkt de Hololens goed. Echter als je de tunnel in gaat waar ze met water dingen schoonspuiten of waar het hard kan waaien, dan kan de Hololens nog wel eens in de problemen komen.
        - Na wat googlen zijn we erachter gekomen dat er ook een soort Hololens bestaat die embedded is in een veiligheidshelm. Dit zou echt ideaal zijn voor het gebruik in de tunnel.

- *Vind je de Hololens comfortabel?*
    - Ja, tijdens het bellen net kon ik de Hololens gewoon ophouden.
    - Ik kreeg geen last van mijn nek oid.
    - De Hololens is wel wat zwaar, het is wel wat gewicht wat je meedraagt natuurlijk.
- *Wat zijn de mogelijkheden van deze technologie die je niet met huidige 2D technologieën op zou kunnen lossen?*
    - Het kunnen helpen op afstand. Als expert kan je meekijken met de Hololens drager en daardoor makkelijker helpen. Je kijkt automatisch mee namelijk. Hierdoor ben je ook veel flexibeler in je 1tje, niemand hoeft de camera goed te houden terwijl de ander daadwerkelijk uitvoert wat er gevraagd wordt.
    - De inspectie route visualiseren is ideaal om iemand ergens makkelijk en efficiënt naartoe te kunnen navigeren.

M.2 Asset owners

Results user study Asset owners

Time: 1:30 - 15:00
Nr. of participants: 4 (3 did tutorial & inspection route app, 2 did sync remote collaboration, 3 joined discussion. 2 participants completely completed the user study)
Company: Provincie Noord Holland
Hololens experience?: Nobody

Observations

Tutorial

- "Ik stotter nog wel eens op de letter *s*, en nu moet ik *select* zeggen."
    - Dit kan wel een nadeel zien van het gebruiken van speech recognition.
- Meeste liepen vast bij het 'hold air tap' gedeelte van de tutorial. Ik moest helpen om door te gaan naar volgende onderdeel.

Inspection route

- Een deelnemer geeft aan het fysieke klikken te missen, op deze manier krijg je geen feedback.
- De groene bol wordt niet altijd gezien. Dat komt omdat deze vrij laag geplaatst is (ter hoogte van een deurklink), ten opzichte van de FoV van veel mensen. Hierdoor valt het target point buiten de FoV.
- De Hologram die verschijnt na het scannen van een QR code is een beetje glitchy.
- De geplaatste inspectiepunten verspringen nog wel eens van plaats. Hierdoor zijn ze door de deelnemer niet meer te vinden of kunnen ze er niet meer op klikken. De oorzaak is niet duidelijk.
- "Gek dat het eerst groen is en daarna rood/roze kleurt. Je zou eerder andersom verwachten."

Sync remote collaboration

- 1 deelnemer was het videoscherm kwijt geraakt. Die was opeens versprongen naar een andere locatie buiten de FoV van de Hololens drager. Hierdoor rees de vraag; is er iets stuk?
- Het tekenen is vrij onnauwkeurig. De tekening staat niet altijd op dezelfde plek als dat de remote gebruiker getekend heeft.
- Doordat de camera's vrij hoog zitten zie je niet precies als remote user wat de local user ziet. Als de local user zijn ogen neerslaat en zijn hoofd recht houd, zien ze beide wat anders. De remote user moest nog best wat bijsturen af en toe om het papier goed in beeld te hebben.

Discussion

- *Samenwerken op afstand applicatie*

    - Het is wel onhandig dat je niet zoals in Teams het beeld van je eigen camera ziet. Je weet dus niet wat de remote expert ziet. Dat zou wel handig zijn.
- *Wat vind je van de ervaring die je net hebt gehad?*
    - Het is tof dat je op deze manier informatie op kan vragen.
    - Moest wel even wennen aan de gebaren, ik kan me voorstellen dat typen al helemaal gek ik op deze manier.
    - Het is ook even wennen dat je je hoofd altijd moet richten op het gene waar je naar kijkt. Anders ziet de camera het niet. Daarnaast moet je ook nog eens steady naar iets kijken, even wennen ook.
    - Echter voelt het wel intuïtief, en als iets waar je snel aan kan wennen.
    - Het is ideaal dat je je handen vrij hebt.
    - Voor onderhoud kan ik me zo voorstellen dat het handig is dat je altijd documenten zoals handleidingen etc. bij je hebt. Je hoeft niet naar iets te zoeken, geen verkeerde of verouderde versies. Dat is wel erg makkelijk.
    - Kan makkelijk de documentatie vinden die bij een bepaald object hoort. Daarnaast kan je ook slimme notities van andere lezen, wat ook erg handig is.
    - Als iets buiten de FoV valt ben je het kwijt en moet je wel erg zoeken. Als het niet direct ziet, denk je al snel dat de app stuk is. Dat kan wel verwarrend zijn.
    - Niet storend dat de FoV vrij klein is. Als je 1 specifieke taak moet uitvoeren is dat wel prima.
    - Het gebruik maken van gebaren om iets te selecteren is wel even wennen. Het tracken van gestures is niet altijd even betrouwbaar. Soms pakte de Hololens de air tap wel met 2 vingers en niet met 1 bijvoorbeeld. Echter denken ze wel dat je er snel aan kan wennen.
- *Zouden jullie nog andere use cases weten waar de Hololens gebruikt kan worden?*
    - De inspectie route app is intuitief, het is duidelijk waar deze voor dient.
    - De inspectie route app dient ook als herinnering voor de inspecteur die de inspectie route loopt. Daarnaast zorgt het er op deze manier voor dat er veel sneller feedback ontvangen wordt.
    - Als je alleen een vinkje hoeft te zetten heb je super snel feedback natuurlijk met informatie zoals; time stamp, dat het geïnspecteerd is, etc.. Je zou eventueel ook meerdere check boxen neer kunnen zetten, zodat je heel makkelijk informatie door kan geven. Je hoeft dan alleen maar de vinkjes aan te klikken.
    - Het is belangrijk om op elk moment te weten hoe een asset eraan toe is. De informatie moet dus zo up to date mogelijk zijn.
- *Notitie maken (typen)*
    - Is het niet handig als je gewoon zou kunnen praten en dat’ie daar tekst van maakt? Dat is veel sneller en makkelijk lijkt me.
        - Speech to text implementeren om tekst te typen. Dat heeft de Hololens op het moment ook al.
    - Zou er ook tekst voorgelezen kunnen worden? Dat is misschien ook wel handig.
- *Hoe zo efficiënt en makkelijk mogelijk geïnspecteerd object documenteren?*

    - Voor het in de gaten houden van het onderhoud is het makkelijk als de inspecteur alleen, net als nu, een vinkje ter plekke hoeft aan te klikken van wat je moet doen.
    - Wanneer er meerdere dingen gecheckt moeten worden, zouden er misschien meerdere vinkjes kunnen staan. Hmm, misschien is dat ook niet ideaal. Hiervoor heb je eigenlijk meerdere profielen oid nodig.
        - Profielen zijn handig om te implementeren
        - Dit functioneert ook als een persoonlijke controle of iemand iets wel gedaan heeft.
- *Wat is volgens jou de toegevoegde waarde van deze technologie?*
    - Je kan snel informatie vinden, en het is ook makkelijk om informatie op te halen.
    - De Hololens is makkelijker om mee te nemen dan mijn zware bakbeest van een laptop bijvoorbeeld. De Hololens is niet zo zwaar.
    - Mensen met een bepaald specialisme kunnen makkelijker meekijken. Ze hoeven niet meer fysiek langs te komen. Daarnaast zullen mensen minder fouten maken door het gebruiken van deze technologie, omdat het ze ondersteund.
    - Het direct kunnen toevoegen van informatie is ideaal. Op het moment duurt dit proces namelijk erg lang en niemand vind het leuk om te doen.
    - Het is goed dat je eerst een punt af moet checken voordat je naar het volgende punt kan. Je moet het dus wel eerst goed controleren en je mist niks op deze manier.
    - Het is ook goed dat je direct al in kan vullen wat je hebt gevonden tijdens je inspectie van een object. Dan hoef je het thuis niet meer te doen.
- *Vind je de Hololens comfortabel?*
    - Wanneer je ook een bril draagt kan het wel een beetje vervelend zijn. Maar over het algemeen geen last van.
- *Wat zijn de voorwaarden om met deze technologie te werken?*
    - Je hebt nu constant een wit puntje in je zicht, kan dit ook uit?
    - Het is niet altijd handig/veilig om gestures te gebruiken als interactie manier. Als je bijvoorbeeld iets met een gevaarlijk gereedschap moet doen wil je liever je handen uit de buurt houden.
    - Safety is wel een belangrijk punt. Als iemand rondloopt met een Hololens op, waar veel camera's in zitten, kan de omgeving zich afvragen wat er door de Hololens vastgelegd wordt. Neemt dit apparaat beeld en/of geluid op? Een privacy/ethische vraag.
        - Denk bijvoorbeeld aan, kan je terug refereren naar wat iemand toen der tijd deed/zei? Ethisch vraagstuk. Kan je bijvoorbeeld over iemand roddelen zonder dat dit opgenomen wordt en tegen je gebruikt wordt?
        - Het is niet de bedoeling dat gesprekken en/of beeld opgenomen wordt, en dit moet ook duidelijk gecommuniceerd worden naar de gebruiker.
    - Een gebruiker moet niet altijd alle data zien. Hiervoor zijn het gebruiken van profielen handig. Echter moet dit ook niet leiden tot mensen die denken 'oh dit is niet mijn taak, dus ik doe hier niks mee'.

        - Er zou eigenlijk een knop moeten komen om dingen die je opvallen, ook al ben je er niet verantwoordelijk voor, wel te kunnen melden.
        - Je moet wel de kans krijgen om alles wat je zou willen te communiceren. Ook als het niet binnen je profiel valt.
- *Wat zijn de mogelijkheden van deze technologie die je niet met huidige 2D technologieën op zou kunnen lossen?*
    - Het grootste voordeel van deze technologie is het kunnen multitasken, doordat je je handen vrij hebt. Dat is veel praktischer en veiliger ook.
    - Daarnaast geeft MR je meer of een ander gevoel dan een standaard 2D scherm. Je bent meer immersed in the experience. Het is toch ook weer anders dan AR. Duidelijke voorkeur voor MR.
- *Kosten aanschaf see-through HMD*
    - De kosten van zo'n Hololens zijn best wel laag. We zouden prima een paar kunnen aanschaffen.

M.3 Inspectors

Results user study Inspectors

Time: 15:00 - 16:30
Nr. of participants: 2
Company: Engie
Hololens experience?: 1 participant not, the other tried an early DIY version of the Hololens, which is not comparable. Both did the tutorial.

Observations

Tutorial

- Gaan super snel door tutorial heen, hebben geen hulp nodig. Lijkt erop dat de jongere generaties toch makkelijker met een nieuwe technologie om kunnen gaan dan oudere.

Inspection route

- Opeens begon 1 van de deelnemers woorden in het engels te zeggen terwijl er naar de QR-code gekeken werd. Toen besefte ik me er onder de knoppen van dat menu staat, dat je ze ook kan selecteren door een bepaald woord uit te spreken. Dat was inderdaad wat de deelnemer probeerde. Daarom vroeg ik of dat een optie was die de deelnemer zag zitten. Het antwoord was absoluut.
    - ``Speech recognition lijkt me echt chil, vooral in een stille omgeving. Want in lawaaiige omgevingen werkt het niet lijkt me?''
- Een van de deelnemers vond de Hololens niet comfortable. De bril bleef niet goed zitten.
- Ook hier werd geopperd of je de tekst niet in/uit zou kunnen zoomen.

Sync remote collaboration

- Misalignment tussen wat remote user en on-sight user ziet. Het menu/scherm waar de video van de remote user op te zien is verspringt nog wel eens. Valt opeens op de grond of de remote user ziet het scherm op een andere manier dan de Hololens drager zelf. Zo stond het scherm een keer voor de tekens voor de remote expert, terwijl de Hololens drager de video achter de tekens zag staan.
- De pijlen die geplaatst zijn door de remote user in de ruimte zijn niet altijd direct zichtbaar door de Hololens drager. Het kan zijn dat de FoVs niet overeenkomen, of dat het kleurcontrast tussen de pijl en de ruimte niet groot genoeg was.

Discussion

- *Wat vind je van de ervaring die je net hebt gehad?*
    - Dat witte puntje in het midden van je zicht is wel even wennen.
    - Ze zien het wel zitten om deze technologie te gebruiken.
    - Er zaten nog wel wat kleine bugs in. Na het maken van de Bloom gesture verscheen het menu, maar ook een ander gek ding waardoor alles heel wazig werd.

    - Een ander nadeel is wanneer je grote documenten zou openen op de Hololens waarin je veel moet scrollen of moet zoeken. Wanneer een document veel pagina's heeft of een gedetailleerd schema is zou ik liever mijn mobiel pakken en het daar opzoeken. Scrollen op de Hololens duurt veel te lang. Wanneer je een document van 1 a4tje hebt oid, of een zoekfunctie hebt, zou het wel handiger zijn om de Hololens te gebruiken.
    - Het werken met iemand op afstand is zeker een pluspunt van de Hololens. Dat kunnen tekenen en het plaatsen van pijlen in de ruimte is handig.
        - De deelnemer zou het wel aandurven om op deze manier een sensor te inspecteren.
        - Ze zien de Hololens tijdens remote collaboration wel als toegevoegde waarde.
- *Als je deze technologie vergelijkt met de huidige situatie, wat zijn dan de voor- en/of nadelen van zowel de huidige situatie en de Hololens?*
    - Met de Hololens heb je je handen vrij, dat is wel erg handig.
    - En je kan gelijk de inspectie uitvoeren en rapporteren.
- *Vind je de Hololens comfortabel?*
    - Wanneer je de bril voor langere tijd zou moeten dragen wordt het waarschijnlijk wel vervelend. Voor 1 à 2 uur is waarschijnlijk wel oke.
- *Wat is volgens jou de toegevoegde waarde van deze technologie?*
    - Het is een voordeel om ter plaatse al je inspectie in te kunnen voeren. Hiervoor zou het gebruik van speech to text wel erg fijn zijn.
- *Voorzie je problemen?*
    - Misschien dat het in krappe ruimtes onhandig zal zijn.
    - Als er krassen op het vizier komen, is het dan makkelijk te vervangen? Hij moet wel een beetje tegen een stootje kunnen.
    - Meestal is er in de tunnel geen gps en geen internet bereik. Dit zijn juist de plekken waar je dat synchroon remote collaboration nodig zal hebben.
    - Dat navigatie pijltje van de inspectie route app leidt misschien wel een beetje af. Je focust voornamelijk op de pijl en niet meer genoeg op de omgeving. Dat kan best gevaarlijk zijn als er ergens een gat in de vloer zit oid.
        - Een andere manier van visualiseren zal misschien beter zijn.
        - Of, wat ook interessant zal zijn, is het automatisch markeren van gevaar. Als er een visualisatie of geluid oid vanuit de Hololens zou komen die aangeeft dat je moet oppassen voor dat gat in de grond, zou het wel weer oke zijn om zo'n pijl te gebruiken.
- *PBM hints verschijnen wanneer ruimte betreden.*
    - Als je pas een waarschuwing zou krijgen wat voor PBMs je nodig hebt in de ruimte zelf, is dat wel vrij laat. Op dat moment ben je al in de ruimte en dan heb je niet de PBMs die je nodig hebt misschien. Het zou logischer zijn om het misschien eerder aan te geven.
    - Echter zouden ze het verder wel handig vinden als er iets was die aan zou geven wat het veiligheidsplan is of the PBMs die je ergens nodig hebt.
- *Wat zijn de voorwaarden om met deze technologie te werken?*

    - Het is pas nuttig voor ons om zo iets daadwerkelijk te gebruiken op het moment dat er een DT is die compleet is, en alle data heeft die we nodig hebben.
    - Je moet makkelijk objecten kunnen zoeken in de asset.
    - Ze moeten bij alle data/documentatie kunnen die ze nodig hebben.
    - Er is namelijk behoorlijk veel data waar ze mee moeten werken. Wel een big data gevalletje.
- *Hierarchy level waaraan documentatie hangt.*
    - Het maakt wel uit op wat voor hierarchy level er gewerkt wordt. Op component niveau kan het behoorlijk overwhelming worden namelijk. Het zou wel handig zijn als het iets gedetailleerder is.
- *Wat zijn de mogelijkheden van deze technologie die je niet met huidige 2D technologieën op zou kunnen lossen?*
    - Een 2D technologie is veel omslachtiger. Deze technologie is makkelijk te gebruiken en direct.