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A DATA VISUALISATION FOR FINDING INFORMATION ABOUT ROBOT AVATARS

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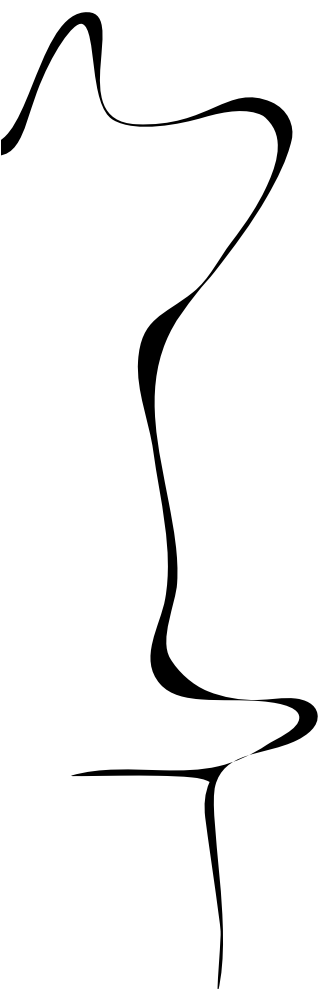
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Abstract

The rapid development of robot avatars, a system that transports a human's senses, actions and presence to a remote location in real time, has caused people working in the robot avatar field to lose the overview of available technologies and projects going on all over the world. This leads to a lot of time spent on doing research which limits the development of robot avatars. This project aims to address this problem by developing an interactive web-based tool that provides a comprehensive overview of the latest developments and current projects in robot avatar technology. The tool is designed to be user-friendly, incorporating features such as filters and interactive visualisations to facilitate easy information retrieval.

Through extensive background research, the project identifies the limitations of existing resources, which either cover robotics too broadly or focus narrowly on individual company technologies. This tool aims to bridge this gap by offering a balanced, focused overview of robot avatar technologies. Using a user-centred design approach, the project is built up through four phases: Ideation, Specification, Realization, and Evaluation. Each phase is iterative and includes user feedback to refine the tool's functionality and usability.

Key findings from user interviews highlight the necessity for structured, credible, and updated information on technologies, key players, and ongoing projects in the field. Through an elimination process starting with seven visualisation ideas, a graphical visualisation was selected for its ability to present a broad overview while addressing specific user needs. This visualisation was developed into a high fidelity prototype and evaluated positively by potential users. The result of this project is a functional tool that enables users to navigate and filter information efficiently and is indicated to be useful in the user's daily work.

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1 - Introduction

Context. A robot avatar is a robot embodiment of a human that is remote controlled [1]. It consists of two subsystems; a remote robot and an operator interface. The operator is able to sense the environment that the remote robot is in, and based on that interact at the other location as if they were there. This is a relatively new field and the amount of developments and breakthroughs are rapidly increasing. Telerobotics can be applied to many different fields, for example in the health sector and disaster management [2].

The development of robot avatars is on the rise all over the world. These new achievements in the field of telerobotics are just the beginning of what is to come in the future. Competitions only promote the creation of the avatar ecosystems even more [2]. ANA Avatar XPRIZE is a four year competition in which a hundred teams participated to create an avatar system. Many new technological advancements were made, due to this competition. With all these rapid changes in the field it is difficult to have a clear overview on all the technological improvements that are being made, which is a problem.

Problem statement. In order for developers and other people in the field to work effectively, they have to have an insight on what new accomplishments have been made in this rapidly changing field. This also prevents unnecessarily “reinventing the wheel”. Currently there is no central space where this information is gathered, this leads to either a lot of hours of research or potentially doing work that has already been done. This limits the potential of growth that is possible in the field of robot avatars.

Project goals. To enable actors in the telerobotics field to quickly get an overview of relevant information, the goal of this project is creating a web-based tool showing an overview of critical masses, actors, relationships between them, patterns, components and more. To ensure that users can get the most relevant information for their own project, the tool will become interactive, for example including filters to further specify the data shown. The starting point of the tool content-wise will be a few of the teams that were finalists in the ANA Avatar XPRIZE competition. In case the tool is successfully created it will be published on the website of Avatars.Report.

State of the art. The overviews that currently exist have a few limitations. To start with the focus of the knowledge centres, they either have the broad scope of robotics in general [3], [4], [5], [6] or are made by a company promoting only their own technology [7], [8]. The disadvantages of this is that if you want to build on your own robot avatar, you get overloaded with information, or you get information that is not relevant to the technologies that you are interested in. The overview that is made during this project aims to be precisely in between these two extremes, only focused on robot avatars, but showing more than only one company or on technology. Besides the focus, also the way of conveying and presenting information can be perceived as overwhelming. There are big documentation navigation pages [7], [8], lists of articles [3], [5] or platforms with hubs with a lot of extra information [4], [6]. A visual representation could help in the effective retrieval of the information, therefore the goal of this project is to have a visual overview clearly conveying information.

However there are some general examples of visual information views that are about a topic different than robot avatars. One example is Gapminder [9], a website having interactive visual representations of data about views on the world. Another example is the Atlas of economic complexities from Harvard’s Growth Lab [10]. Some inspiration can be taken from these existing overviews, for example the world map colour legenda [9] or the combination of interaction options, (time, location, parameters) [10]. Improvements on the shortcomings of existing resources about robot avatar technology and the strong points of the data visualisations about other topics, are combined to create an efficient and interactive tool during this project.

Research questions. The research question is:

How can a tool be created to give an overview of the latest developments in robot avatar technology?
To answer the main question there are several sub questions to provide guidance:

1. What is the goal of the users for using this tool and what information would the users like to have access to?
2. Which type of visualisation(s) can communicate the relevant information in a good way to the users?
3. Which interactions can be added to the tool to make the information retrieval easier?

Plan of approach. During this project, the design process for Creative Technology is applied [11]. This technique combines user centred design approaches and the classical engineering design principles. There are 4 phases that guide the project; Ideation, Specification, Realization and Evaluation.

In the Ideation phase the focus is on defining the design question, analysing the problem and finding inspiration. Activities in the first phase may include tinkering and research to related work. The outcome is an elaborated project idea with problem requirements [11] and several sketches of visualisation ideas.

This lays the foundation for the specification phase, where three of the visualisations are developed into low fidelity prototypes. The experience and functional requirements are specified by the constant feedback loop between the development of the different prototypes.

In the next phase, Realisation, the improvements of different prototypes are combined and one idea is finalized, which then is developed into a high fidelity prototype.

The last phase is Evaluation where the high fidelity prototype is reflected upon. During all these phases evaluation is of importance and the targeted user group is involved in every step in the process. This results in a balance between Divergence-Convergence and Spiral models of Design Practice [11].

Idea of results. The intended result of this research is an insight in what data is available about robot avatars, how users would use the overview and how relationships between data can be visualized. From this knowledge an interactive web based tool is made where users can access relevant data regarding robot avatars.

Organization of report. In Chapter 2 the background research is conducted, this includes both an insight into the technologies of robot avatars and the state of the art of data visualisations. In Chapter 3 the methodology is discussed. The four steps in the process are Ideation, Specification, Realisation and Evaluation, all these steps are discussed in their own chapters; Chapter 4, 5, 6 and 7 respectively. Chapter 8 has discussions and future work. And to summarize there is a conclusion in Chapter 9.

2 - Background

The goal of this chapter is to gather the prior knowledge needed for the development of the tool. There are three main parts of knowledge; the ANA Avatar XPRIZE competition and its teams, technical knowledge about robot avatars, and currently existing information visualisations and visualisation types. Information about ANA Avatar XPRIZE competitions is gathered by internet and literature research. Technical knowledge about robot avatars is acquired by a literature review. State of the art and visualisation types are explored via internet research.

2.1 Literature and internet research

During the literature and internet research both scientific and non-scientific sources are used. These sources are compared to acquire knowledge of basic facts. This section is divided into information about the ANA Avatar XPRIZE competition and its participating teams.

2.1.1 ANA Avatar XPRIZE competition

The ANA Avatar XPRIZE competition was held from 2018-2022 and the goal was to build telerobotic avatar systems [12]. The competition was hosted by XPRIZE, a non-profit organisation [13] whose mission is to “inspire and empower humanity to achieve breakthroughs that accelerate an abundant and equitable future for all” [14]. XPRIZE organises competitions over seven different scopes to find solutions for various big problems. The scopes are biodiversity and conservation, climate and energy, deep tech and quantum, food and water and waste, health, learning and society, space and exploration [14]. Within these scopes there are several competitions, each tackling a specific problem. Examples are water scarcity, carbon removal, artificial intelligence data alliance, and robot avatars [14].

The goal of the ANA Avatar XPRIZE competition was for the participating teams to “advance and integrate multiple emerging technologies to develop a physical, nonautonomous avatar system with which an operator can see, hear, and interact within a remote environment in a manner that feels as if they are truly there. A second objective was that a person at the remote end, the recipient, would feel that the operator was present in the avatar.” [13] (page 1). The robot avatar competition was sponsored by All Nippon Airways (ANA), the largest airline in Japan [2]. They offered mentorship, industry knowledge and 22 million US dollars [13], which was used for operational costs and prize money. The winner got 5 million dollars, the runner up received 2 million dollars and the third place got 1 million dollars. The partners for the competition were the companies Swift engineering and Immersion. They supported the teams with mentorship and relevant discounted or free services.

The competition consisted of several rounds, 99 teams registered, of which 77 teams qualified. After submitting a detailed paper and a video about their avatar system, 37 teams were selected for the semi-finals. In 2022 the finals were held with 17 teams [13]. The finals consisted of test course with 10 tasks that simulated a mission on an extraterrestrial planet [12]. The three main categories of these tasks were connectivity: human-to-human connection (task 1-4), exploration: the new era of travel (task 5-7), and skills transfer: expertise with boundaries (task 8-10) [13]. The tasks can be found in the schematic of the test course in Figure 1.

The teams had 30 minutes to train a non-expert judge to operate the system and then had 25 minutes for the tasks on the course [15]. Only four teams managed to finish all the tasks within this time limit. The teams were graded by the judges for experience, together with the amount of tasks completed, it resulted in the final score. If multiple teams had the same score, the time would be taken into account.

2.1.2 Participating teams

The winner of the competition was NimbRo, a team from the Autonomous Intelligent Systems Lab at the University of Bonn in Germany [13]. The team managed to complete all tasks in 5 minutes and 50 seconds, with a perfect judge score of 5 [13]. Pollen Robotics also completed all tasks with a perfect score, but it took 5 minutes longer, resulting in second place. The robot was made by Pollen Robotics SAS from Bordeaux in France [13]. The third place is team Northeastern based at

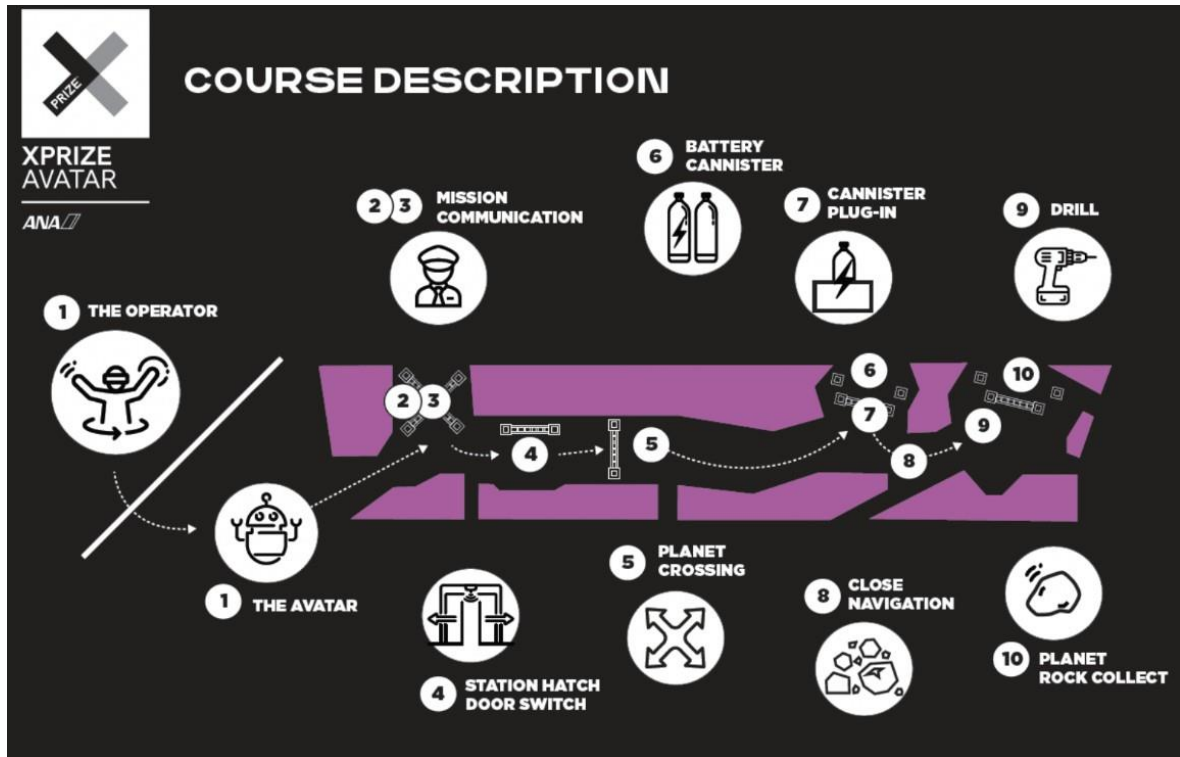


Figure 1 Schematic of finals test course provided by XPRIZE, from Hauser et al. [12] (page 8)

Institute for Experiential Robotics at Northeastern University in Boston in USA [13]. Other teams were from various countries, including Korea, Mexico, Italy, Singapore and Japan. Also iBotics from the Netherlands participated. This is a consortium of TNO, Halodi, Haption, ETH Zürich – RSL, Sensiks and University of Twente.

2.2 Literature review

In the literature review the technical knowledge about robot avatars is acquired. In the literature review peer-reviewed papers used to compare the positions of the different authors. Due to the time span of the project, it is not possible to gather all relevant information for the users about everything in the robot avatar field. However, once the tool is developed with the basic information, more data can be added later on. The starting point is technical information about the robot avatar systems that the finalist teams made in the ANA Avatar XPRIZE competition. This literature review consists of three parts. First a definition for robot avatar is found. Then the technologies of the robot avatars are explored. And to conclude there is an analysis of the lessons learned by the participating teams.

2.2.1 Definition of robot avatar

Robot avatar is defined by many different researchers in similar wording, however there are some differences in views on whether it can be categorized as telepresence. According to Behnke et al. [13] the definition of a robotic avatar is a “system that transports a human’s senses, actions and presence to a remote location in real time”(page 1). Also, Luo et al. [15], Cisneros-Limón et al. [16], Bremner et al. [17], Dafarra et al. [18] and Vaz et al. [19] have similar definitions. They use slightly different wording, but all definitions mention the same characteristics. A remarkable finding is that Correia Marques et al. [20] use this definition to describe telepresence, while Luo et al. [15] specifically mention that “telepresence goes one step further by emphasizing the importance of operator immersiveness”(page 1). Hauser et al. [12] agree with this, putting an emphasis on the bystanders also have the feeling that the human is present at the location. The definition of robot avatar that is

used to determine whether a certain piece of technology may be included in the overview is “system that transports a human’s senses, actions and presence to a remote location in real time”. An important note on this definition is that Behnke et al., Luo et al., Cisneros-Limón et al., Dafarra et al. and Correia Marques et al. all participated in the same competition. And therefore use the same definition, potentially the definition used by the competition organizers. However, also Bremner et al. [17] use a similar definition while they were not participating in the competition, making it highly possible that the definition is used as a standard through the whole field.

2.2.2 Technologies of avatar system

According to the definition of the robot avatar, every avatar system consists of two parts, at one location the remote robot and at another location the operator. To comprehend the technologies and hardware that is used in these systems first a view on the system as a whole is taken. After which the separate subsystems are discussed.

Wang et al. [21] name the operator haptic devices, the master subsystem, and the remote robot is named the slave subsystem. Everything the remote robot senses has to be communicated to the operator, who can then make decisions that have to be received by the remote robot, making it a two way communication [12]. The most common way to do this, is making an exoskeleton for the operator and providing feedback through for example force, vibration and visuals, as done by Schwarz et al. [22]. But even within this approach there are many different possibilities to combine techniques. Hauser et al. [12] published an overview of the technologies that were used by the 17 teams that participated in the finals of the ANA Avatar XPRIZE competition, it can be found in Figure 2 and

Figure 3, separated by the master subsystem and slave subsystem technologies respectively.

Function		Device		Teams	
Vision		HMD (14)	VIVE (7)	i-Botics, Team UNIST, INBIODROID, Team SNU, iCub, Cyberselves & TouchLab, JANUS	
			Valve (3)	NimbRo, Team AVATRINA, Tangible	
			Meta (2)	Pollen Robotics, AlterEgo	
			VARJO (1)	Avatar-Hubo	
			Not clear (1)	AvaDynamics	
		Monitor (3)	Team Northeastern, Dragon Tree Labs, Last Mile		
Haptic	Hand	Force(+Vibration) (11)	Glove (8)	SenseGlove (4)	NimbRo, Team AVATRINA, Team UNIST, iCub
				Haptx Gloves (3)	i-Botics, Tangible, Cyberselves & TouchLab
				WEART (1)	Avatar-Hubo
				Custom (3)	Team Northeastern, INBIODROID, Team SNU
		Vibration (4)	VR Controller (4)	Pollen Robotics, AlterEgo, AvaDynamics, JANUS	
		Not applied (2)	Joystick (2)	Dragon Tree Labs, Last Mile	
		Arm (force feedback)		Robot arm (8)	NimbRo, Pollen Robotics, Team Northeastern, i-Botics, Team UNIST, INBIODROID, Team SNU, Cyberselves & TouchLab
			Not applied (9)	Team AVATRINA , AlterEgo, Dragon Tree Labs, Avatar-Hubo, Last Mile , AvaDynamics , iCub , Tangible , JANUS	

Figure 2 Overview of technologies used by all finalist teams in the ANA Avatar XPRIZE competition for the master subsystem from Hauser et al. [12](page 15)

In this literature review the technologies that three teams used are analysed, these are the teams that published a paper fully describing the technologies in their system. The three teams are NimbRo (winner of competition), iCub (placing 14th) and JANUS (placing 17th). The analysis of these robot avatars that these teams build is divided into two parts, first the master subsystem and second the slave subsystem. These are each divided into smaller categories; the same categories that Hauser et al. used in their overall analysis of the competition [12].

Function	Methods		Teams
Vision	Mono (3)		Dragon Tree Labs, LAST MILE, Team Northeastern
	Stereo (14)		AlterEgo, AvaDynamics, Avatar-Hubo, Converge Robotics, Cyberselves, i-Botics, iCub, INBIODROID, JANUS, NimbRo, Pollen Robotics, Team AVATRINA, Team SNU, Team UNIST
Manipulation	Arm	one arm (2)	AvaDynamics, LAST MILE
		two arm (15)	AlterEgo, Avatar-Hubo, Converge Robotics, Cyberselves, Dragon Tree Labs, i-Botics, iCub, INBIODROID, JANUS, NimbRo, Pollen Robotics, Team AVATRINA, Team Northeastern, Team SNU, Team UNIST
	Hand	Anthropomorphic (12)	AlterEgo, Avatar-Hubo, Converge Robotics, Cyberselves, i-Botics, iCub, INBIODROID, JANUS, NimbRo, Team AVATRINA, Team SNU, Team UNIST
		Parallel Jaw (3)	AvaDynamics, Dragon Tree Labs, LAST MILE
		3 Finger (2)	Pollen Robotics, Team Northeastern
Navigation	Omni-directional (11)		AvaDynamics, Converge Robotics, Cyberselves, INBIODROID, LAST MILE, NimbRo, Pollen Robotics, Team AVATRINA, Team Northeastern, Team SNU, Team UNIST
	Differential Drive (4)		AlterEgo, Avatar-Hubo, Dragon Tree Labs, i-Botics
	Bipedal (2)		iCub, JANUS

Figure 3 Overview of technologies used by all finalist teams in the ANA Avatar XPRIZE competition for the slave subsystem from Hauser et al. [12](page 11)

Master subsystem

The master subsystem are for all three teams exoskeletons, however they do have different approaches for visual displays, navigation control, force feedback, shared control and communication technologies. Only the first three aspects, visual displays, navigation control, and force feedback, are discussed in this review. Visual displays of all three teams are done with Head Mounted Displays (HMD). Schwarz et al. [22], Dafarra et al. [18] and Cisneros-Limón et al. [16] describe that their operator visual display is a HMD, although from different brands. Schwarz et al. [22] explains that NimbRo chose an Valve HMD to promote the feeling of immersiveness, Cisneros-Limón et al. [16] mention that iCub chose a VIVE headset because it belonged in the HTC VIVE family of technologies, of which they used more equipment to promote connectivity of different compartments in the system.

The navigation of NimbRo is done with an omni-directional base [22], while iCub [18] and JANUS [16] both use bipedals. Dafarra et al. [18] say the use of bipedals propose instability issues, therefore iCub balancing is completely handled by the remote robot and detached from directional operator input. Cisneros-Limón et al. [16] do not mention that JANUS had the same issue as iCub, but point out that legged robots have better capabilities when climbing stairs or crossing uneven terrains. A point of discussion that has to be added is that JANUS and iCub were the only two teams out of 17 that used the bipedal approach, the most popular was an omni-directional base, which 11 teams used. Approaches to force feedback varies a lot between teams. Cisneros-Limón et al. [16] writes that JANUS does not use force feedback on the robot arms. Schwarz et al. [22] and Dafarra et al. [18] on the other hand do state that NimbRo and iCub have force feedback. However, the way of providing the feedback to the user is different. NimbRo [22] does this with a coloured VR overlay, while iCub [18] has iFeel haptic nodes vibrating according to the amount of force. Dafarra et al. [18] point out that the weight that is measured by the force and torque sensors directly translates to the feedback of the user. Schwarz et al. [22] discusses that NimbRo opts for a weightless feeling and only gives feedback to let the user know the limits of the robot arm in regards to speed and position.

Slave subsystem

The slave subsystem also has similarities and differences between the teams in the area of navigation, manipulation, vision and head movement, and force and tactile sensing. All three teams did manipulation with two arms and anthropomorphic hands capable of minimum 3 kg of force [16], [18], [22]. JANUS, iCub and NimbRo all describe having had problems related to vision, however the specific problems that were highlighted in the papers were different. Schwarz et al. [22] state that the team of NimbRo had to think of a solution to show the whole face of the operator on a screen on the remote robot, while the operator was wearing a VR headset. JANUS [16] did not have this problem because they used a silicone robot head. However, showing facial expressions was still a challenge. Cisneros-Limón et al. wanted to use motors with 8 degrees of freedom (DoF), however, when installing a vision PC inside the head, four motor drivers were

blocked, which limited the possibilities of facial expressions. Cisneros-Limón et al. [16] describe that they had to make the consideration between the vision PC or more expression control. Eventually they decided to disable four motors resulting only in 4 DoF. The third vision related problem is a struggle that the team of iCub had, Dafarra et al.

[18] mention that there was lag in the vision system. Schwarz et al. [22] also suffered with the same problem but solved it by changing camera hardware.

To conclude, all the teams in the finale of the ANA Avatar XPRIZE competition used various techniques and technologies in their builds, both in the slave subsystems and the master subsystems. All of these technologies bring their own advantages and disadvantages, nevertheless all these technologies will be incorporated into the overview of robot avatars to give an as complete as possible overview of the developments in the field.

2.2.3 Lessons learned from building robot avatars

In total five teams that published a paper in which they shared the lessons they had learned, 16 different big problems were mentioned, 10 of which were shared by multiple teams. These were not exclusively all the challenges that were faced, and perhaps more teams had similar challenges. However, these are the main lessons learned and publish in the papers of the teams NimbRo, iCub, Northeastern, AVATRINA and Hubo. Of all these lessons, only three are discussed in more detail in the coming section. These are two challenges that multiple teams experienced, and one challenge that only one team mentioned but has big impact.

The first challenge that all teams experienced was some form of latency or lag. This resulted in jerky behaviour. The cause of this lag was different for the teams. Luo et al. [15] state that the delays were caused by network latency, due to a lot of teams using the network at the same time. Cisneros-Limón et al. [16] on the other hand mention that they experienced delays not related to network communication but incorrect configuration.

Secondly, NimbRo [22], Northeastern [15] and AVATRINA [20] all experienced troubles with a lock of the system, this happened for example when limitations of the remote robot were reached. Schwarz et al. [22] from NimbRo state that they should improve the control loop of the NimbRo avatar. While Luo et al. [15] from Northeastern and Correia Marques [20] from AVATRINA mention a different solution, they both state that making a remote recovery protocol would be a good way to fix this issue.

The third lesson that is discussed was only mentioned by one team, but is highlighted because it can be an important element in the overview of the robot avatars. Luo et al. [15] state that the amount of control the operator has over the remote robot can be overwhelming. They found that with the design of the interface for Northeastern “less is better” and keep a simple design not showing all capabilities, even though that contradicted with the literature. This is an example that shows the importance of testing the system with novice users and implementing their feedback, even if it may be contradictory to what is common in literature.

Besides these three lessons that are discussed in detail, examples of other challenges were shared autonomy, problems with too small field of view, remote robot colliding with itself, lack of telepresence feeling, challenges with combining components and management of failures.

2.2.4 Conclusion of literature review

The goal of this literature review was to get knowledge about the technical side of robot avatars, to create an interactive overview of the developments in the robot avatar field. The starting point of this literature review were the finalists in the ANA Avatar XPRIZE competition. This competition enabled teams from all over the world to work on robot avatar technology. A robot avatar is a system that transports a human’s senses, actions and presence to a remote location in real time, it consists of a master subsystem controlled by an operator and slave subsystem which is the remote robot. A robot avatar consists of a master subsystem and a slave subsystem. The most common technology used for vision in the master subsystem is a head mounted display. For the hand six different technologies are used, and different ways of force feedback were applied by the teams, force, vibration or no physical feedback. The slave subsystem navigation was handled in three different ways; omni-directional, differential drive and bipedal. Also, different techniques for arms and hands were used by the teams to create the remote robots. Some of these technologies led to struggles for the teams. Lessons learned by the teams are ways to handle lag or latency in the system, implementing error

protocols and importance of testing.

An important point of discussion is that only the robot avatars that were made by teams participating in the ANA Avatar XPRIZE competition are analysed, therefore this is not a complete picture of the robot avatar field. Besides, the only teams that were discussed were the teams that published a detailed report about their robot avatar. Also, one of the sources used was a summarizing and analysis report of the whole competition co-written by the organizers, judges and team members. This resulted in overlapping authors of different sources, which could have been the reason for similarities between research papers.

Recommendations for future research are to gather more information about robot avatars that are created that are not part of the competition, or more research about which component can be useful to include in an overview that is not related to the technological side of robot avatars.

Besides these critical points and limitations, enough essential information has been gathered for starting the development of the interactive tool.

2.3 Internet search

An internet search was conducted to understand the state of the art and to explore currently existing data visualisations. This is done by informal internet search because scientific sources are not needed to find this information.

2.3.1 State of the art

If an internet search is done to find information about robot avatars, there are several results, this includes websites from different companies and general robotics associations. All of these websites provide a lot of information that has the potential to be applicable to the specific project someone is working on. However, the overviews that currently exist have a few limitations. There are several robotics organisations like The American Society of Mechanical Engineers (ASME) [3], IEEE Robotics & Automation Society (IEEE RAS) [4], A3 Robotics [5] and The Robot Report [6]. These pages offer information about codes, standards, certifications, accreditation, events, competitions, products, trends and more and can be seen in Figure 4. This is a very broad scope and does not focus on robot avatars. If you are looking for more technical information you get to documentation sites like PyRobot [7] and Robot Operating System (ROS) [8]. These are documentation pages with explanation for software developers, however, they only focus on one specific product. The software is explained by the means of examples and help is offered in the form of courses, literature and possibilities to get in contact with the help desk.

The initiatives described above may be very useful for people working in the field, but it does not give a visual representation of the field of robot avatars. The home pages of these websites have lists of articles, like ASME and A3 Robotics, or are platforms with information hubs where a lot more is on the home page, like IEEE RAS and The Robot Report. This information is not presented in a visual way. Some examples of interactive data visualisations do exist, however not on the topic of robot avatars. Examples of this are Gapminder [9] and the Atlas of economic complexities from Harvard's Growth Lab [10]. These visualisations are showing the economic and social development of countries around the world over time. The visualisation tools are interactive and the user can select which data they want to see. Besides this, also specific parameters can be filtered out or highlighted. Both tools offer various options of visualisation and an easy switch can be made between the visualisation types. The visualisation types in the two tools described above are, among others, bubble charts, mountain charts, trend lines, bar charts, product space, ring charts, tree maps and geographical maps.

Examples of data visualisations that are more network related are LinkedIn InMaps [23] and Research Rabbit [24]. LinkedIn InMaps provides the user with a visual representation of their network of LinkedIn connections. Research Rabbit is a tool finding research papers connected to the paper that the users input. Both these visualisations are made with network graphs.

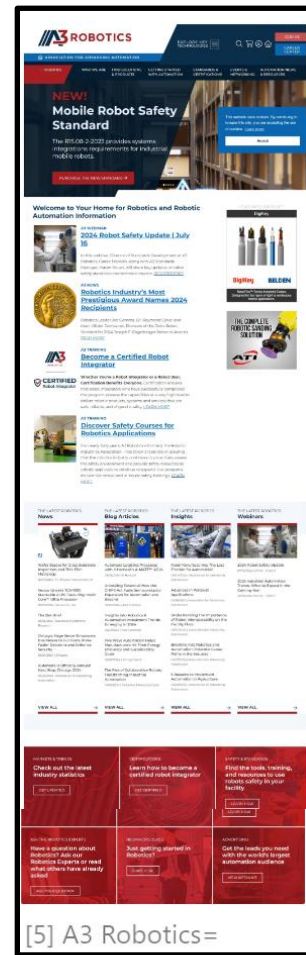
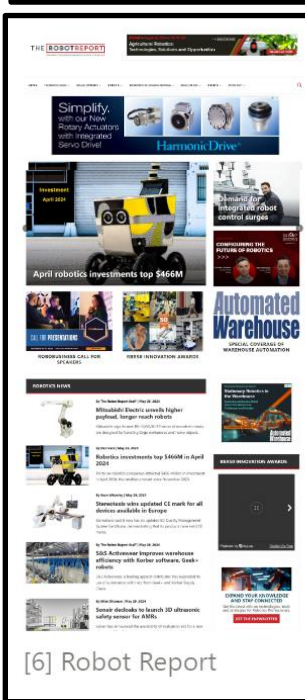
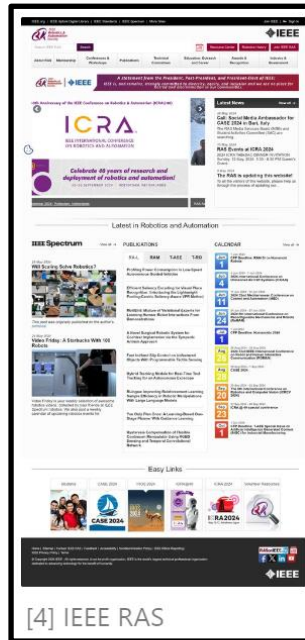
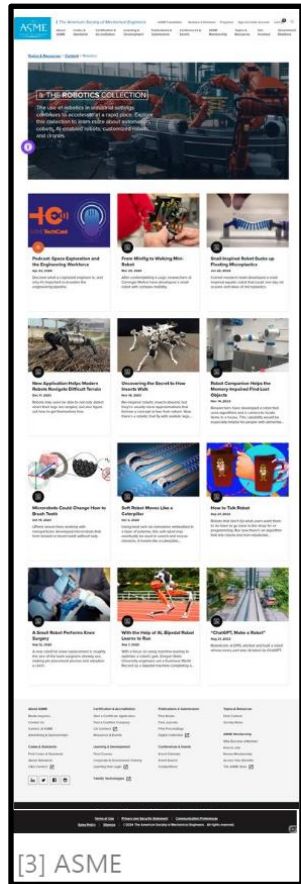


Figure 4 State of the art - robot avatar related data collections

2.3.2 Data visualisations

The variations in different ways visualising the big data in the named examples are limited. Therefore also a separate internet search was done to broaden the field of visualisation types. This search is not focused on finding visualisations related to robot avatars, or having visualising a large amount of data. This search is meant to find ways of visualising data in general. Different lists of visualisation types exist, the visualisations that sparked interest or have potential can be found in

Figure 5. These visualisation are very diverse, including location based visualisations, graph visualisations and other forms. Also a combination of visualisations could be made, like what can be seen in the filterable dashboard.

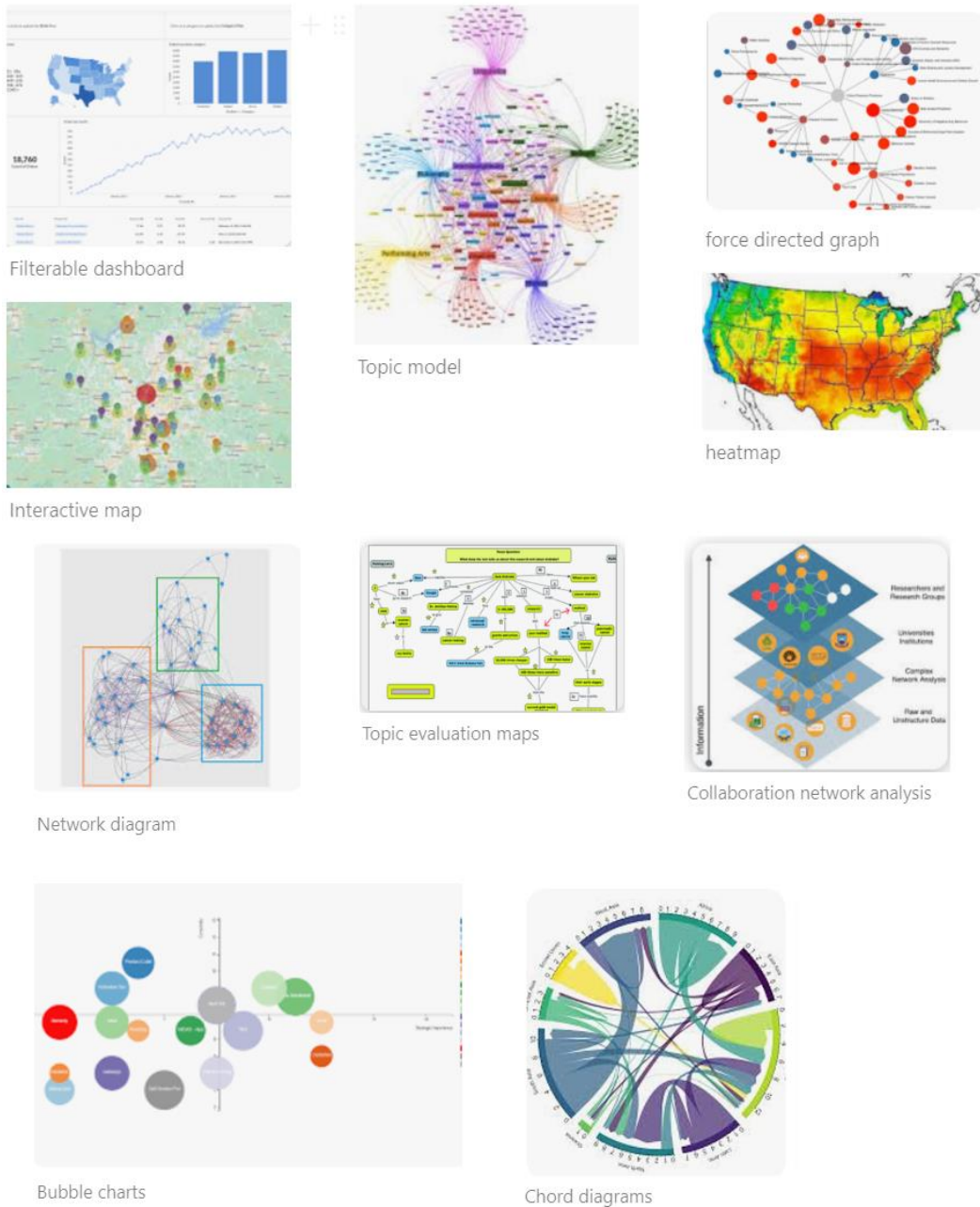


Figure 5 Visualisation types with names

2.4 Conclusion and discussion of background research

In conclusion, the background research provides an understanding of the ANA Avatar XPRIZE competition, technologies used to build robot avatars and state of the art.

The ANA Avatar XPRIZE competition led to a big development in robot avatar technology. The goal of each participating team was to create robot avatars that lead the operator to be immersed in a remote environment and were tasked to complete a course with 10 challenges. The teams had many different approaches, using a mix of technologies. The robot avatar systems consisted of master subsystems and slave subsystems. Head Mounted Displays (HMDs) were commonly used for vision and providing feedback to the operator. Navigation examples were bipedals, but more common, omni-directional bases. Also force feedback mechanisms varied across teams, some teams used vibration by haptic nodes, others used visual feedback.

In the lessons learned was more similarities between teams, covering latency issues, system freezes and error handling. Also the importance of simplified user interfaces was mentioned by one team.

Despite the important insight into robot avatar technology that was gained through the literature review, it is important to be aware and critical of the fact that this review had limitations, due to only focusing on the competition to find information about the technologies.

The state of the art showed that current data centres were providing a lot of information about robotics in general, or only focusing on the workings of one specific product. The way this information is provided is mainly in the form of articles, blogs, event calendars and documentation pages. However an important note is that, even though effort has been put into exploring the state of the art, it is possible that similar projects exist but were not found in the internet search.

The general examples about data visualisation tools were helpful to gather examples of communicating a lot of data in a clear way to the users. The visualisation types that were found can be used in the following steps of creating the tool.

The background research has provided a solid base of knowledge to continue the development of the interactive tool about robot avatar related activities.

3 - Methods and technologies

In this chapter the methodology is discussed, the method for this project is the Creative Technology design approach [11]. Next to this other techniques that are used in this project are explained.

3.1 Methodology

The approach that is used in this project is the Creative Technology design approach [11], which consists of four phases that can be seen in Figure 6. In this section all of these phases are discussed and there is a description of how this method is applied in this project.

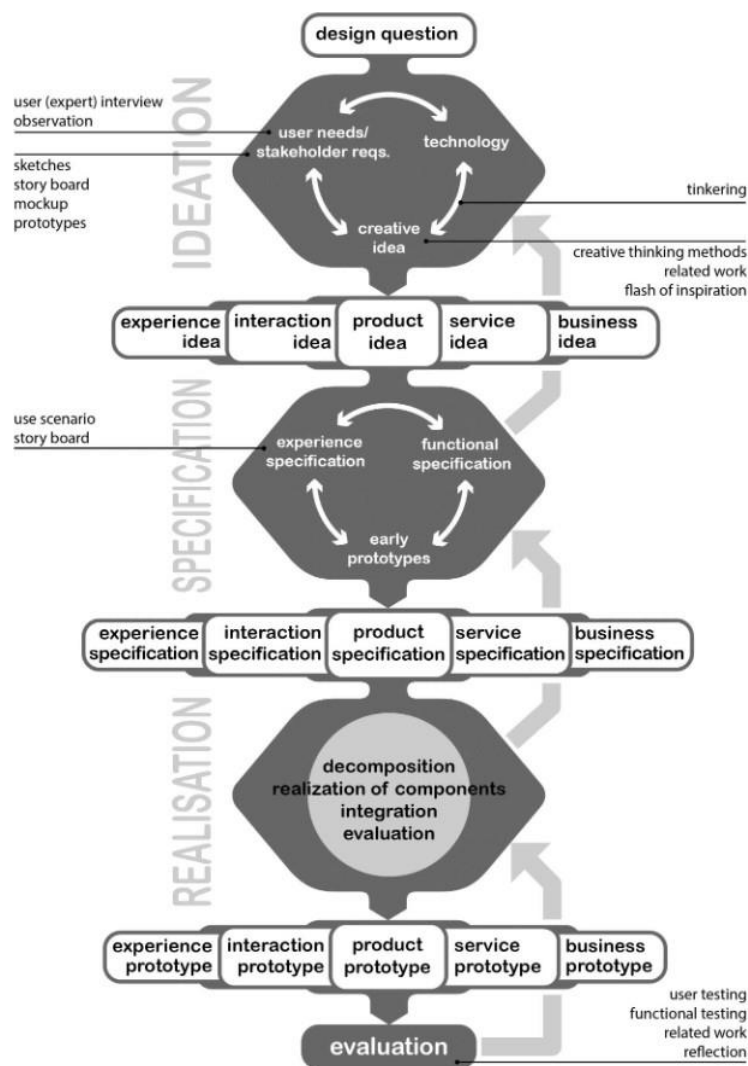


Figure 6 Schematic of Creative technology design process by Mader and Eggink [11]

In the ideation phase the user needs are identified and a creative idea is generated by tinkering. Tinkering is a technique that is mentioned by Mader and Eggink [11] (as cited in [25]) who describe tinkering as “a

playful, experimental, iterative style of engagement, in which makers are continually reassessing their goals, exploring new paths, and imagining new” (page 164). With this technique it is possible to come up with creative ideas and solutions in which technologies will be applied in new ways.

This project started with a goal to solve a problem. In the ideation phase ideas are created as a solution to the problem. However, before the solutions can be created, first the problem is analysed and the prior knowledge needed in this project is acquired. This is done by literature and internet research, literature review and internet search. Literature and internet search means that both scientific and non-scientific sources are compared to acquire knowledge of basic facts. Literature review on the other hand only uses peer-reviewed papers and compares the positions of the different authors. Internet search is used for the state of art to find sources. Based on this knowledge, several visualisation ideas are sketched out. These sketches are evaluated with potential users from the target user group. In these interviews also a deeper understanding of the user’s needs is acquired. Based on this evaluation, a selection of sketched out visualisations is made and taken to the next phase.

The specification phase is all about creating various low fidelity (LoFi) prototypes and evaluating each of them. At first, the sketches of the selected ideas from the previous phase are made into a LoFi prototype, that means that interaction is added. These first prototypes are evaluated by potential users from the target user group and then there adjustments are made. This process is repeated in three rounds. Every time with the goal of improving the functionality and experience of the tool. The prototype adjustments are done rapidly, and therefore a lot of interviews in a short time span are held. After the iterations of all the low fidelity prototypes, one idea is selected and taken to the next phase.

In the realisation phase the strengths and weaknesses of the LoFi prototype is analysed and new requirements are made. The visualisation is developed into a high fidelity (HiFi) prototype. This HiFi prototype is a web-based tool and is seen as the result of this project. The difference between the LoFi and HiFi is that the LoFi prototype only is a visualisation with interaction and the HiFi is a webpage connected to a data sourced and a visualisation with which can be interacted.

Evaluation is the most important part of working on a project, that is why it is already incorporated in the three phases that came previous. In the last phase the HiFi prototype and the process of the project is reflected upon. The evaluation of the HiFi is done in the form of interviews with the user group. The participants have five tasks they have to complete, this will show if the tool is efficient in use. Both the strengths and weaknesses of the process and HiFi are discussed and based on this future recommendations are given.

3.2 Gathering information from interviews

During this project information is gathered from interviews with potential users in the target group. Even though the content of the interviews differ per phase in the project, the main setup is the same. All interviews are semi-structured interviews. The participants are all potential users in the target user group.

All interviews start with a brief overview of the project and explaining the goal of the interview that is being conducted. During the interviews handwritten notes are made using keywords. Right after the interview the handwritten notes are structurally noted in an online document, highlighting the key points. From these notes diagrams are created to compare the responses of the different participants. More detailed information about content and parts of the interviews that are conducted per phase can be found in the chapters respective to these phases.

3.3 MoSCoW requirements

In different phases of the project an overview of requirements is made. This is done with the use of the MoSCoW requirements method. This method divides the requirements into four categories; Must have, Should have, Could have and Won’t have. This method gives more depth than just giving a list of the requirements the project will and will not have. By dividing the first category into three, a ranking is created indicating the priority of the requirements. This is beneficial for the project because of the limited time scope. This gives a clear focus on which requirements have the most priority, and which requirements are not necessary, but just additions.

4 - Ideation

In the ideation phase seven sketches of visualisations were made. Inspiration for these sketches were the data visualisations that were found in the background research. The sketches only contain the rough idea for the visualisation, it does not include style elements like colour, thickness of lines, and transparency. Also the interaction is not yet incorporated in these designs, this will only be added in the next phase Specification (Chapter 5). The sketches were evaluated by conducting interviews with potential users from the target user group. The target user group are the experts working in the field of robot avatars. Next to gathering preferences for data visualisations, also questions were asked about the current way of information collection.

4.1 Explanation of sketches

The chord diagram in Figure 7 consists of an outer circle with topics that are divided into three categories; fully integrated systems, technical compartments and people. Fully integrated systems are robot avatars that are already fully developed and in use. The technical compartments shows different technologies that are used in different robot avatars. These contain technologies in the slave subsystem, the master subsystem, but also technologies that are responsible for communication within the whole system. People shows individuals, but also groups like universities, research groups, teams, companies and more. In the middle of this circle there are connections between the three categories. A user can start from any category, pick a specific subtopic and follow the lines to see the connections. This shows which people are working on which technologies and what interventions they are used for. Also the thickness of these connections matters, for example, if you follow the chords of one specific university and there is a chord occupying 50% of this block, this topic is researched more by this university in comparison with a chord that only takes up 10% of the block. This idea follows the normal way of presenting data in a chord diagram.

The layered diagram in Figure 8 consists of planes and lines through these planes, this visualisation was based on the collaboration network analysis of the general list of visualisations. The implementation however is different. Each plane represents its own topic, here the examples are the master subsystem, the slave subsystem and the teams participating in the ANA Avatar XPRIZE competition. Every plane has circles with subcategories. The user can just focus on one of these planes and find the information per topic and subtopic. But to not lose the general overview, there are lines through these planes to see how the different topics are connected.

The task-based diagram in Figure 9 is a word web. However, there is not one centre but several main points representing the different fields in which robot avatars are used. This idea came from the topic model from the general list of visualisation types. The goal of this

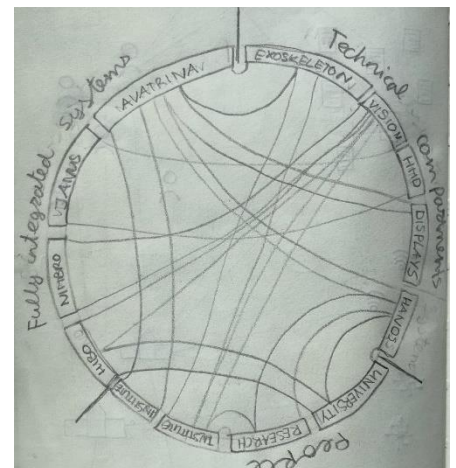


Figure 7 Chord diagram sketch

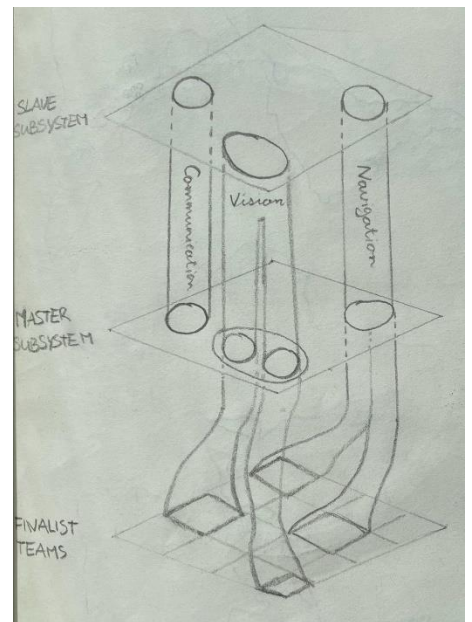


Figure 8 Layered diagram sketch

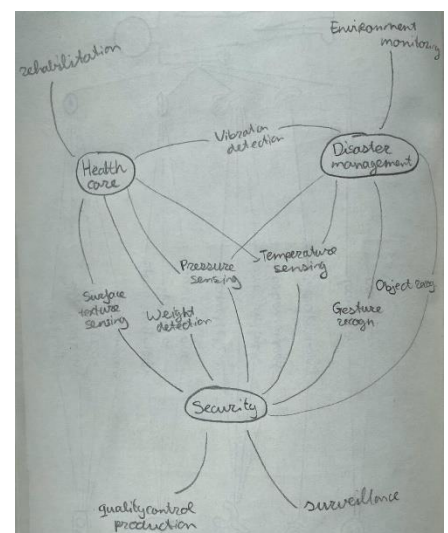


Figure 9 Task-based diagram sketch

visualisation is showing information based on the tasks that the robot should be able to perform. The tasks are linked to different fields of application, giving the developer a broader view of the robot avatar field, not just their own subfield. In this example the subfields are health care, disaster management and security, but this can be expanded. Some functions are only used in one specific field, other functions can be applied in multiple, if not, all fields.

The map visualisation in Figure 10 shows where the centres of activities are. This type of visualisation was used a lot in the Gapminder tool and Atlas of Economic Complexity. The timeline shows how this progresses over time. On the map institutes, companies, universities and teams are displayed. The goal of this visualisation is for the user to get an understanding of where the important actors in the field are in the world.

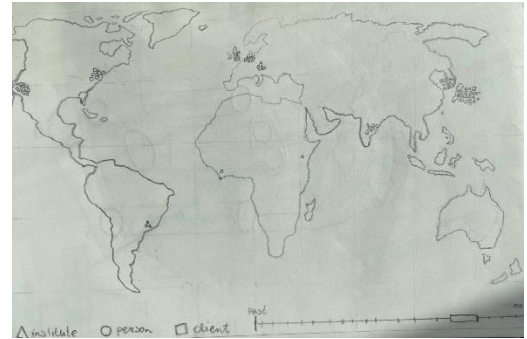


Figure 10 Map sketch

The network diagram in Figure 11 focuses on research papers. These papers could be very broad explaining a whole avatar system or the papers could be very detailed and oriented on one specific topic. The idea for this visualisation came from the Research Rabbit tool mentioned in the state of the art. However, what differs from this visualisation is that not only references, citations and authors are connected, but also topics and institutes play a role in this overview. To indicate the differences, icons are used instead of bubbles. Also the grouping plays a role, this was based on the network diagram from the general list of visualisations, where there are borders in a network graph to indicate different groups. The placement of the icons on the graph is inspired by this.

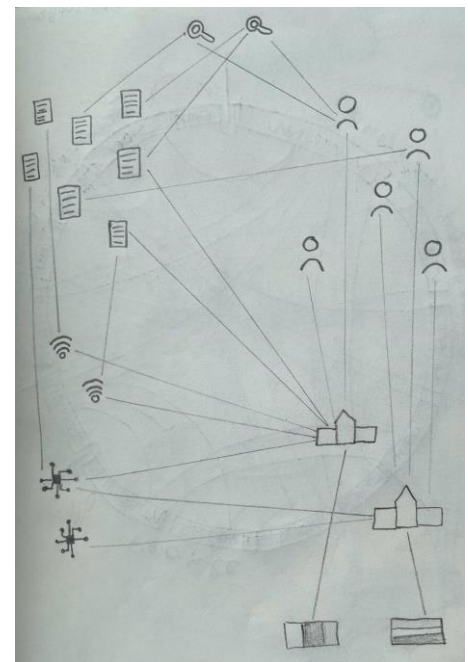


Figure 11 Network diagram sketch

The sense-based diagram in Figure 12 is showing the senses or body parts of the human operator and how it connects to the robot. Per sense of the human there is a connection to what they output and what they receive. This is matched to the technologies and hardware of the robot. Only one fully integrated system is shown in the visualisation, the goal is for the user to get an understanding of how the technologies in that system work. The icons in the visualisation are the eye, mouth, hand, ear, but also the foot. This visualisation was inspired by an explanation video on the website of Avatars.Report, which is also where the result of this project will be published [1]. The original visualisation can be found in Figure 14, the added difference is that in this sketch the topics are grouped by senses and body parts to allow the user to find what they are looking for more easily.

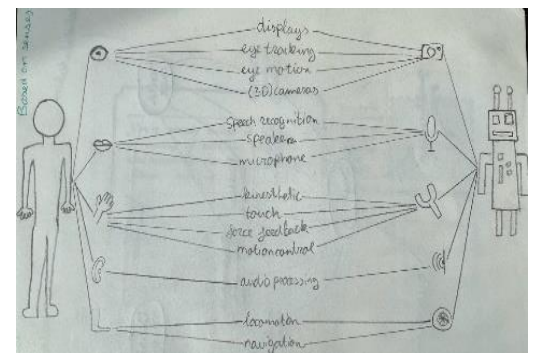


Figure 12 Sense-based diagram sketch

The last visualisation is the topic evaluation Figure 13. This is word web just like the task-based diagram. The difference however is that this diagram does have one central point: Robot avatars. From here there are several topics are evaluated. In this example the topics are evaluation, the teams that participated in the ANA Avatar XPRIZE competition and the technologies used in the avatar systems. These topics can then be subdivided to

give a better understanding. Here the technologies are divided in the remote robot and the operator. Also connections between these subtopics are made to see how they are related. At the smallest scale there are connections to research papers, people and institutes working on the technology. The inspiration for this visualisation came from the topic evaluation from general list of visualisations. The goal is to give an overview of the whole field, with a broad view, also including different subfields like evaluation. To summarize, sketches of seven different visualisations were made. An overview of the inspiration, goal and dimensions in each of these visualisations can be found in Table 1.

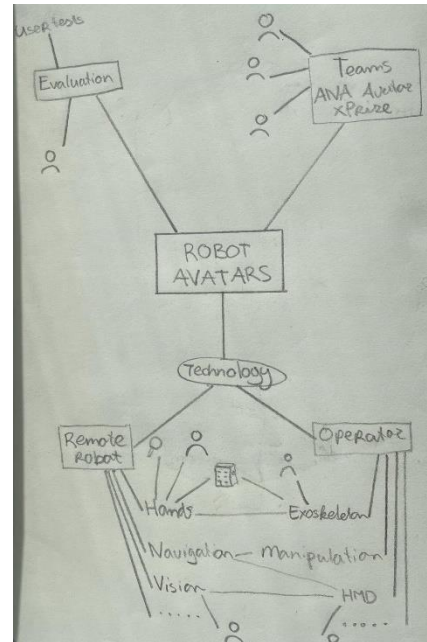


Figure 13 Topic evaluation sketch

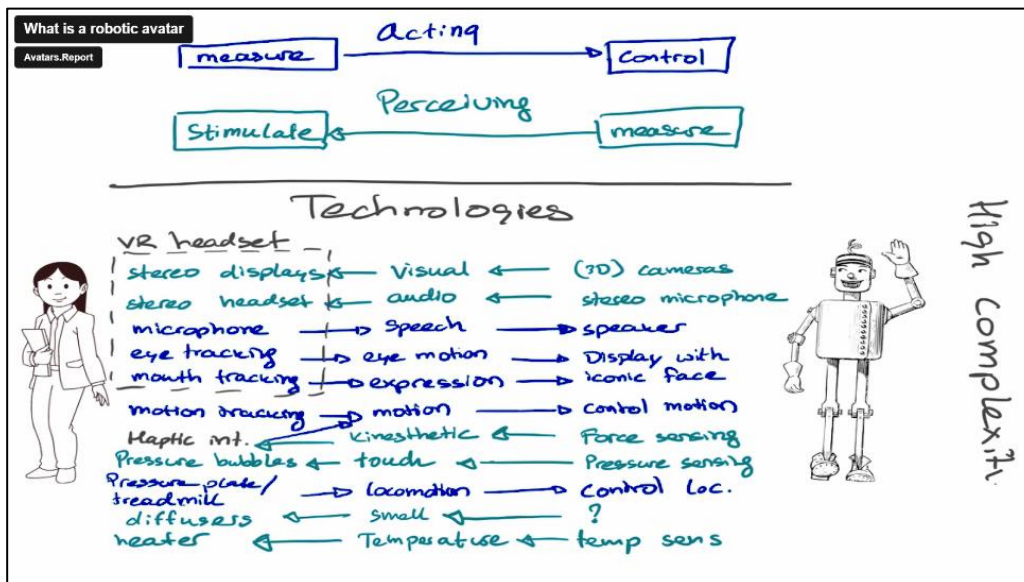


Figure 14 Screenshot of explanation video What is a robotic avatar on Avatars.Report

Name	Inspiration	Goal	Dimensions
Topic evaluation	General visualisations: Topic evaluation diagram	Containing everything in one graph with a lot of different elements, that also show interconnectedness	Evaluation, ANA Avatar XPRIZE Teams, Technology (split into the remote robot and the operator)
Layered diagram	General visualisations: Collaboration network analysis	Being able to focus on a specific plane (only one subtopic) while still seeing the connections to other subtopics	Slave subsystems, master subsystems, finalist teams of the ANA Avatar XPRIZE competition
Map	State of the art: Gapminder and Atlas of Economic Complexity	Overview of where the centers of activities in the world are and how they develop	Location, Time
Network	General visualisations and state of the art: Combination of research rabbit and network diagram	Relation of research papers, authors and topics	Research papers, research topics, people, institutes, countries
Chord diagram	General visualisations: Chord diagram	Relation of systems and separate parts, including who works on what	Fully integrated systems, technical compartments, people
Sense-based diagram	Other: Explanation video on Avatars.Report	Finding hardware possibilities	Topics grouped by senses/body parts (eye, mouth, hand, ear, foot)
Task-based diagram	General visualisations: Topic model	Find information based on the robot's intended capabilities	Application fields, tasks

Table 1 Overview of visualisation ideas with their point of inspiration, goal and dimensions

4.2 Interviews with potential users

Four interviews with potential users were conducted. These are the end users of the tool and people working in the field of robot avatars. Even though they all work in the same robot avatar field, their work was really different, sometimes even in a different subfield. Nevertheless, all these potential users are included because the goal of this visual overview is that it can be used by all people that work in the robot avatar field, regardless of their specific work. In the coming section an introduction to the potential users is given.

The first interview was with a researcher of robotics software for 3D navigation and mapping. This is used for a robot that firefighters can use when the circumstances of a fire is too dangerous for a human to go in. The information that this potential user needs in their work is an overview of technologies and hardware that may be used in these robots. Currently this information is found by a general exploration on internet.

Struggles that arise with searching information is that there does not exist a lot of academic research due to the application field being niche. At a certain point all the research is found, then new technologies have to be explored and new applications can be tested. Another struggle is to figure out the quality of a certain technology. It is hard to know if something actually works or if there are just “empty promises”.

The next potential user focuses on the development of robot hands, they are mainly responsible for the system engineering and hardware. The information that this potential user needs in their work is a) an understanding of what technology is available, who owns it and what it does, and b) what applied projects are, who owns them and who funds them. Currently this information is gathered by personal network, going to congresses, visiting information talks, subscribing to the Google newsletter and contacting specific people to discuss ideas. The most important thing in this information gathering is credibility of the information, engagement and network of the people and the structure of the information.

Another potential user focuses on control and manipulation of a robot, they develop the software for the movement of the robot. The information that is needed in their work is getting an idea of what is on the market, finding the right technologies to use in a new project. The current way of finding this information is by internet searches, research papers and personal network. The struggles in finding the information is because the market is very niche, it is hard to find the newest technology on the market, and need to know a lot about a technologies in order to make a good decision on what technology to use. The main criteria are that the piece of equipment is robust, fast, and simple to use.

The last potential user works on recognizing human behaviour to model interactions of robots with machine learning, this is mainly used in social robots. The information needed in this work is datasheets with the developments in new technologies in electronics. The current way to find this information is literature, but also informal internet search. The main struggles are that the application that is needed is very niche, this leads to having to do a lot of research before a proof of concept can be made.

4.2.1 Current information retrieval

It is important to know what information the users currently need in their work and how they retrieve this information. From the struggles that they experience now, a lot can be learned about possible requirements for the tool.

The main point of information that the users are searching for is technologies that are on the market. They like to know what technologies are made, who owns it, who funds it and how it is used. This information is needed for selecting which technologies to use in their own projects. Currently the main methods of finding this information is internet search, reading academic papers and through personal network of contacts. Some other methods are going to congresses, signing up for newsletters of tech companies, or visiting information talks. Requirements that were mentioned for good information are credibility, good structure of information and the information being up to date. However, currently it takes a lot of time to find good information and there are quite some struggles that are experienced by the potential users. The main struggle is that when potential users are searching for which hardware they can use, they are looking for a proof of concept. However, the ways that they are applying technologies is often in a niche branch with innovative ideas of application or combination of technology. This makes it hard to find a proof of concept in academic literature or internet search. There are some smaller struggles that, when combined, cause this struggle. For example; not knowing if a technology is optimally functioning or if the designers make “empty promises”, where they promote the product to be better than what it actually is. Also, sometimes the interview participant is working in such a nice market that they eventually already know everything that is available in that specific niche, if this is not what the interview participant is looking for, this becomes a problem. It is also hard to find the newest technologies, users mention that it is hard to stay up to date. The last struggle that was pointed out by an interview participant is that someone needs to know a lot about a lot of different technologies, in order to make a decision of what technology they can use. This can be overwhelming to someone that is new to the field, or to a user that has to work outside their normal niche. To summarize in Table 2 there is an overview of the interview participants can be found with their information sources, content of information and struggles with finding information.

In this overview there are several components that seem to be important for the users. These can be taken into account when selecting ideas in the next steps and phases of this project, some interesting components for the content of information are the people working in the field, hardware possibilities and projects. This also relates to the way of information gathering where internet search, research papers and personal network take the lead. These elements can be the main goal of the users to use the overview to gather information. Therefore, it is important to see how these elements can be incorporated in the visualisation ideas. In Table 3 an overview can be found what the current matches between the ideas and potential goals are. Besides that, the network and the task-based diagram also touch upon a specific way of information gathering and solving a struggle of the users.

	Information sources						Content of information					Struggles finding information					
Expert	Internet search	Research papers	Congresses	Personal network	Information talks	Newsletter	Overview of hardware	Functions of people	Projects	Hardware in projects	Contacting new people	Too niche	Quality	Credibility	Structure	Newest updates	A lot of prior knowledge needed
	4	2	1	2	1	1	3	2	2	1	1	3	1	2	1	3	1
Researcher of 3D navigation and mapping	x						x	x				x	x			x	
Robot hand developer	x		x	x	x	x		x	x	x	x			x	x		
Software developer	x	x		x			x	x				x	x			x	
Researcher human robot interaction	x	x					x					x				x	x

Table 2 Overview potential users, information sources, content of information and struggles with finding information

	Overview of hardware	Functions of people	Projects	Extra notes
Topic evaluation	x	x	x	
Layered diagram			x	
Map				
Network		x		Research papers
Chord diagram		x	x	
Sense-based diagram	x			
Task-based diagram				Too niche

Table 3 Overview of visualisation ideas in comparison with the goals of potential users to use overview

An improvement that can already be made on basis of this insight is, instead of only showing the hardware of one system in the sense-based diagram, showing different hardware possibilities in subcategories. Also a link to projects can be added to make the visualisations more useful for the users.

4.2.2 Evaluation of sketches

Due to the different nature of the work of the interview participants, different visualisations were preferred. After explanation of the seven sketches, preferences were asked. There were no limits to the amount of visualisations they could speak their preference towards, they named between two and four visualisations. Topic evaluation and the sense-based diagram both had preference of three interview participants. Chord diagram and network diagram were both named twice. The map visualisation was no one's favourite, the others were just named once. This can be seen in an overview in Table 4. The interview participants provided feedback on the sketches that they preferred. In the following section the feedback for each visualisation is explained, in the order of most preferred to least preferred, and afterwards an overview of feedback that applies to all visualisations is given.

	Topic evaluation	Layered diagram	Map	Network	Chord diagram	Sense-based diagram	Task-based diagram
	3	1	0	2	2	3	1
Researcher of 3D navigation and mapping					X	X	
Robot hand developer	X					X	X
Software developer	X			X		X	
Researcher human robot interaction	X	X		X	X		

Table 4 Preferences interview participants had towards the visualisations

The sense-based diagram is a good overview of translating from the human to the robot and functions as a bridge. The potential user that works with firefighters can also use this visualisation to communicate to the users of the robot avatar system. Without having to have technical knowledge, the overview can give the firefighters an idea of how to use the system. Some points of feedback are that the distinction has to be made clear if it is ingoing or outgoing sense. This was mentioned by all the interview participants. Other points of feedback were that it must have more detail and that technical communication should be included as well. In the current state of the visualisations, just separate parts are named, however, actual integration and communication between different parts of the system is still lacking. When this visualisation is worked out further it is important that there is also a brainstorm about what more components should be included. A potential user mentioned the idea that there are more functions that are mapped from human to robot and vice versa that are not included in the typical 5 senses. This is why also the body parts, like the foot, are included.

The topic evaluation was appreciated by the interview participants, the main reason for this is that it feels complete. A lot of different pieces of information can be found within this way of visualizing the data. Therefore even interview participants whose working field was completely different, still favoured this visualisation in the same way. This graphical way of visualising also allows for easily expanding the visualisation to other areas, examples that the interview participants named are communication, tools and transportation layer. This does bring up the question where to draw the line with expanding the database on which the visualisation is based. Too much information will be overwhelming. Another remark made by a potential user is that systems can have a philosophical different approach, which if decided to be included in this overview, does not fit in the structure of separating the system into the human operator interface and the remote robot.

The network visualisation was preferred by the two interview participants that also indicated that a part of their current way of information retrieval is research papers. However, the main warning was that it can get

very complicated when more data points are added. Another feature could be that also the links between research papers are shown. This will give the user an idea of citations, references and relationships of the papers. An advantage of this visualisation is that it could be possible to automatically update the overview if it is based on research papers. This would help with the accuracy of the overview and the ability to access the newest information. Because of this element, this visualisation could also be of interest to the other interview participants, since it solves the struggle of not being able to find the newest research papers.

Two interview participants indicated that they like the chord diagram, however this was mainly because of the content that was shown, and less about the actual visual way of presenting the information. The main disadvantage was the amount of lines which makes the overview difficult to read and gives it a messy impression. Possible improvements that were mentioned is adding colour and interaction to the diagram. Filtering out information and being able to highlight certain elements would make the finding the exact information the user needs more manageable. The content where you link separate parts to fully integrated systems is appreciated. Also the inclusion of people in this overview is beneficial for the users. One interview participant mentioned that a preferred way of visualising this content would be in a graph visualisation. The layered diagram was mentioned as useful only by one interview participant. They liked that there is a possibility to just focus on one subtopic, by only looking at one plane. However, they would prefer to see the visualisation horizontally instead of vertically. This gave the impression that the subtopics are stacked with an ordering of importance, which is not the case. Another interview participant did not like this visualisation because they were confused and did not understand the data at first glance.

The task-based diagram shows a perspective that is really different than the other visualisations. This visualisation forces the interview participant to think about the tasks the robots should perform and the functionalities the robots should have. This also allows the users to look into the applications of robot avatars in a subfield different than their own. This is also a struggle that was mentioned by the interview participants, their subfield is too niche and specific. Even though this was a struggle that 3 interview participants mentioned, this way of visualising was not preferred by the interview participants. Interestingly enough, the interview participant that chose this visualisation as a sketch that has potential, was the only interview participant that did not report having the struggle of their field being too niche. Feedback on this visualisation includes that there should be more detailed information to be useful, and it would be more applicable to the working field if it also includes technologies and hardware. Because one interview participant mentioned that they would not imagine a way how they would use this visualisation in their actual work.

The map visualisation is not useful for the users. None of the interview participants put this visualisation on their favourites list. It also has none of the dimensions which can be seen in Table 3, and address a different struggle or specific information gathering technique. The interview participants said that the map visualisation would be fun to look at, but not useful in actual work because the users don't take a location based approach while searching for information.

There are also quite some general points of feedback that could be applied to multiple or all visualisations. The most important thing is adding colour, transparency and thickness of lines to get more variation in relationships. Also, interaction is needed to filter out irrelevant information. All interview participants mentioned that they would also like to be able to highlight and focus on specific parts of the visualisations. A big topic that was missing in all the overviews but would be useful for the interview participant that works with robot hands is the communication between technologies. Other interview participants mentioned this too but put less emphasis on it. The next point of feedback is the importance of showing the difference between quality and quantity. Evaluation is important for users that are trying to find new technologies that they could work with. The last point is that a few visualisations could be combined to give a more complete overview of the field. Combinations that were mentioned more often was topic evaluation, sense-based diagram and network diagram.

Other ideas for the tool that were not directly related to the visualisation type were also discussed during the interview. A notification centre would be nice to know what new information was added to the tool. Also, an indication of sources that were already visited is useful to not having to repeat research. This would solve the struggle of finding the newest information.

From all of this feedback, a list of requirements for the tool can be made. For this, the MoSCoW method is used. With this method requirements are ranked based on their priority into the categories: Must have, Should have, Could have and Won't have. In the development process the order of implementing new features will follow the order of these categories. The requirements that can be found in Table 5 are general requirements that could be applied to all the visualisations.

Must...	Should...
... have interaction	... have difference in colours
... be intuitive to understand	... show difference between quality and quantity
... have a filter for information	... be as complete as possible
	... be understandable for people without a lot of prior knowledge
Could...	Won't...
... have difference in transparency	... have too much information that overwhelms the user
... have difference in thickness of lines	
... have a notification centre where newest additions to the overview are shown	
... have evaluation of technologies	
... have an indication of sources that the user already visited	

Table 5 MoSCoW requirements for the tool based on the feedback from the potential user interviews

4.3 Conclusion of interviews

Based on the findings from the interviews the first sub question can be answered; *What is the goal of the users for using this tool and what information would the users like to have access to?* The goal of the users that want to use this tool is to quickly find information that is structured, credible and updated, without having to spend a lot of time researching. The information that the users would like to have access to differs per person, but the main three categories are people working in the field, hardware possibilities and/or already existing projects.

4.4 Selection of ideas

In the ideation phase seven ideas for visualisations were made and sketched out. The visualisations were topic evaluation, layered diagram, map, network diagram, chord diagram, sense-based diagram and the task-based diagram. These were evaluated by conducting interviews with potential users working in the field. From these interviews also other insights were acquired, such as current methods of information retrieval and the struggles that the interview participants currently phase with this. From this feedback a list of MoSCoW requirements are made.

From the seven sketches a selection must be made to continue to the next phase (Specification). This selection is based on how many interview participants chose this visualisation on their favourites list. The visualisation with zero votes or just one vote are immediately eliminated. This is the map visualisation with zero votes, the task-based diagram and the layered diagram only had one vote. The sense-based diagram and the topic evaluation, however, were the most voted visualisations and chosen by three interview participants each. Therefore, these two visualisations are taken to the next phase. Then only the chord diagram and the

network diagram are left, both with preference from two interview participants. These two visualisations are in the middle field, not good enough to be favoured by most interview participants, but not bad enough to be immediately discarded. A closer look at the feedback and other criteria has to be taken. The feedback makes it clear that one interview participant only voted on the chord diagram because they liked the categorization that was used, however spoke very clearly against using the chord diagram as a visual representation of this categorization. This feedback can be taken into account and this categorization may be applied to another sketched idea. Since this selection is purely about the visualisation type, the chord diagram will not be taken to the next phase. This only leaves one visualisation, the network diagram. From the feedback it can be found that multiple interview participants did see potential in this visualisation, this is because research papers are a component in information gathering for two express, and also allows the user to find people, which is an essential part of information that is needed by the interview participants. All of this together makes the network diagram a visualisation with enough potential to be taken to the next round.

To summarize, the three visualisations that are worked out further in the specification phase are the sense-based diagram, the topic evaluation and the network diagram. An interesting remark is that when combination ideas were mentioned by the interview participants, it always was a combination of two or all of these visualisations.

5 - Specification

In the specification phase the sense-based diagram, the topic evaluation and the network diagram is developed into low fidelity (LoFi) prototypes. The prototypes are made in a software called Figma, which can be used for designing interfaces and adding interactions. The design is made in an iterative process consisting of three rounds. Each round feedback is provided by two participants. After the interviews evaluating the prototypes, feedback is implemented, and a new round starts where the process is repeated. In the coming chapters each iteration round is discussed, in every round the current state of the LoFi prototype of each visualisation is explained, afterwards the feedback is given. To reduce the time spent on making the LoFi prototypes, but still ensuring that the evaluation participants can understand the overview, only one example of an interaction is made and not all data is incorporated. The goal of the LoFi prototypes is quickly gathering feedback and testing if the visualisation would be a useful tool.

5.1 LoFi interview structure

For each iteration round there were two interviews, this was repeated three times. That makes six interviews in total. All these interviews had the same structure and were with the same two participants. The participants are potential users from the user target group, but were different to the interview participants in the ideation phase. The interviews took between 30 and 50 minutes. With the interviews of the first iteration round taking the longest because more things had to be explained. Every interview started with a welcome and a small briefing of what happened in the project prior to the interview and the goal of that interview. In the first interview round also the software Figma was shortly described and the sketches of the ideation phase were shown.

When the participants were shown the LoFi prototypes they did not get an explanation about the visualisation. They were free to interact with the overview without any guidance or time limit. They could ask questions and make comments at any point in time. The feedback was often given gradually, i.e. some comments were made while interacting with the tool and when all the pages of the tool were explored, an overall feedback of the visualisation was given. After this a conversation about the feedback started in which new ideas were proposed from both sides, the interviewer and the interviewee.

During the interview quick notes were written down, which were eventually worked out and compared in a Venn diagram per visualisation per iteration round. Most of the feedback is implemented for the next round, in case the participants say contradictory things, either the developer chooses what they think fits best. If both options are made they may be asked for more feedback, or the developer will choose between them. If the feedback does align with both participants, or if ideas from both are different but have the potential to be combined, the developer does not have a choice and makes the improvements according to the feedback.

5.2 Iteration round 1

In the first round the LoFi prototypes were created from scratch. At first, interface was designed just like the sketches. Afterwards interactions were added and improvements to the design were made. Not all interactions that are intended are already in the overview, also not all data is in the overview yet. There are already some changes to the visualisation compared to the sketches, the biggest change is that there are different pages, to which the user can click to get more detailed information about certain topics. Also use of colours and use of pictures and icons are introduced. Also some other small improvements are made based on the feedback of the interview participants from the ideation phase, these specific changes are discussed in the explanation of the LoFi prototype per visualisation.

5.2.1 Sense-based diagram

The home screen of the sense-based diagram can be found in Figure 15. The home screen contains the main overview, which looks similar to the visualisation in the sketch. However, now there are pictures instead of

drawn icons. Arrows are added to indicate the direction of the connection between a sense and a technology, this was feedback of the interview participants from the ideation phase. Another change is the goal of this visualisation, at first this visualisation was intended to just show one fully integrated system and how the technology in that system works. However, after the interviews with the potential users, a more useful visualisation idea was brought up, now the visualisation is about robot avatars in general and has the goal of showing the users different hardware possibilities for different human-robot connections, just like what was mentioned in 4.2.2 *Evaluation of sketches*. The interactions that have been added in this overview is that the user can click on one of the senses to get a more detailed overview and more information about that topic. The example that is working in the LoFi prototype is the eye-camera category, when clicking on either of these pictures, or the topics between them, the user goes to the detailed eye-camera page in Figure 16. On this page the user sees the eye and the camera pictures and all the topic that belong to this category in the yellow blocks. These yellow topic blocks are divided into blue subtopics, these are different technology groups that exist within the topic. For example, Head Mounted Displays (HMD) and monitors are both subtopics of displays. Between the blue subtopic blocks there is a overview in grey listing all the companies that sell hardware of this kind. If the user clicks on one of these grey blocks they go to an overview page of that hardware, of which an example can be seen in Figure 17. On this overview page there is information about the company, its products and robot avatars that use this specific hardware. On this page the user has the option to navigate to other companies selling the hardware, on the top right of the page. Or go back to the previous overview or main overview by clicking the buttons on the top left of the page.

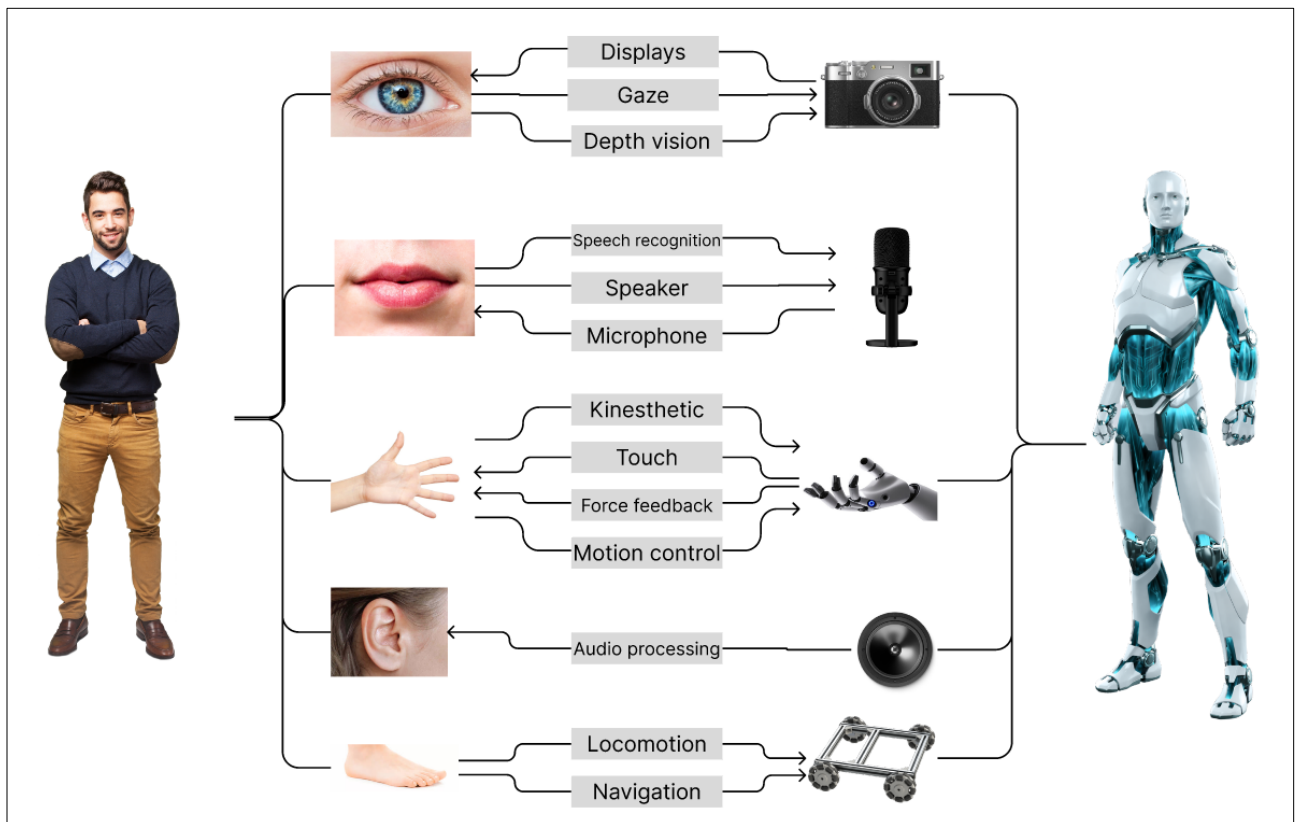


Figure 15 LoFi sense-based diagram round 1 - main overview

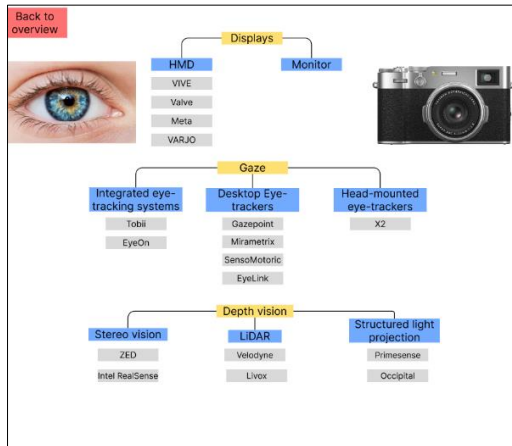


Figure 16 LoFi sense-based diagram round 1 - sense overview with subcategories

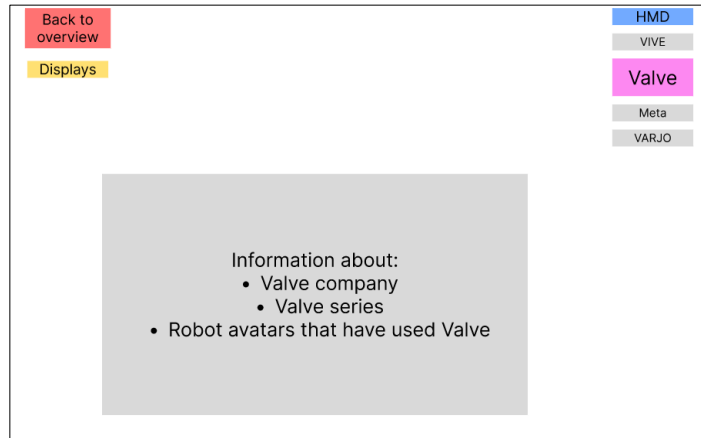


Figure 17 LoFi sense-based diagram round 1 hardware overview page

The feedback on the sense-based diagram differed a lot between the two participants. The Venn diagram of the feedback can be found in Figure 18. Overall the visualisation was clear, but the main point of improvement is the navigation and some ideas of extra features that can be added.

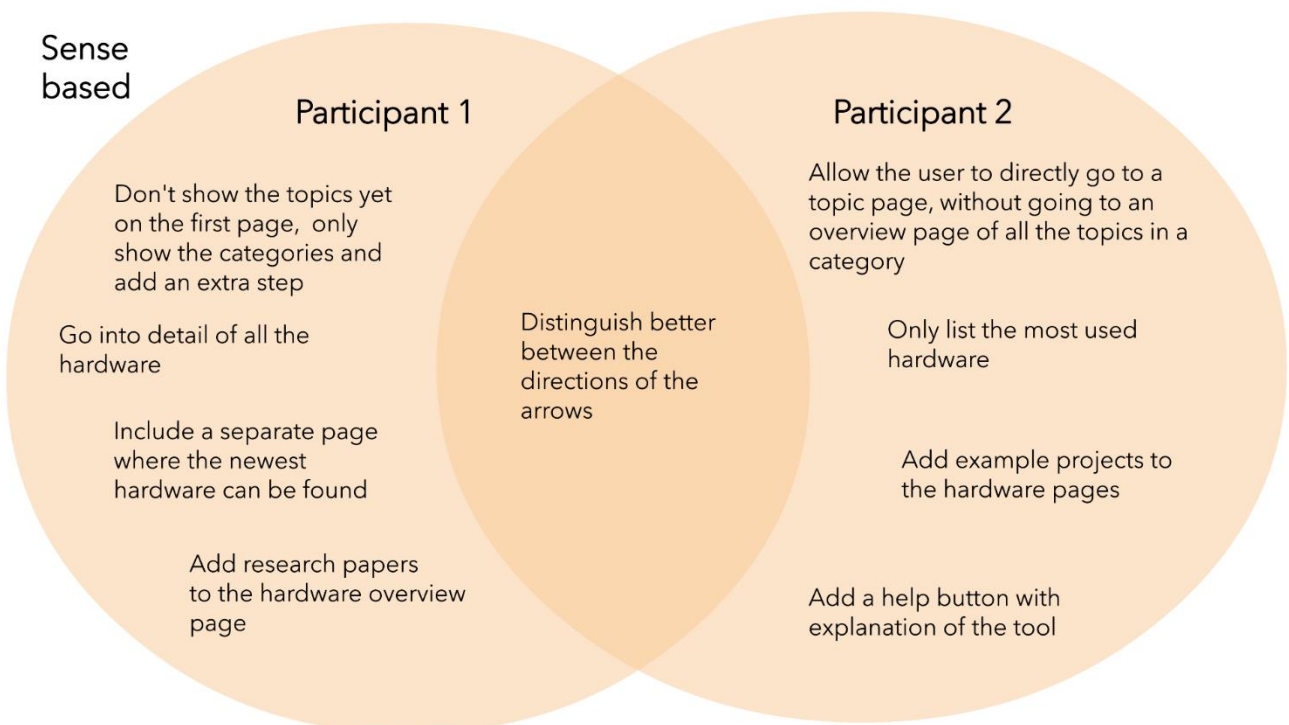


Figure 18 LoFi sense-based diagram round 1 - Venn diagram of feedback

5.2.2 Network diagram

The main overview page of the network diagram can be seen in Figure 19. The network diagram is the visualisation idea of which the LoFi prototype differs the most from the sketch. The biggest differences are

the layout and grouping of information. In the sketch the research papers were all grouped and connected to the icons of the topics with lines. The sketch showed individual people and institutions with the countries they are from. The interview participants from the ideation phase gave the feedback that the countries are not important to them, therefore the flags were deleted. The rest of the changes were made because of practicality with amount of research papers. When increasing the amount of research papers shown in the overview, the layout from the sketch is not practical, since there would be too many lines crossing. Grouping all the research papers and keeping the topics separate also was not functional, instead in the LoFi the papers are scattered over the whole overview, but grouped in circles representing the topics. The research papers are connected to teams participating in the ANA Avatar XPRIZE competition instead of individual authors. This is because the overview would have too many lines and would be too packed with information. In the LoFi there are 21 research papers, these are all the existing results from the search (ANA AND Avatar AND XPRIZE) in Scopus, online bibliographic database, at the time of creating the LoFi. The categories were created by grouping at the titles of the papers with similar topics. These categories are similar to the categories that were often used in the papers from the background research in Section 2.2 *Literature review*.

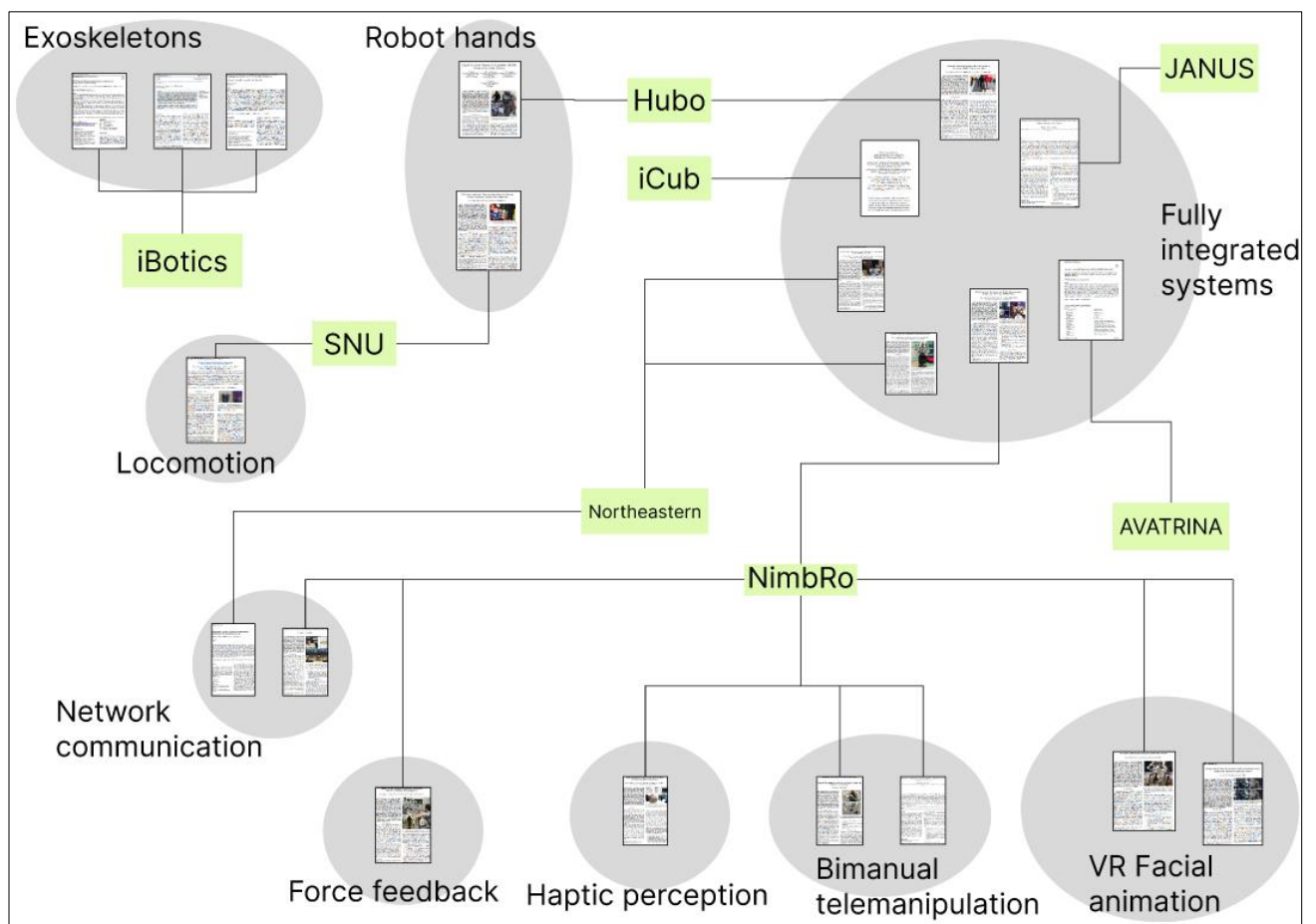


Figure 19 LoFi network diagram round 1 E main overview page

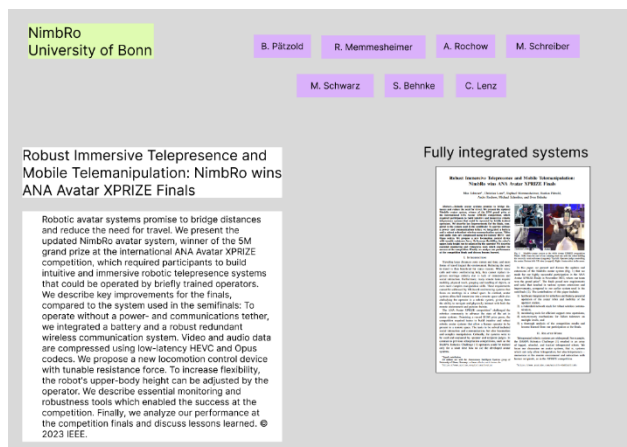


Figure 20 LoFi network diagram round 1 - research paper page

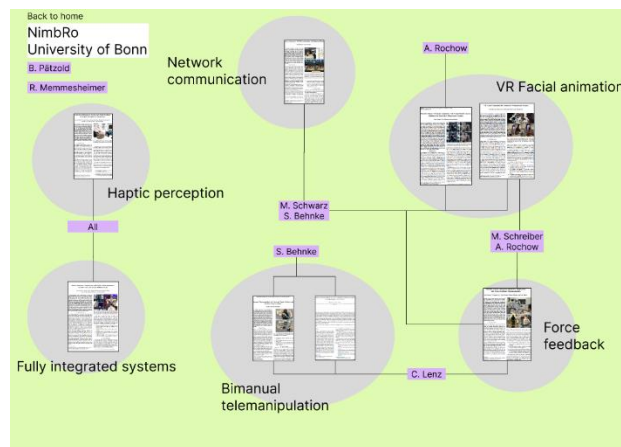


Figure 21 LoFi network diagram round 1 - team overview page

From the main view the user can click on a research paper or on a team, they will see the pages in Figure 20 and Figure 21 respectively. On the team overview page all the research papers belonging to that team can be seen, the papers are still categorized. Also, the authors of the pages can be seen, in the purple blocks, and they connect to the research papers they have written. In order to reduce the amount of lines in this overview, some authors are grouped and there is a purple block for all the writers. On the research paper page the user can see the title, abstract, first page, category name and the authors. From both the research paper page and the team page the user can click on the authors. This will lead the user to the page of that specific author, an example can be found in Figure 22.

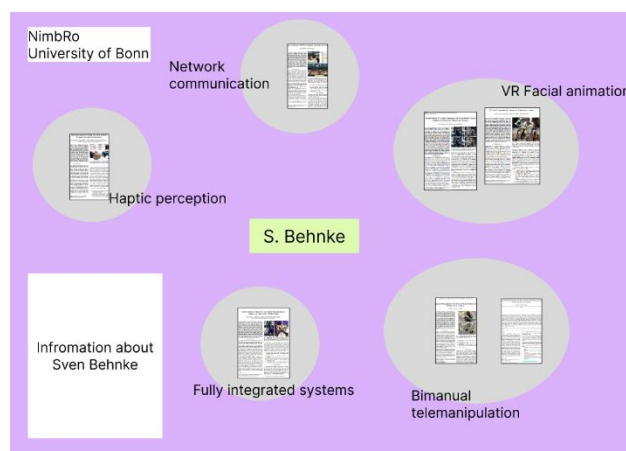


Figure 22 LoFi network diagram round 1 - author overview page

From any page the user can navigate to the team page of that corresponds with their current position. From the team page the user can navigate to the main overview page. The colours could help the user with navigation. The colours of the blocks on which the user clicks correspond to the background colour of the pages where the user navigates towards. For example, the user clicks on a green team block in the overview page, they will get to the green team page, from there the user can click on a purple author block and will navigate to the purple author page.

The feedback of the two participants from the LoFi interview had quite some overlaps, which can be seen in Figure 23. The main improvement that had to be made is the navigation, because both participants got lost while interacting with the tool. Also, the connections and the lines were not clear from the first glance. This mainly was the case in the team overview, where the authors are linked to the research papers. In order to avoid having a lot of lines some authors were in the overview twice. For example, S. Behnke, who was an author of most of the research papers, has its own purple block, but also is present in a combined block with the M. Schwarz, because on they were working together on six research papers. This was not noticeable for the participants and therefore during the interview several new ideas were made to visualise this in a better way. Both participants named the same idea of separating the authors on one side of the overview and the papers on the other side of the overview. There were a few other points of feedback, but the main feedback was about the navigation and way of visualising the author-paper connection.

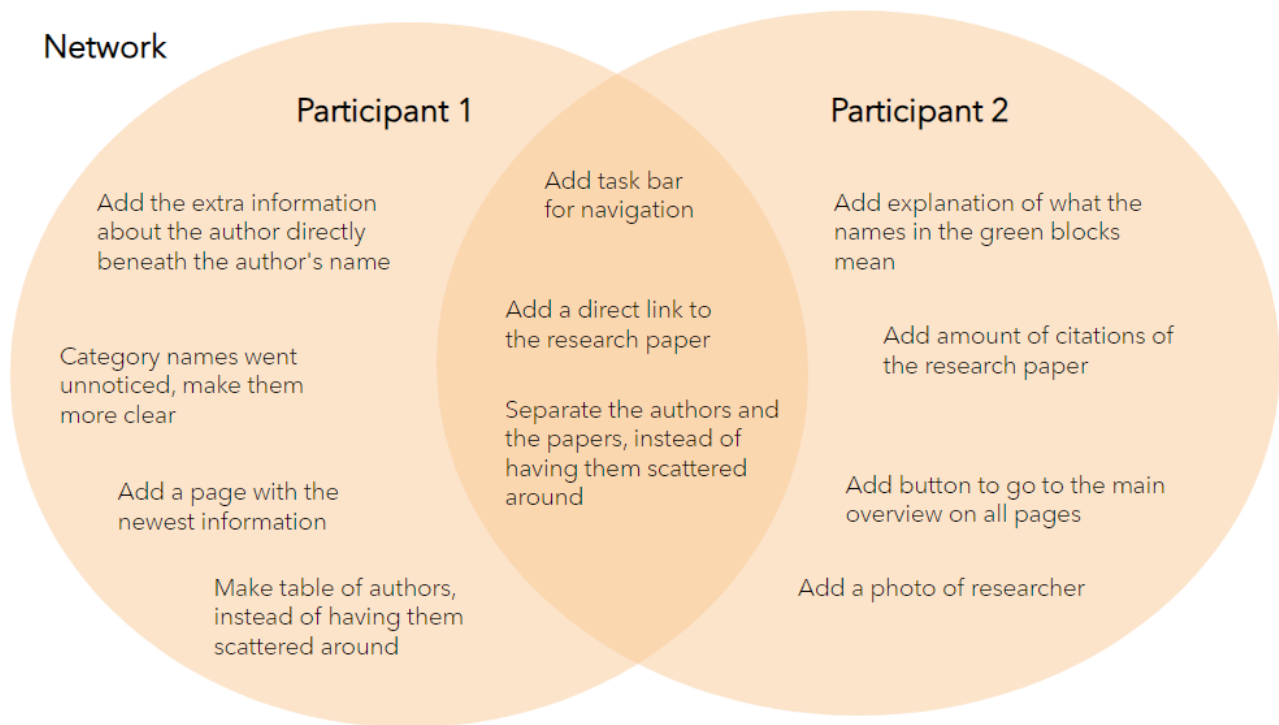


Figure 23 LoFi Network diagram round 1 - Venn diagram of feedback

5.2.3 Topic evaluation

The topic evaluation LoFi can be seen in Figure 26 and still looks similar to the sketch, the only difference is that there are also research papers added to the visualisation. This addition was made because the goal of usage of this visualisation changed. The interview participants from the ideation phase mentioned that they often have to find people working in the field and what their functions are. Therefore the focus of this visualisation shifted to allow this tool to be used in that way. On the main overview page the user can click on the icons of the research paper or a person to find more information about it on their overview pages, which can be seen in Figure 24 and Figure 25 respectively. On the research paper page the user can find the people that were involved with this paper and what their role was. These people are connected to institutions which can be seen with the institute symbols. There is also some information about the topic in which the research paper falls, in this example exoskeletons. The person page is similar, the user can find the institutions that this person belongs to, the research papers of which this person had a role has listed and also an explanation of their main work field can be found on the page. From both of these pages the user can click on the institute icon and will arrive at the institute overview page, which can be seen in Figure 27.

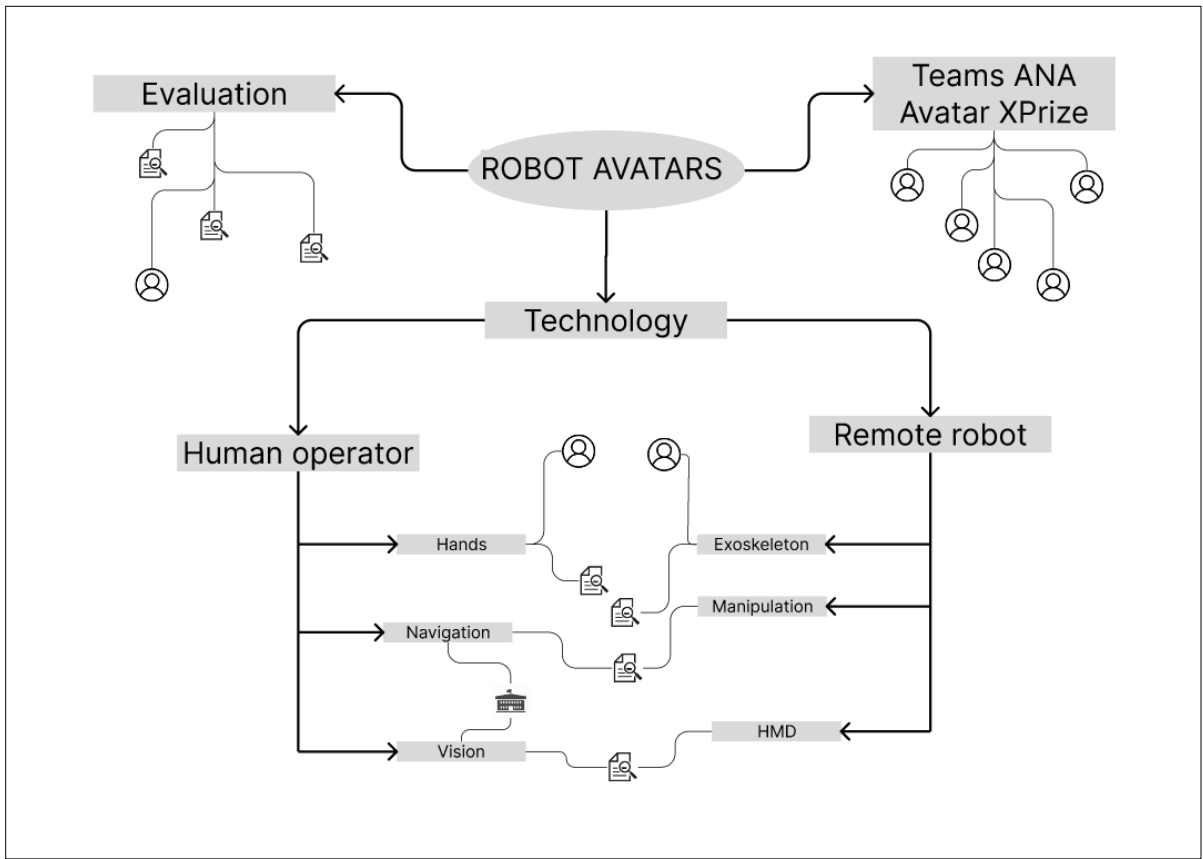


Figure 26 LoFi topic evaluation round 1 - main overview page

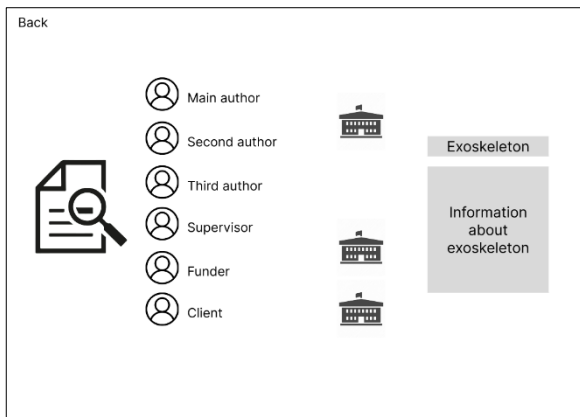


Figure 24 LoFi topic evaluation round 1 - research paper page

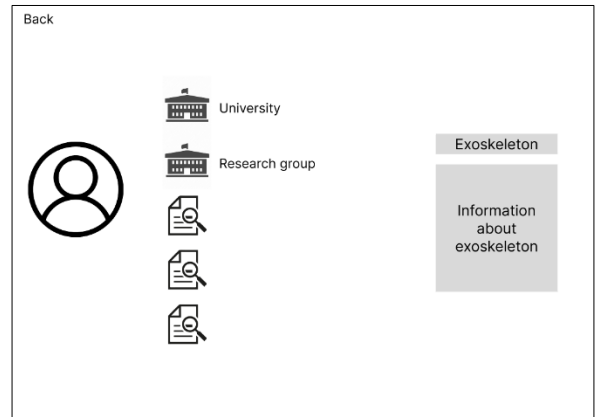


Figure 25 LoFi topic evaluation round 1 - person page

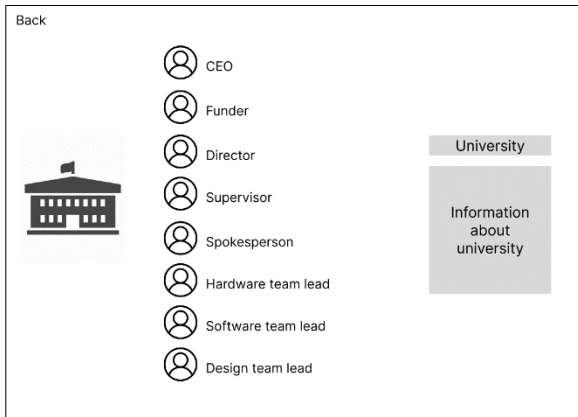


Figure 27 LoFi topic evaluation round 1 - institute page

On the institute page the people connected to this institute can be found with their corresponding role. Also more information about the institute can be found, in this example a university. On all the pages there is a back button in the top left corner, which will lead to the main overview page.

The feedback from the LoFi interviews about the topic evaluation can be found in Figure 28. The topic evaluation was the LoFi that was not fully developed yet because of the change in focus in this visualisation. The new goal of this visualisation, however, was not clear to the participants. This could be improved by changing the word that is in the centre of the graph and by using projects instead of research papers. This allows a more varied view of the field and also comes closer to what the users actually need as information. When there is a focus on the projects, research papers can still be included, but play a less significant role in the overview.

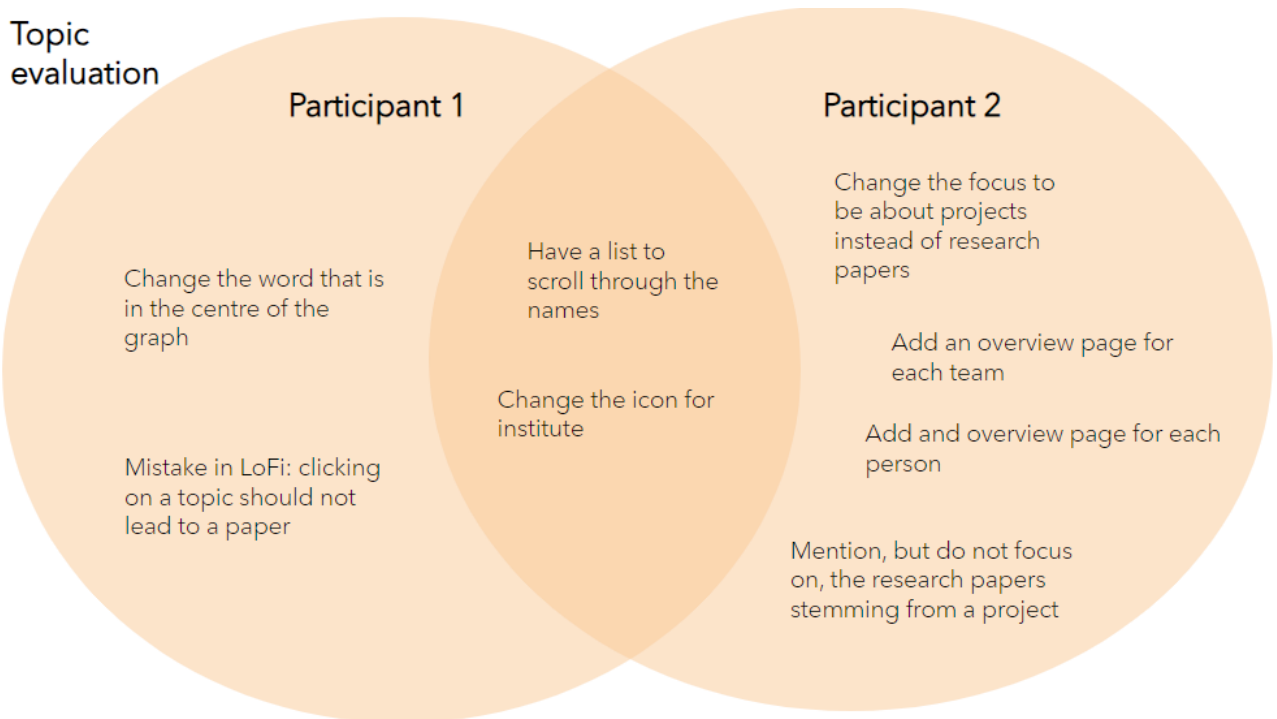


Figure 28 LoFi topic evaluation round 1 - Venn diagram of feedback

5.3 Iteration round 2

In the second iteration round the feedback from the master students was implemented. These changes were then shown again and new feedback was gathered. In the coming part of the section the changes made to the LoFi prototypes is discussed.

5.3.1 Sense-based diagram

The improved version of the sense-based diagram can be seen in Figure 29. The arrows now have colours making it easier to distinguish the directions. Blue arrows lead from the robot hardware to the human sense, and the red arrows lead from the human sense to the robot hardware. A see more button was added to the overview to reduce the amount of topics that are shown per category on the main page. The see more button contains multiple topics, therefore there are no directional arrows and no coloured lines to this block. Two more buttons are added to the overview, see what's new and help. The first button would give a list of hardware that was added to the overview since the last time the user looked at the overview. The help button leads the user to an explanation of the tool, which can be seen in Figure 30.

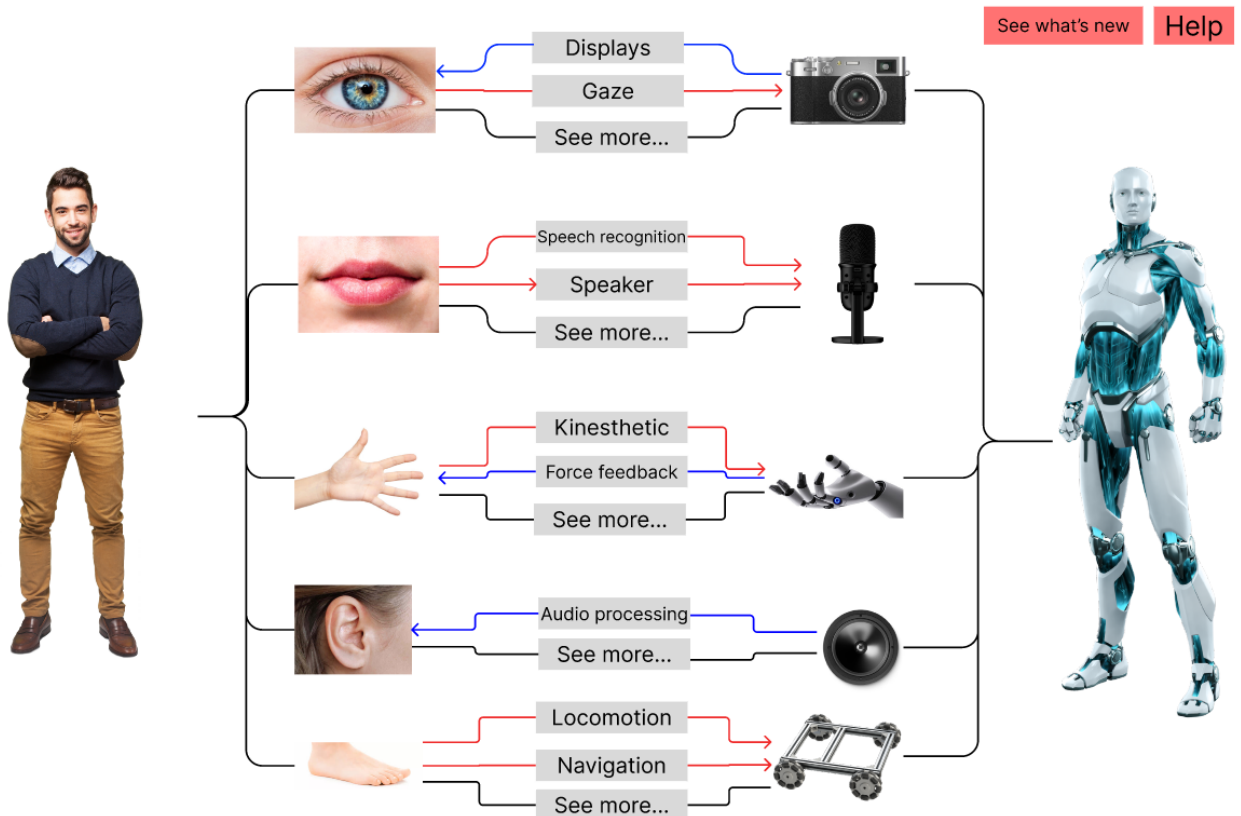


Figure 29 LoFi sense-based diagram round 2 - main overview page

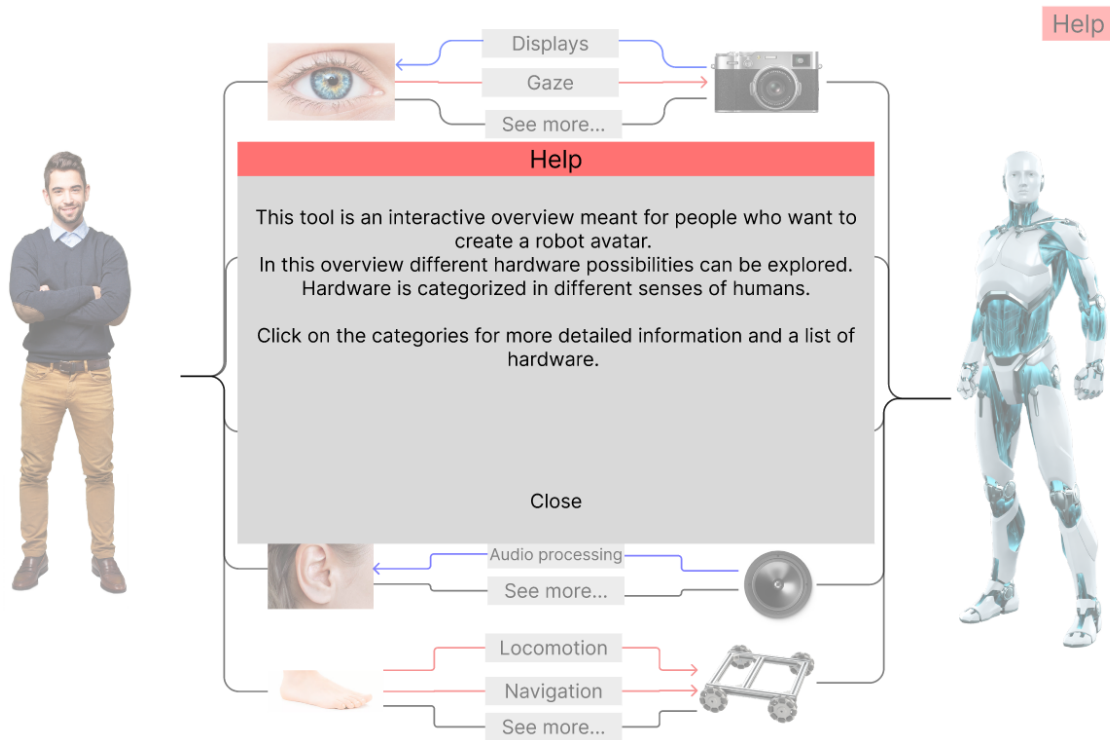


Figure 30 LoFi sense-based diagram round 2 - help

The biggest point of feedback for the sense-based diagram was the navigation. The new way of navigating in this improved version is having separate pages for the topics within the categories, for example, the topic *displays* now has its own page (Figure 31), and the category *eye-camera* also has its own page (Figure 32). This allows the user to directly click on a topic from the overview page and navigate towards this topic's page. In the last version when the user would hover their mouse over a topic, it would still be registered as just hovering over a whole category, and therefore go to the category overview page. On the topic page, there is a menu at the bottom of the page to allow users to navigate to different topic in this category. When *see more* is clicked the user will navigate to the overview page.

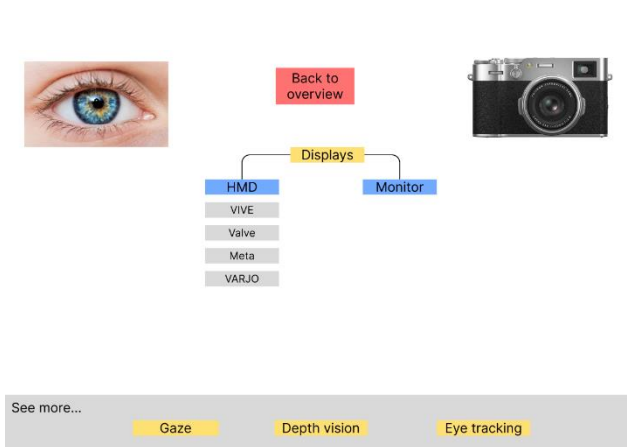


Figure 31 LoFi sense-based diagram round 2 - topic page

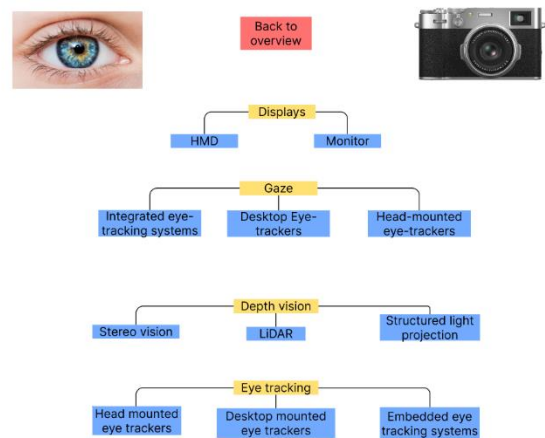


Figure 32 LoFi sense-based diagram round 2 - category page

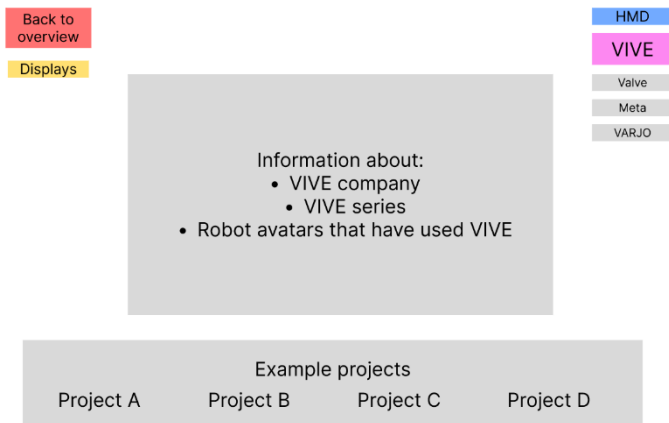


Figure 33 LoFi sense-based diagram round 2 - hardware page

The hardware page did not change a lot, the only addition is the example projects, in which the hardware is used, on the bottom of the page. This can be seen in Figure 33.

The feedback on the sense-based diagram from the evaluation interviews can be found in Figure 34, where participant one provided most feedback about adding more explanation and images to help guide the user. Participant two gave feedback about improving the navigation. Both participants mentioned the same improvements for the main page, where there are two connections per category. Clicking on one of these connections will lead to an overview of all the topics in that category connection. There is also an additional page showing all the topics of the category, regardless of the connection.

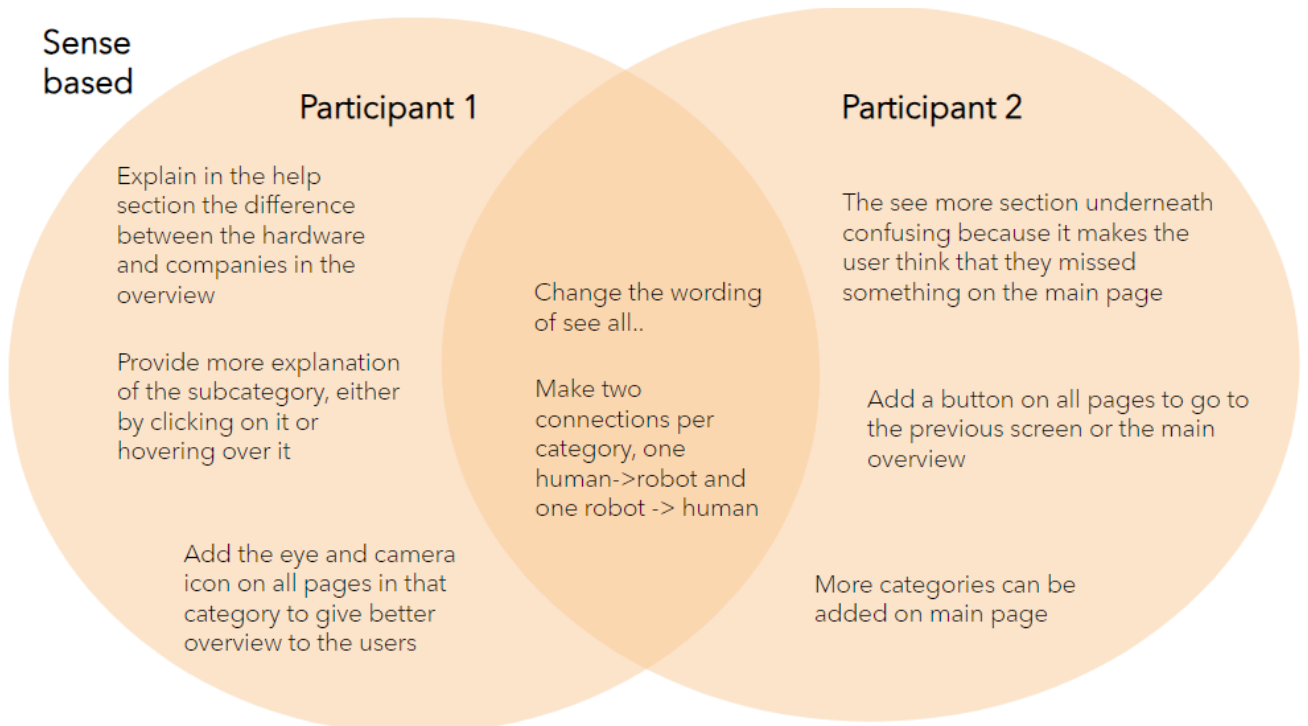


Figure 34 LoFi Sense-based diagram round 2 - Venn diagram of feedback

5.3.2 Network diagram

The main overview page of the network diagram did not change a lot compared to the previous round. The only addition are two buttons What's new? and Help, similar to the sense-based diagram. The Help button leads to the explanation of the tool which can be read in Figure 35.

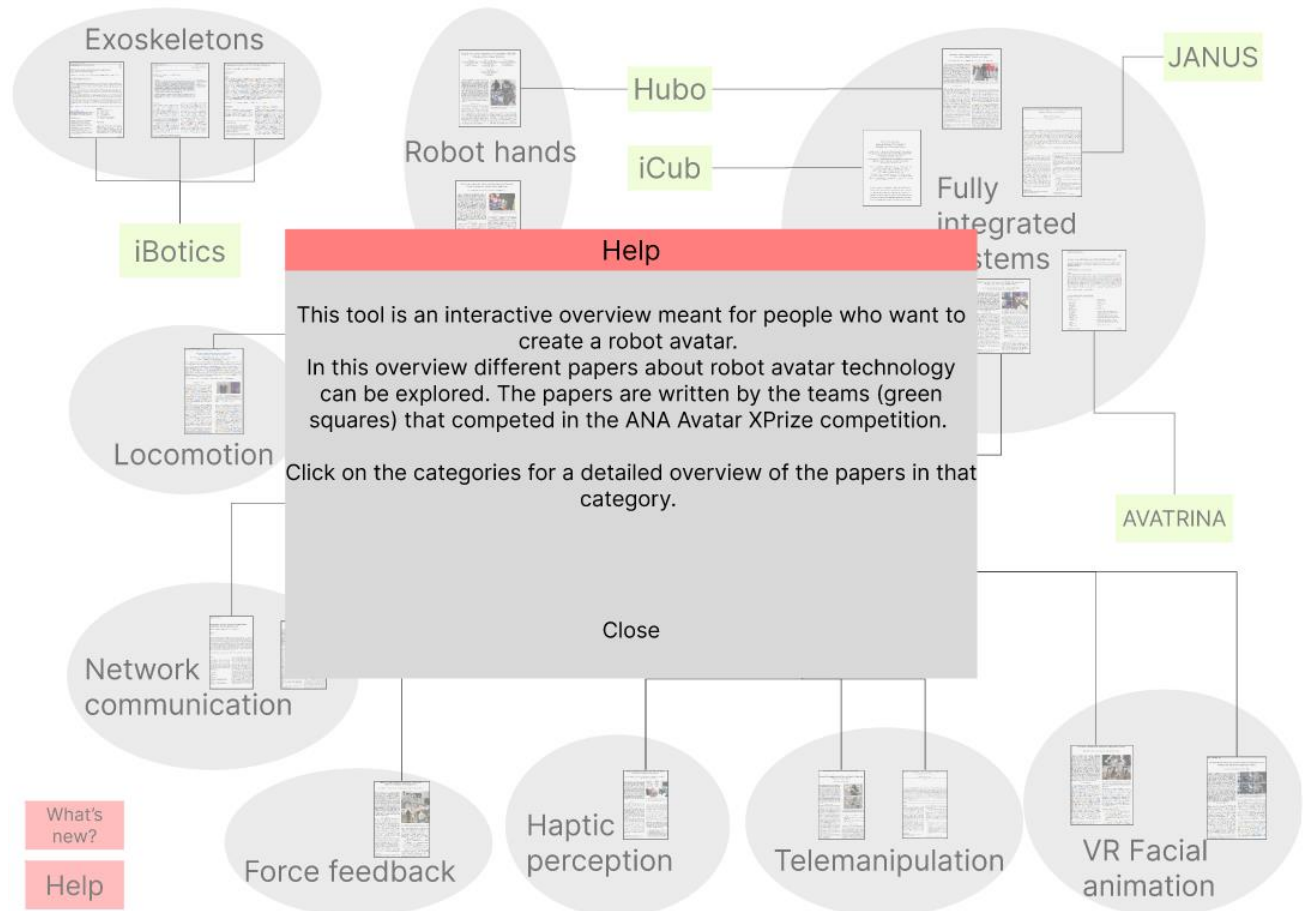


Figure 35 LoFi network diagram round 2 - help

The two biggest things that had to be improved for the network diagram were the navigation and the team overview where the authors and the research papers were linked to each other. A new brainstorming and visualisation research was done to find a solution to the visualisation problem. The feedback was to separate the authors from the research papers, the papers are still grouped in their categories which is indicated by the name and lines, which can be seen in Figure 37. A new way of visualizing the relationships could be with a Sankey diagram, an example of which can be seen in Figure 36. A Sankey diagram is a flow diagram that is normally used to visualise exchange and direction. Even though this is not the case in the team overview, the principle can still be applied. The thickness of the lines could show the amount or percentage of which the author contributed to the research paper. The Sankey diagram was not worked out with the correct data, because of software and time constraints. First, feedback was asked from the participants, in case the Sankey diagram does turn out to be useful a different software will be used to create the overview.

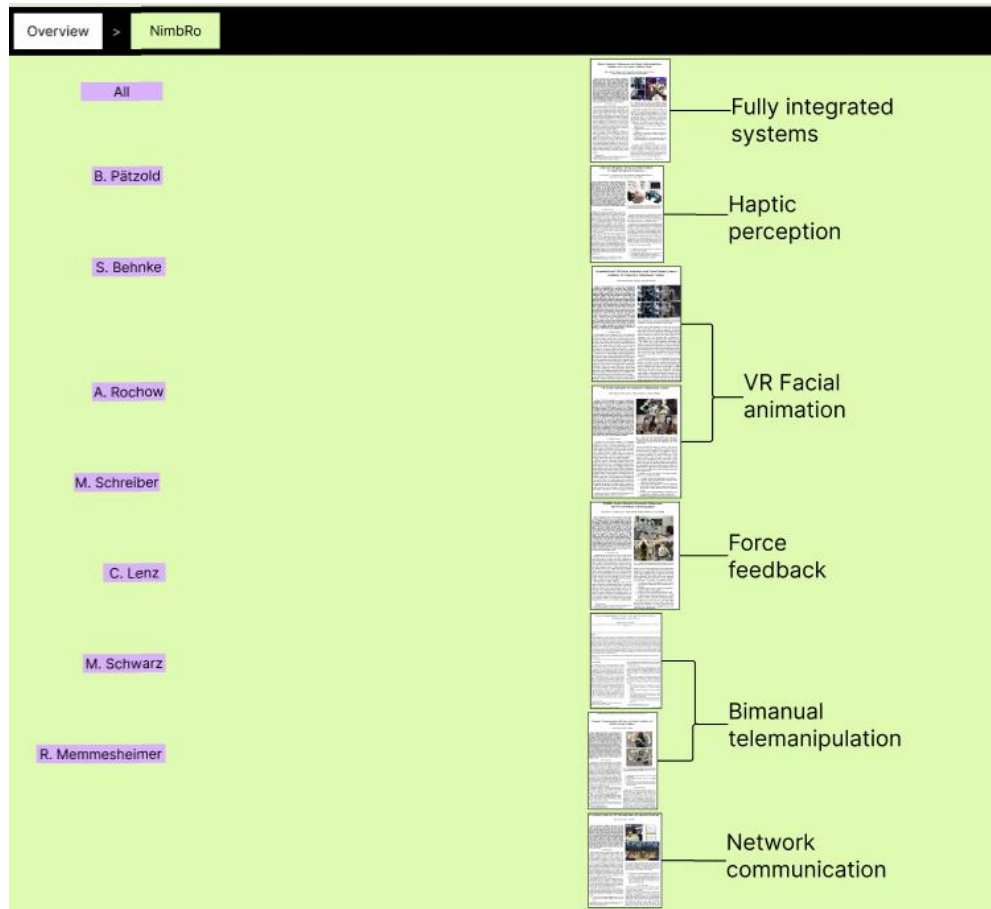


Figure 37 LoFi network diagram round 2 - team overview page



Figure 36 Sankey diagram example

Other changes made to the LoFi prototype is the addition of a category page. This page was not yet present in the previous round, but is useful to give a more complete overview. The category page, which can be seen in Figure 38 shows the papers belonging to that category and the teams who wrote the paper. By clicking on the team, the user navigates to the team overview page, by clicking at the research paper the user navigates to the research paper page. The author page also changed following the feedback from the previous round, which can be seen in Figure 39. A picture of the author is added, with a short explanation of their work. The explanation text includes links to webpages, where more information can be found. Also the layout of the category groups is done better. The title of the category is now in the circle, making it more clear that that is the group the research paper belongs to.

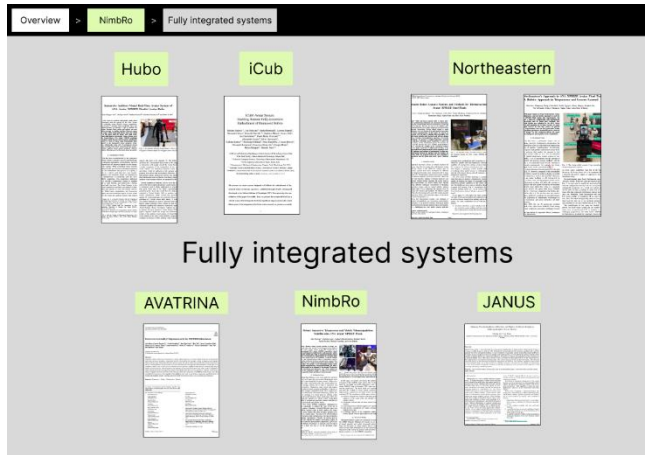


Figure 38 LoFi network diagram round 2 - category page

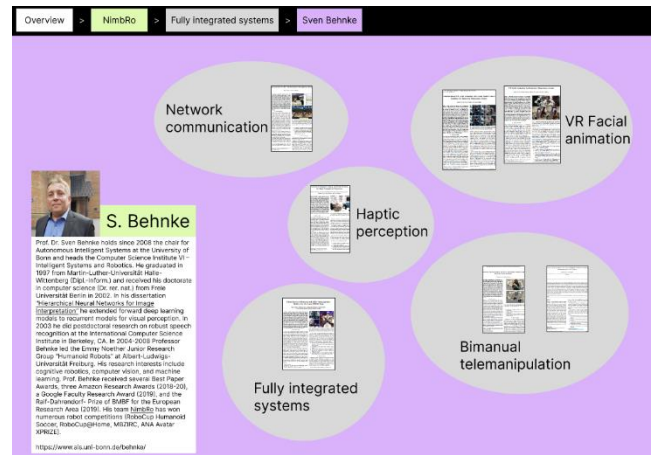


Figure 39 LoFi network diagram round 2 - author page

Also a navigation bar is added to the top of every page, this shows the path to get from the initial overview to the current page, with all the direct steps of all the categories. An example of this can be seen in Figure 40, which is the navigation bar on top of the research paper page. The colours match with the main colour of the corresponding page. This helps the users navigating based on the mental image of the page they would like to get to. This also allows the user to navigate back to the main page at any moment of their interaction with the tool. Another feature that will help with the navigation is information at the tooltip. For example, when you hover over a research paper, the title of this paper will show up at the tooltip. This way, the user does not have to click on the research paper to see the title.

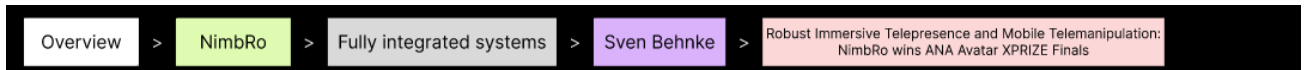


Figure 40 LoFi network diagram round 2 - navigation bar of the research paper page

In Figure 41 the feedback on the network diagram can be found. Both participants saw potential in visualising the author to research paper connection with a Sankey diagram. There was, however, a difference in opinion about the taskbar. The current taskbar shows the same path, regardless of the path the user took to get to the specific page. Looking at the example in Figure 41, the user is located on the research paper page, all the categories that lead to that page are displayed; the team, topic and main author. However, the user did not necessarily take this path, it could be possible to reach the research paper page by directly clicking on a research paper on the main overview. If path history of the user would be shown, only the first block and the last block would be visible in the navigation bar. Participant one would prefer the history path approach, participant two would rather keep the navigation as it is, showing all categories, even if the user did not visit those pages. The rest of the feedback given are small points of improvement, that can be read in Figure 41.

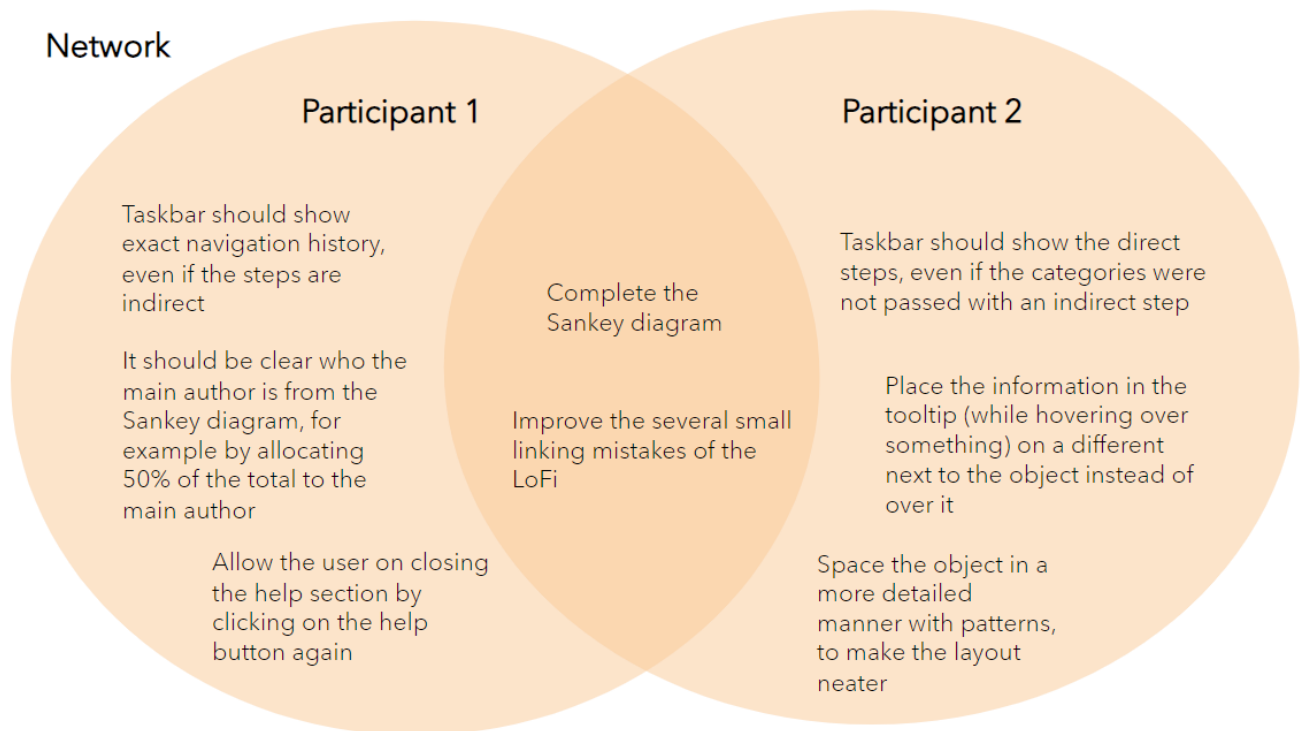


Figure 41 LoFi network diagram round 2 - Venn diagram of feedback

5.3.3 Topic evaluation

At first glance it looks like the topic evaluation did not change after this round, but there are small changes which have a big impact. The overview page, in Figure 42, has new buttons What's new and Help. The help button will show the explanation of the tool in Figure 43. In this explanation the new focus of the visualisation is explained, which is now on projects instead of research papers. Therefore, all the research papers are removed from the main overview. From here the user can only directly navigate to people, teams and projects. In the previous overview, the teams had the same icon as an individual person. In order to avoid confusion, the team icon is changed to show more people. This also means that there are two pages added, a team overview page and a project page. On the project page, which can be seen in Figure 44, there are people, people's functions, institutions, a brief explanation of the project and the research papers that resulted from the project. The layout of this information is similar to the other pages in this overview to keep the same structure between the pages. The people, institutions and papers on this page can all be clicked, which will link to those pages.

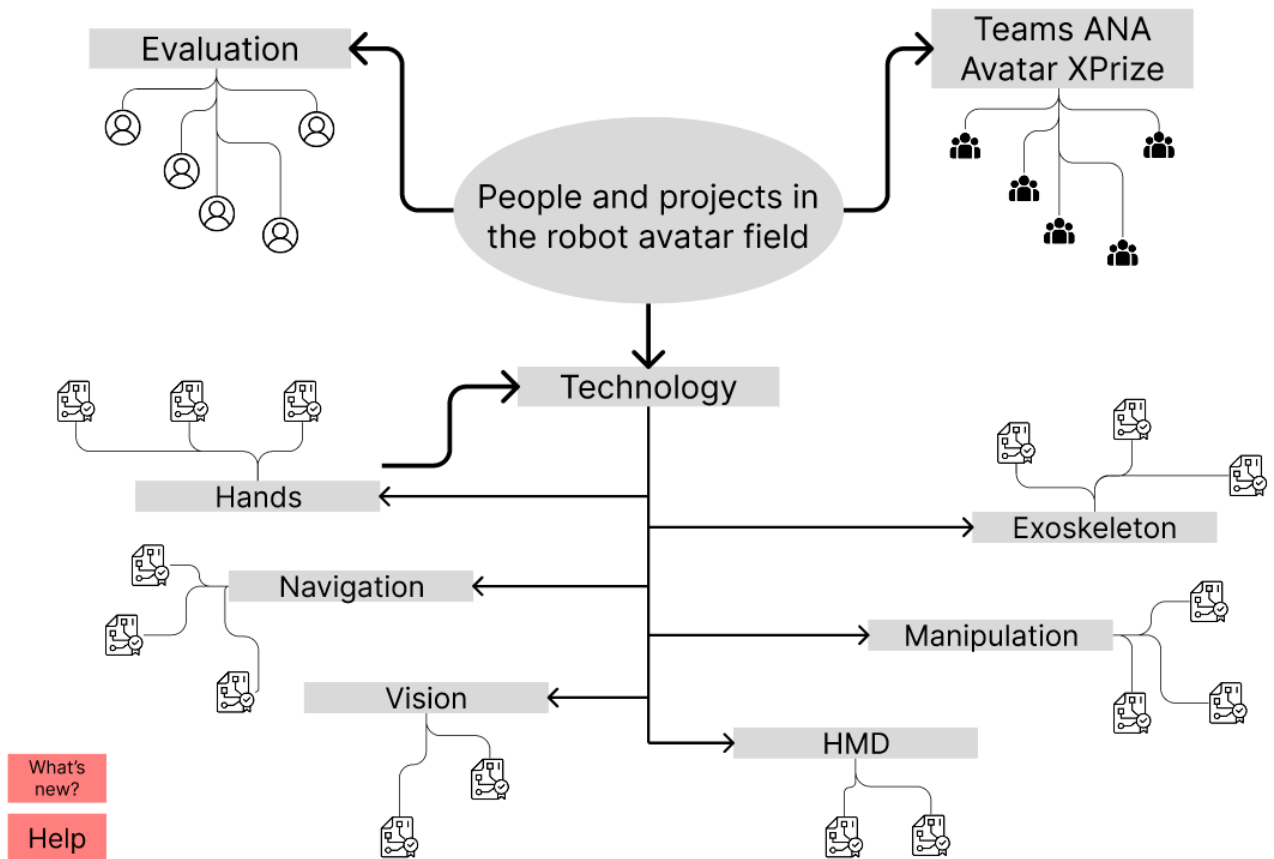


Figure 42 LoFi topic evaluation round 2 - main page

Help

This tool is an interactive overview meant for people who want to create a robot avatar.

In this overview different the connections between people who work in the field can be explored. The connections are ordered by projects in different categories.

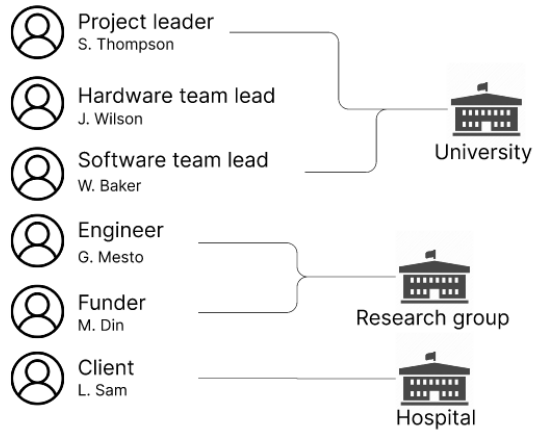
Click on the categories for a detailed overview of the projects in that category.

Close

Figure 43 LoFi topic evaluation round 2 E help

Back

Hybrid Assistive Limb



One notable exoskeleton project is the HAL (Hybrid Assistive Limb) developed by Cyberdyne Inc. It's designed to assist individuals with mobility impairments by detecting bioelectric signals from the wearer's muscles to provide support and enhance strength and endurance. HAL has applications in medical rehabilitation as well as industrial settings where heavy lifting is required.

Research papers from this project

Name paper

Name paper

Name paper

Figure 44 LoFi topic evaluation round 2 - project page

The newly added theme overview page and the updated individual person page, now show similar information. The role of the people working on the projects is shown and links to research papers and institutions are added. The pages can be seen in Figure 45 and Figure 46.

Back

J. Wilson

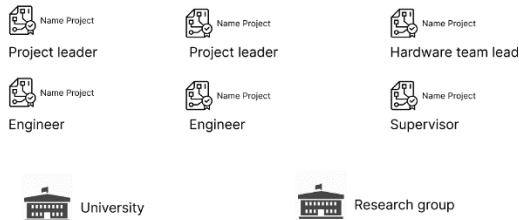


Figure 45 LoFi topic evaluation round 2 - person page

Back

NimbRo



Winner of ANA Avatar XPrize, NimbRo, has a long history of success in robotics challenges, which gives them unique experience in what is necessary to develop complex, cutting-edge robotic systems that deliver performance in real-world situations. Their approach is to work on the full Avatar experience rather than focus on individual sub-problems. They perform continuous testing of the entire system to make sure that users are comfortable while fully immersing in the remote situation.

Research papers from this team

Name paper

Name paper

Name paper

Figure 46 LoFi topic evaluation round 2 - team page

The feedback from the interviews about the topic evaluation can be found in Figure 47. The new goal of the overview was appreciated and the was clear from the new layout. In both interviews there was a little brainstorm about what more can be added to the overview to make it more complete. The suggestions were adding more competitions, showing the progress of the teams and/or adding the institutions on the main overview page. Even though the icons were changed from last round, they were still not all clear. The different institutions should have different icons and a legenda of the icons can be added in the help section.

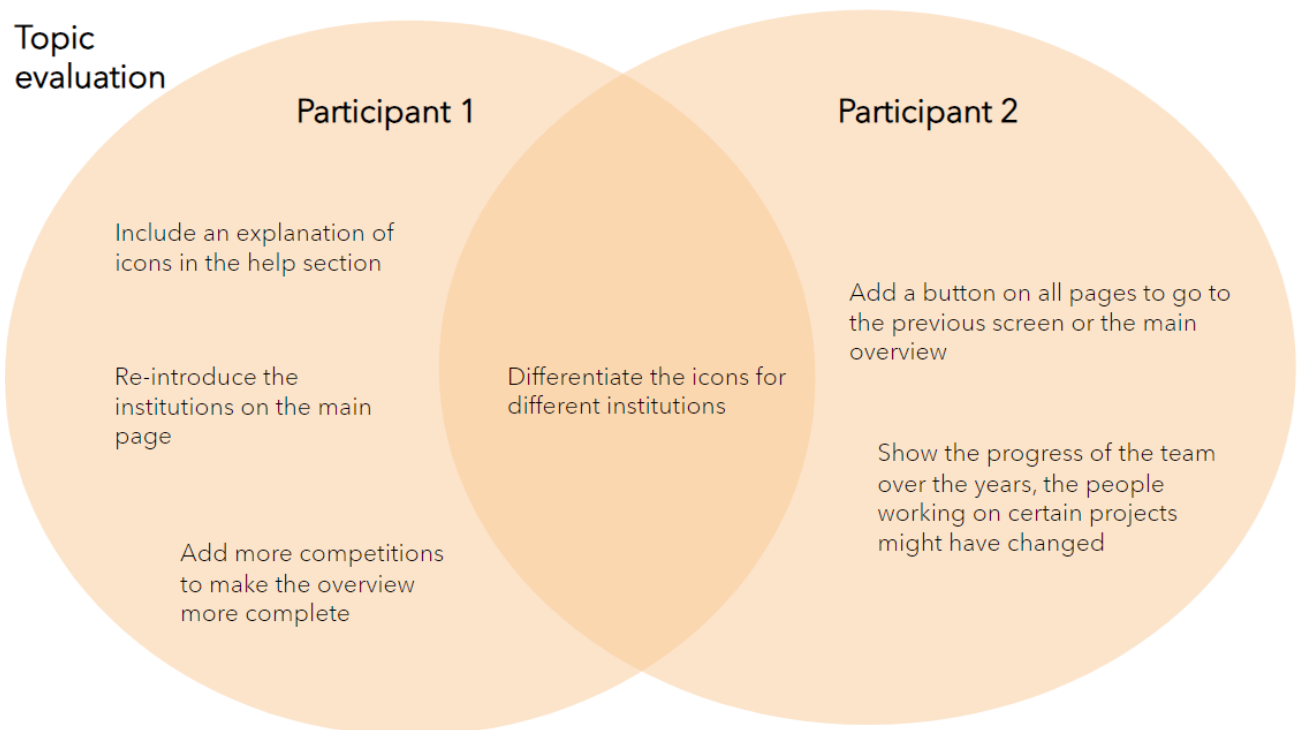


Figure 47 LoFi topic evaluation round 2 - Venn diagram of feedback

5.4 Iteration round 3

In the third iteration round there is a big change. During the evaluations of round 2, it was discovered that the goals of the different visualisations and showing the LoFi prototypes, multiple big similarities between the topic evaluation and the network diagram were noticed. The topic evaluation has as goal to find people and project in the robot avatar field, but also shows research papers. The network diagram, focuses on the research papers, but also shows the people and teams that worked on them. Since both goals are important and have a lot of overlapping features, the visualisations of the network diagram and the topic evaluation can be combined. Both visualisations categorize the papers and projects in similar categories and have a graphical layout. The decision was made to combine the two visualisations, resulting in round three only having two LoFi prototypes. The individual prototypes for the network diagram and topic evaluation were not developed further. But since it is a combination, the feedback on these visualisations from round two were applied to the combined visualisation wherever possible. The visualisation ideas are not yet discarded, but from the feedback in round three, the best visualisation is chosen.

5.4.1 Sense-based diagram

In Figure 48 the main overview page of the sense-based diagram can be seen. The new categorization is made based on the feedback from round 2. Each category now has 3 blocks, the robot-human connection, the human-robot connection and a see all block. Naming these blocks led to the discovery that the microphone and speaker were connected to the wrong sense. They have been swapped and are now linked to the ear and the mouth respectively. There is still an inconsistency in dividing the categories this way. While the mouth-speaker connection and microphone-ear connection do exist, the inverse of these connections don't. However, they are kept in the overview to discuss possible solutions for this problem during the interviews.

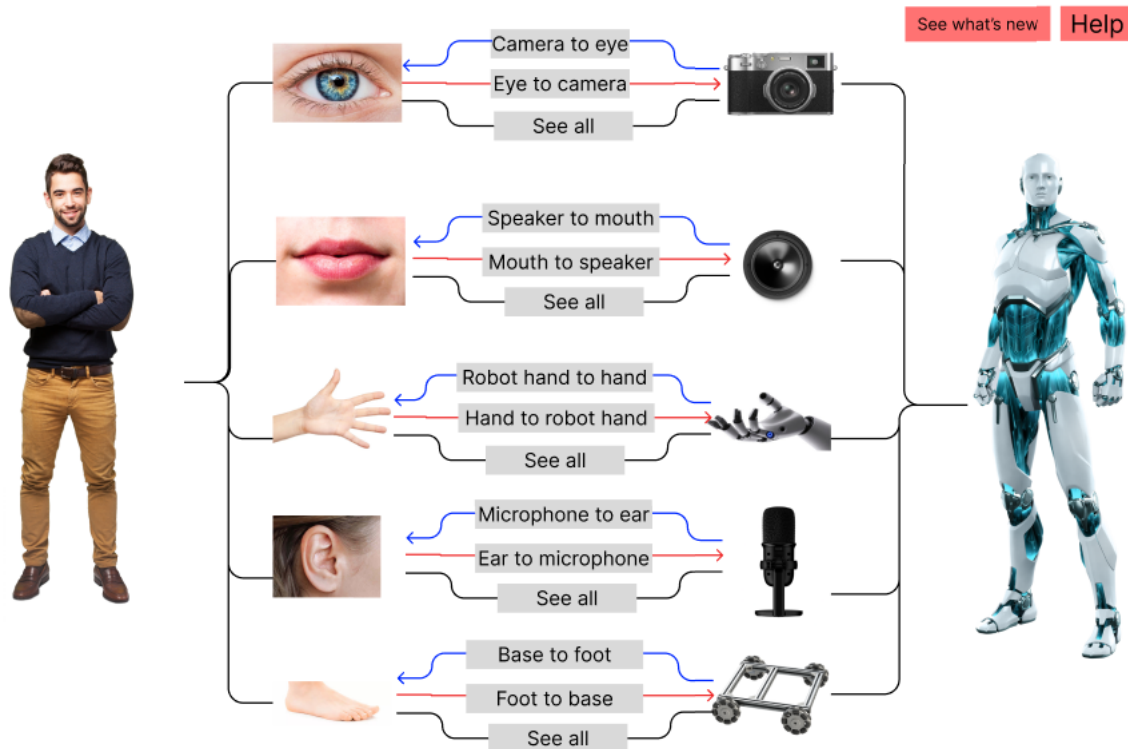


Figure 48 LoFi sense-based diagram round 3 - main overview page

To the overview three new pages were added, for every block in the category one page, and is meant for scrolling. It is a combination of the two separate pages for the one way connections. From all the three pages the user can still click on the blue blocks which lead to the hardware overview page, which has not changed since the previous round.

The other improvements have also been implemented, there are buttons to the main overview on all the pages and the explanation in the help section has been updated.

The feedback on the sense-based diagram from the last evaluation interview is in Figure 49. Both participants came with the same solution to solve the eye, ear, speaker, microphone-problem. They proposed to combine those four into a new category named *sepaking and listening*. Other proposed ideas were to add more information about different features of the hardware, and letting the user filter these to make the overview more useful when a new piece of hardware needs to be found for a new project. Also more information would be nice about the subtopics in the blue blocks. Previously only the hardware got their own page, like HMD and monitor, but now also a page for the general subtopic displays should be added. The other points of feedback were navigation related.

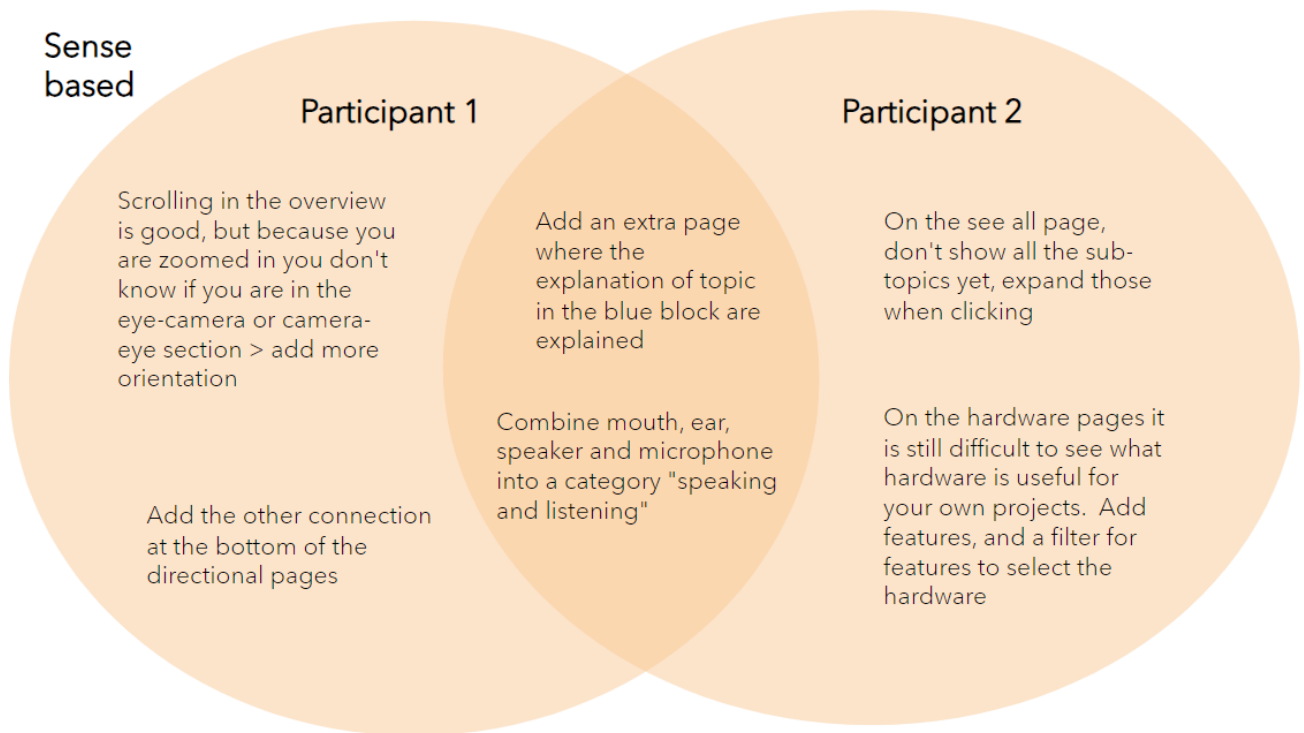


Figure 49 LoFi sense-based diagram round 3 - Venn diagram of feedback

5.4.2 Combined diagram

The combined diagram has a graphical layout that can be compared to a word web, this layout is based on the topic evaluation. The main page can be seen in Figure 50. Not all the lines in this LoFi are added, the overview should have all the yellow circles connected to the magenta circles, also all the yellow circles should be connected to grey circles. This is not worked out everywhere, but in the part of the main interaction (the green ANA Avatar XPRIZE circle) all these connections have been drawn.

The graphical layout consists of five levels (i.e. the five colours), however, only the contents of the first three levels are readable. The idea is that if you zoom in on the overview, the text in the other two levels are also readable. But to not overwhelm the user with too much information, in the overview these are purposefully left out. This idea is inspired by an existing visualisation that is shown on the Cytoscape examples website. An example called *Wine & Cheese* shows a main overview (in Figure 51) where all the nodes are visible but the text is not readable. When the user zooms in the text appears in the circles, as can be seen in Figure 52. In the LoFi of the combined diagram there is already text visible, but the zoom in from the *Wine & Cheese* example is applied to the deeper levels.

To make this overview, the feedback from the topic evaluation and the network based diagram are combined and applied where possible. One change based on the topic evaluation feedback is multiple competitions are included. Currently only the top three teams are shown, but if you click on a competition all teams are in the circle, as can be seen in Figure 54. From here more details can be seen, by clicking on a team, which from here shows more information about a deeper level. The earlier levels are also still visible, but are pushed to the outside, as can be seen in Figure 53.

Help

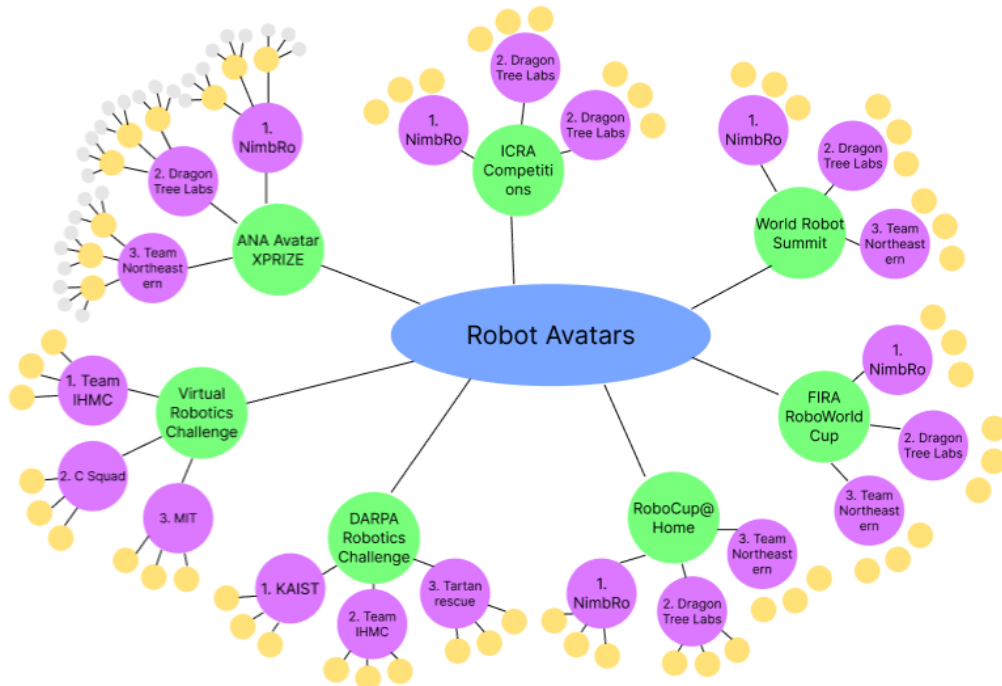


Figure 50 LoFi combined overview round 3 - main overview page

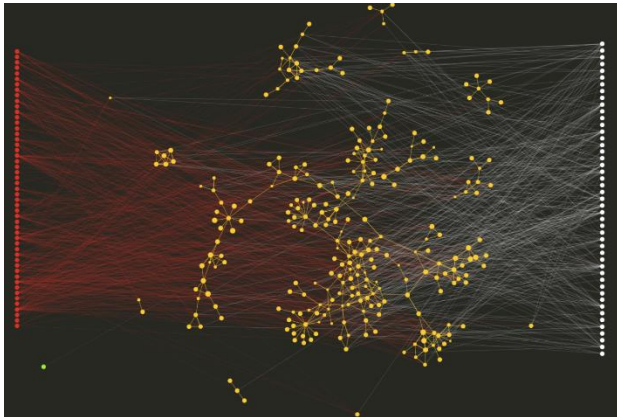


Figure 51 Inspiration of existing Cystoscape visualisation - main overview

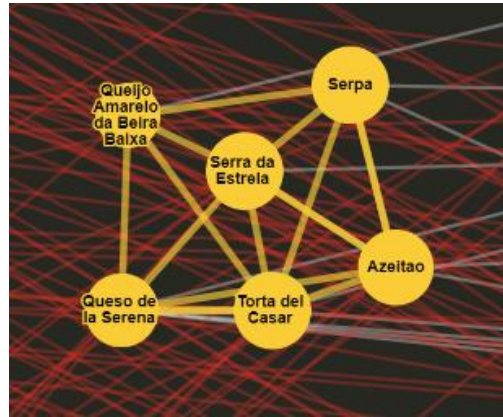


Figure 52 Inspiration of existing Cystoscape visualisation - zoomed in on overview

Help
Back
Home

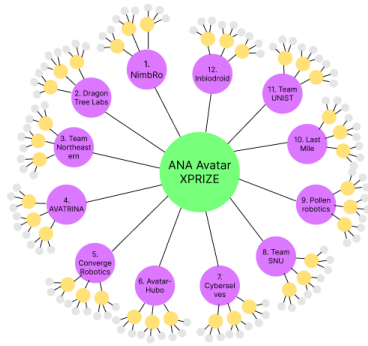


Figure 54 LoFi combined diagram round 3 - competition page

Help
Back
Home

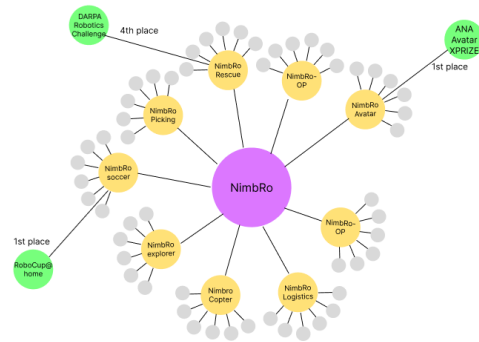


Figure 53 LoFi combined diagram round 3 - team page

Help

Help

This tool is an interactive overview meant for people who want to create a robot avatar.
In this overview competitions, teams, projects and information about parts can be found.

Click on the categories for a detailed overview in that category.

Robot Avatar Competitions Projects Teams Topics

Close

Figure 55 LoFi combined diagram round 3 - help

In the help section the goal of the overview is explained, also a legenda for the colours is placed here. This came from the feedback about the topic evaluation. Another point of feedback from that visualisation that can be applied to the combined overview is adding a button to go to the previous page and a button to go to the main overview on every page. Feedback that can be applied from the network diagram is closing the help section by clicking on the help button again and the equally spaced layout of the main groups. Similar to the network diagram there are pages about topics, and similar to topic evaluation there are pages about projects. These can be found in Figure 57 and Figure 56 respectively. The levels that were closer to the centre earlier are now on the outside. On the project page the research papers and the topics are on the same level. The placement of a project in a competition is notated at the line that shows the relationship between two nodes.

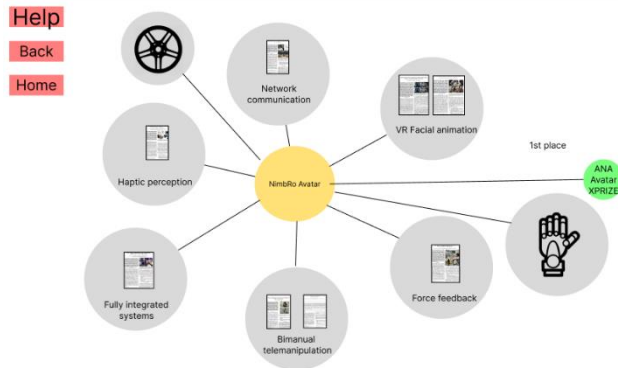


Figure 56 LoFi combined diagram round 3 - project page

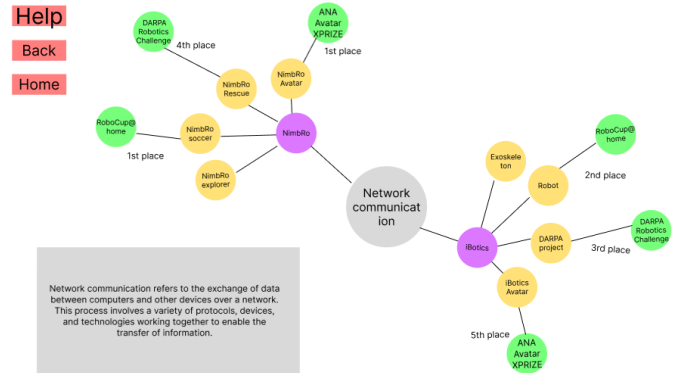


Figure 57 LoFi combined diagram round 3 - topic page

The combined overview was well received and the feedback can be seen in Figure 58. There are some improvements that need to make the interaction with the tool easier. One of which is adding a filter that allows the user to quickly search and find information in the overview. With the way the levels are currently designed it can be hard to go, for example, find something quickly about robot hands. The user would first have to click on a competition, then a team, then a project before they can click on the robot hand page. The filter would allow the user to access the robot hand page in one step. Another way that the user would be able to find robot hands quicker is if the topics would be the first level in the overview. Although, this will make it more difficult to find information about a competition, for example. Therefore the idea of letting the users select the focus of the overview is introduced, where the users can pick what the first level in the overview is. Another improvement that would be nice is separating the topics and the research papers on the project page, this can be done either by colour, placement on the page or by adding an extra level. Also, to keep the overview and layout more consistent there should be no text next to the connection lines. This was confusing for the participants. The rest of the feedback points are in Figure 58.

Combination

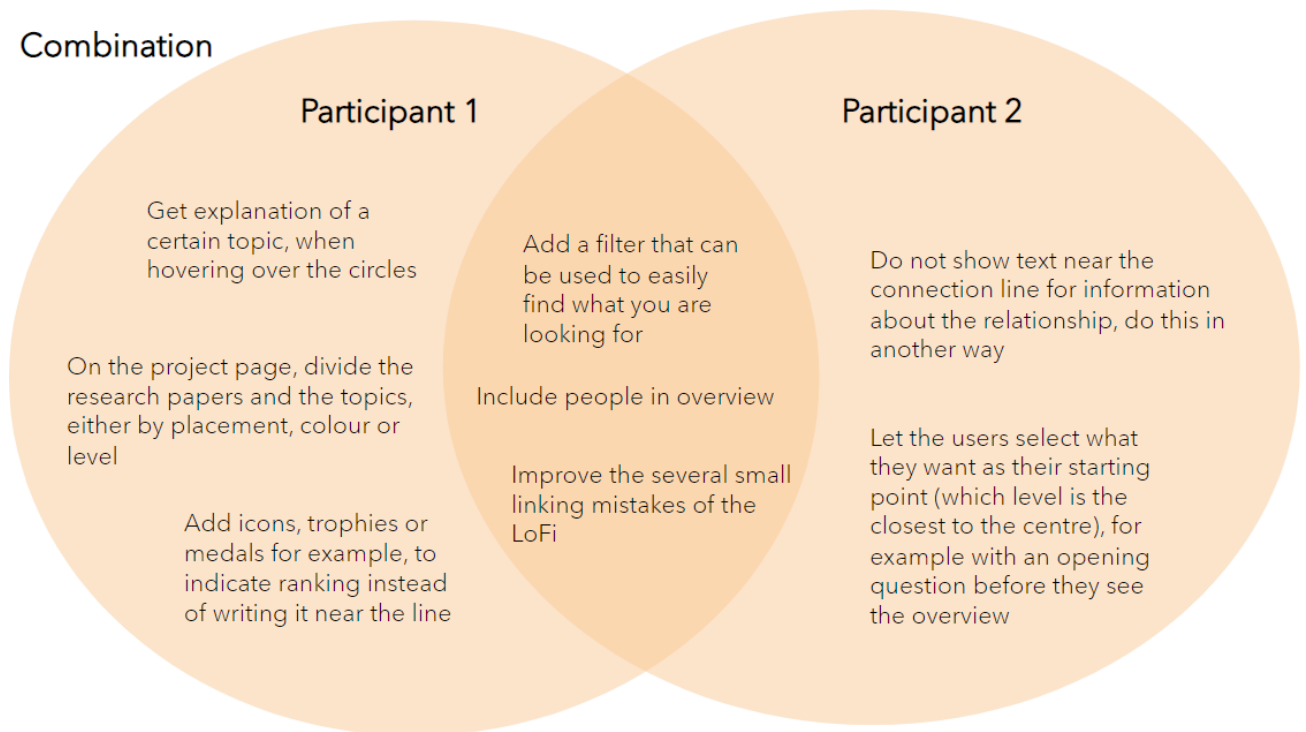


Figure 58 LoFi combined diagram round 3 - Venn diagram of feedback

5.5 Conclusion specification

The end of LoFi iteration round 3 also marks the end of the specification phase. In this phase six interviews were conducted with two master students to evaluate the LoFi prototypes. In this section a concluding look on the interviews is made and the idea is selected to be developed in the next phase.

5.5.1 Interviews

In general the interviewees were positive of the visualisations and gave a lot of valuable feedback. Some small mistakes were found in the LoFi prototypes. And when bigger problems arose there was a small brainstorm during the interview to find creative solutions. The main topics of feedback were the navigation in the overview, consistency in the layout and focusing on the information that is most essential to the user. The navigation is an essential part of the interaction, therefore improvements in this area were made in every round for every LoFi. All the different LoFi's had different navigation techniques, for example a navigation bar, back and home buttons, zooming in and clicking on parts that interest the user. The preferences for these techniques did sometimes differ between the two participants. This shows that even when trying to optimise the overview over different iteration rounds, there are still always differences between how different user receive and interact with the tool.

5.5.2 Selection of idea

The specification phase started with three visualisation ideas, the topic evaluation, sense-based diagram and network diagram. However, in round three the topic evaluation and the network diagram were combined, this only leaves two visualisations to select from. The sense-based diagram allows the user to find hardware options and maps these technologies from human to robot and vice versa. The combined diagram allows the user to find projects, competitions, people and teams in the field and research papers, where the focus of the overview can be selected by the user. Both of these visualisations have potential in being a functional tool. However, only one visualisation is developed into a HiFi prototype in the Realisation phase. In order to select one of these two ideas, an overview with advantages and disadvantages per diagram is made in Table 6.

Sense-based diagram		Combined diagram	
Pros	Cons	Pros	Cons
Presents the information visually	Difficulty in making category for mouth, ear, microphone, speaker	Gives a very broad overview of the field with a wide arrange of topics	Only contains text and no visual elements
3 out of 4 interview participants interviewed indicated that they have to search for hardware during their work	Provides less structure to the user than the combined diagram	All interview participants mentioned at least one of the topics addressed by this visualisation	Did not go through multiple iteration rounds and therefore is not yet optimised
With the added features, it has potential to show the quality of the hardware	Difficult to keep up to date, which is more important in this overview to be a successful and helpful tool	Can be made in the same software as the already existing overview on the website of Avars.Report	
		Allows the user to select the focus of the overview	
		Shows research papers	
		Allows the user to explore further than their subfield	

Table 6 Advantages and disadvantages of the sense-based diagram and the combined diagram

This shows that the combined diagram has more advantages and less disadvantages than the sense-based diagram. It also shows that the combined diagram fits better to the result of the potential user interviews. Part of the content that the users are searching for is in this visualisation, namely the projects, hardware and people. Also the information sources that the users use the most are included, these are research papers and internet search. The user can navigate through the overview and the end result is a research paper or an overview page with links to internet sources. Also some struggles in finding information is addressed. The problem that the information needed is too niche is partly solved by showing information on one topic in a very broad part of the field. This allows the users to also see what is happening outside of their subfield. The struggle about the structure of information is solved by the different layers of information that is colour coded and the filter that allows the user to quickly select information. Adding the newest updates is not necessarily something that is solved with the design, but in the graphical overview it is easy to quickly add new nodes with information. Considering the advantages and disadvantages of both diagrams and the important elements mentioned by the interview participants, the combined diagram is the visualisation selected to be developed in the realisation phase.

From the interviews about the LoFi prototypes, the last two sub questions can be answered. Sub question two is *Which type of visualisation(s) can communicate the relevant information in a good way to the users?* The selected idea of the combined diagram is a good way to structure information to the user. This diagram is a word web where competitions, teams, people, topics, projects and research paperers are shown with different levels and colours. This visualisation was selected as the final way of visualising because it addresses the topics that users would like to have information about, it includes the current sources of information and helps solving a few of the struggles that users currently have when searching for information. The third sub question is *Which interactions can be added to the tool to make the information retrieval easier?* The main interactions that were added and evaluated as useful for the LoFi prototypes were navigation and filtering. The navigation is done by a combination of zooming in and clicking on nodes in the graph. Other useful interactions are hovering over an element to get more information about it. All these interactions will also be in the HiFi prototype in the realisation phase.

6 - Realisation

The HiFi prototype is made in the Realisation phase. In this chapter, first the MoSCoW requirements of the prototype is presented. Afterwards the creation of the prototype is explained.

6.1 MoSCoW requirements HiFi prototype

Before creating the HiFi prototype a new MoSCoW requirements list is made. Due to the limited time span of this project not all functionalities can be properly implemented. The MoSCoW requirements are meant to guide the development of the prototype, such that the functionalities with the highest priority are developed first. The overview is in

Table 7, where can be seen that the must section solely focuses on the structure with the database, the webpage and the visual layout of the overview. The should section focuses on adding the most important interactions with the overview, while the could section is focused on adding interactions that are nice, but not necessarily needed. The won't section shows the limitation of this HiFi, namely that not a complete picture of data can be included.

Must...	Should...
... have a main overview page	... allow the user to interact with the overview and zoom in on clicked nodes
... have a clear layout with colours for the different categories	... have a way for the user to switch the central topic of the overview
... be connected to a database	... connect the nodes from different parts of the overview that also have a connection
... be a webpage	... have a help button with explanation
	... have a small explanation of the node
	... have a search function
Could...	Won't...
... have a button that resets the overview to full fit	... have a completed dataset
... show more nodes when zooming in on the overview	
... allow the user to zoom in	

Table 7 MoSCoW requirements of HiFi prototype

6.2 Workings of the prototype

The HiFi prototype is made with Excel datasheets, the Cytoscape desktop app, Cytoscape.js library, JavaScript files, CSS files, HTML files, JSON files, Node.js program and a webpack builder. Code for the HiFi is based on the GitHub example of the aforementioned *Wine & Cheese* example in Figure 51 and Figure 52. The process of making the graph is divided into three elements, the data, the layout, and the interactions with the graph. All these parts are done with different software, which is explained in this section of the chapter.

6.2.1 Data in Excel

The data for the tool is managed in two Excel datasheets. The first sheet is called *name_type*, this is where all the nodes are stored. There are three columns, the first is called *name* and there the text that is displayed on the node is written. The second is *type*, where the category is placed, for example competition or project. The third column is *information*, here some nodes have an explanation that is shown in the overview. A part of the first few rows is in Figure 59.

	A	B	C	D
1	Name	Type	Information	
2	Robot avatars	Main	A robot avatar is a rem	
3	ANA	Competitions	The ANA Avatar XPRIZE	
4	RoboCup	Competitions	RoboCup is an internat	
5	FIRA	Competitions	The FIRA World Cup is :	
6	NimbRo	Teams	NimbRo, a robotics tea	
7	Pollen Robotics	Teams	Pollen Robotics is know	
8	Team Northeastern	Teams	Team Northeastern fro	
9	B-Human	Teams	B-Human is a prominer	
10	HTWK Robots	Teams	The HTWK Robot team,	
11	rUNSWift	Teams	rUNSWift is the RoboC	
12	Team Osaka	Teams	Team Osaka, also know	
13	HTWK Robots_2	Teams	The HTWK Robot team,	
14	B-Human_2	Teams	B-Human is a prominer	
15	NimbRo Avatar	Projects		
16	NimbRo CARL	Projects		

Figure 59 Small excerpt of the *name_type* file with the names, types and information of the nodes

The second Excel sheet is called *matching* and holds the information about the edges. There are just two columns, *source* and *target*. From the source node an edge is drawn to the target node. A small part of this file can be seen in Figure 60. The data that is used is found with general searches on internet, the terms that were found in the background research were used in naming the nodes. The selection of the data is random and is definitely not complete. Effort is put in to only have accurate representations, but this is not guaranteed. Besides this, the research papers are not actual research papers, but just dummy nodes numbered from 1 to 108. All this data is in two Excel sheets in one workbook and is imported into the Cytoscape desktop app.

	A	B
1	Source	Target
2	Robot avatars	ANA
3	Robot avatars	RoboCup
4	Robot avatars	FIRA
5	ANA	NimbRo
6	ANA	Pollen Robotics
7	ANA	Team Northeastern
8	RoboCup	B-Human
9	RoboCup	HTWK Robots
10	RoboCup	rUNSWift
11	FIRA	Team Osaka
12	FIRA	HTWK Robots_2
13	FIRA	B-Human_2
14	NimbRo	NimbRo Avatar
15	NimbRo	NimbRo CARL

Figure 60 Small excerpt of the matching file with source and target nodes, indicating the edges in the overview

6.2.2 Layout in Cytoscape desktop app

The visualisation is created in the Cytoscape desktop app by importing the two separate networks. The first file (name_type) is imported with the name column being the source nodes, and the other two columns being source node attributes (see in Figure 61). This will only show the nodes, without any edges or layout to the graph. While this network is selected, the second Excel sheet (matching) is imported with the first column as the source node and the second column as the target node (see in Figure 62).

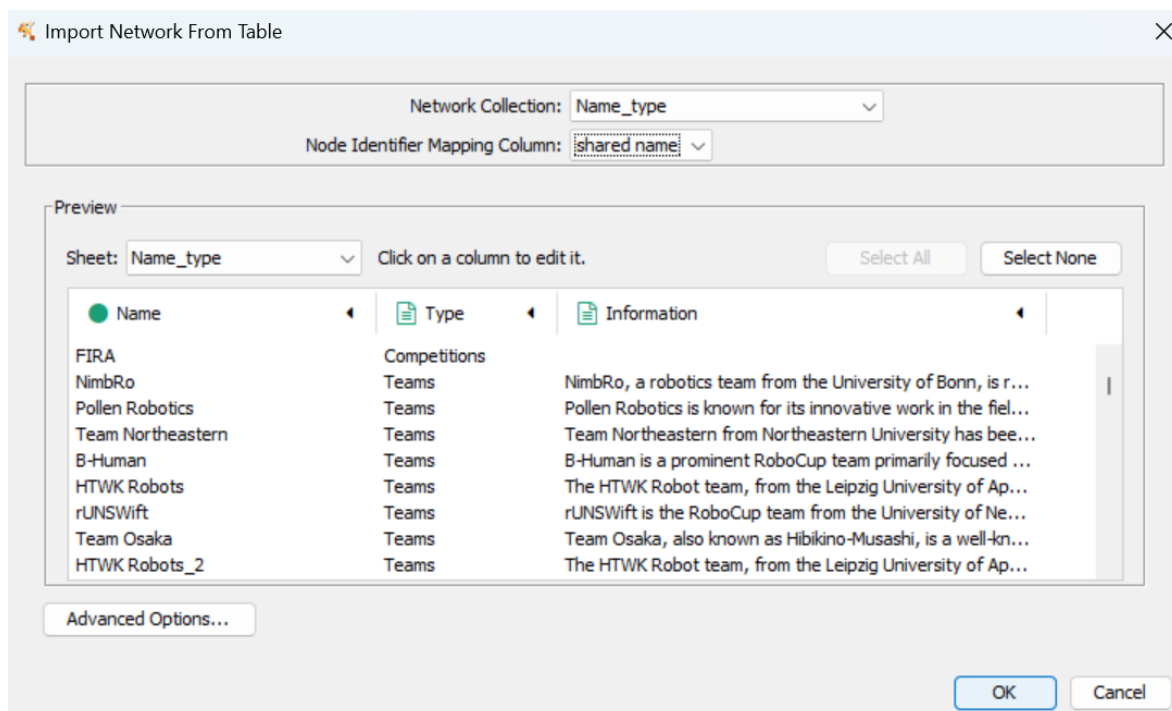


Figure 61 Importing name_type Excel sheet into the Cytoscape desktop app

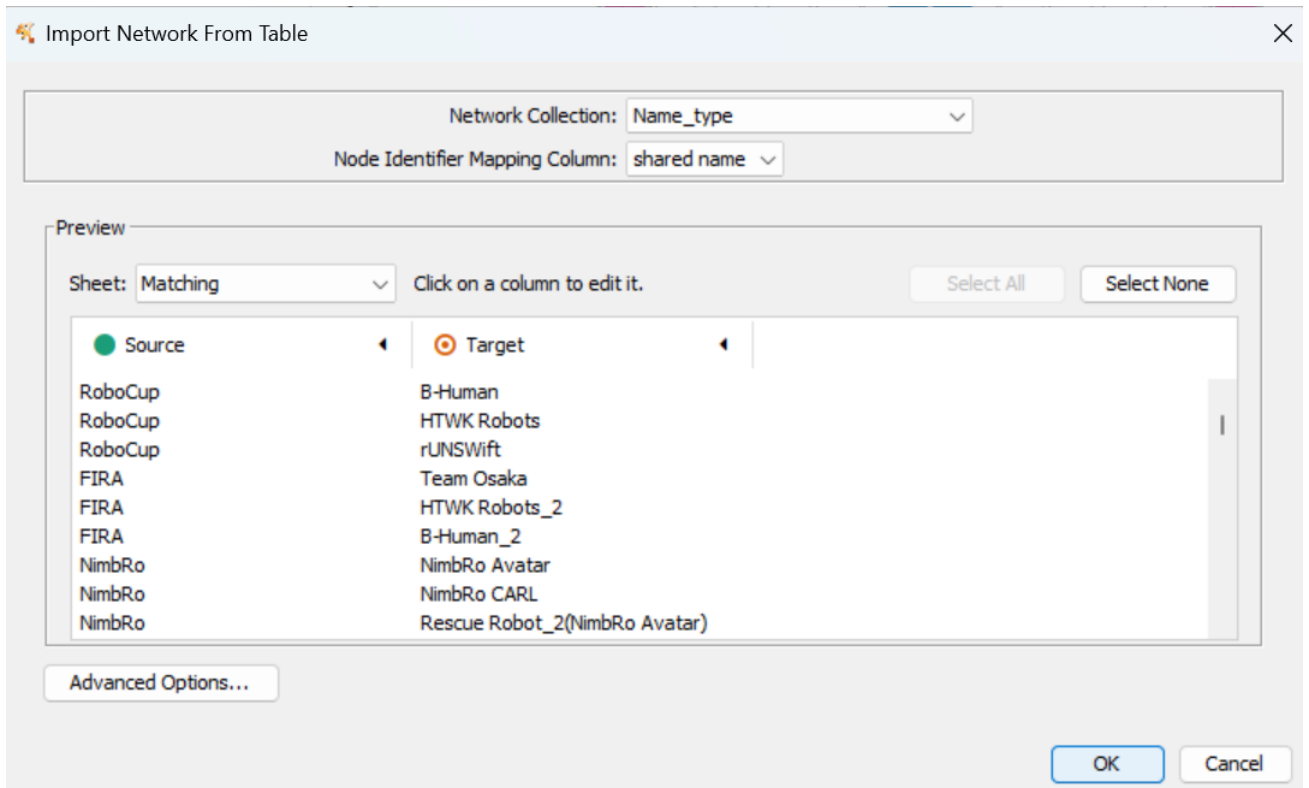


Figure 62 Importing the matching Excel sheet into the Cytoscape desktop app

With the second file also imported, the network is fully loaded. The layout of nodes is done algorithmically, with the help of the *yFiles Layout Algorithms* plugin. The specific layout used for the nodes is the *yFiles Radial Layout*, and the dimensions of the graph are changed with the built-in Cytoscape layout tool. Colouring the nodes per category was done in the app for making it easier to do the layout of the graph. But this is not necessary because the styling of the graph is handled with the code. The colouring of the nodes was done by applying a discrete mapping of the *Type* column in the *Fill colour* section of the *Style* tab. The visualisation up to this step can be seen in Figure 63. This visualisation is exported with the function *Network to webpage*, where the option *Networks and Style JSON files only (No HTML)* is selected.

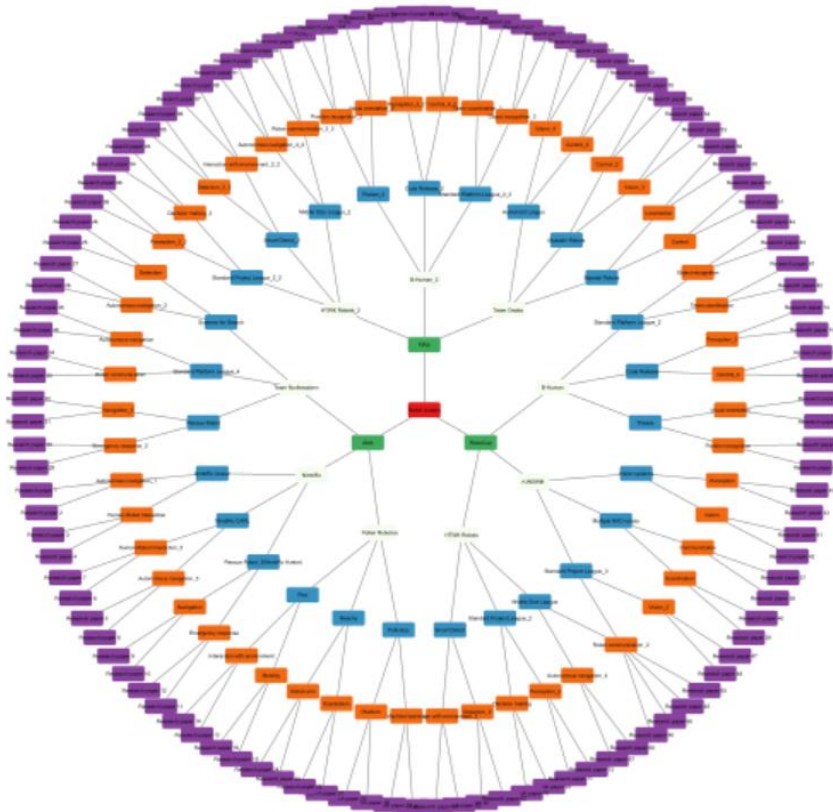


Figure 63 Visualisation after applying the layouts to the nodes in the Cytoscape desktop app

6.2.3 Interaction with JavaScript

The files that are exported from the Cytoscape app are used in the code for the visualisation. The HiFi prototype is a website that is run locally on the device. The code is based on the GitHub code from the *Wine & Cheese* example on the js.cytoscape website made by *maxkfranz*.

In the main folder there is an `index.html` file running the whole website. Here there are links to `bundle.css`, `bundle.js` and `polyfill.js`, all these files are created with the Webpack build, which is initiated in the command prompt. These files are responsible for bundling all the code of the other files, allowing the whole program to just run on these files, because they are built from the individual files.

The two most important files, that are discussed in this section are the `elements.js` and `controller.js` files, these are used for data storage and adding interaction respectively. The `elements.js` file is made with the use of the exported files from the Cytoscape desktop app. A bit of processing is needed for the file to correctly be used in the code. This is just a matter of copy pasting the data into the different structure, which can be seen in Appendix A – Conversion of exported file to `elements.js`. The `controller.js` file is where the main part of the interaction is handled.

The final visualisation of the HiFi prototype can be seen in Figure 64. The full graph is visible in one glance, next to that there are three buttons. In the bottom left corner there is a button to reset the visualisation, which will lead to the view in Figure 64, and there is a help button. When the user clicks on a help button, there is a pop up, explaining what the tool can be used for, how to interact with it and explanation of what there can be seen. This can be read in Figure 65. In the top right corner there is a search function. The user can enter any search term and all the nodes that have all or part of the search query are shown in a list. The overview itself is a ring of circles, each being its own category. The centre node is the biggest node, which is called robot avatars,

indicating the topic of this tool. The first level from this centre node are the competitions in green, after which there are projects in blue, topics in orange and research papers in purple. Both the node size and font size decrease, the further the layer is from the centre of the visualisation.

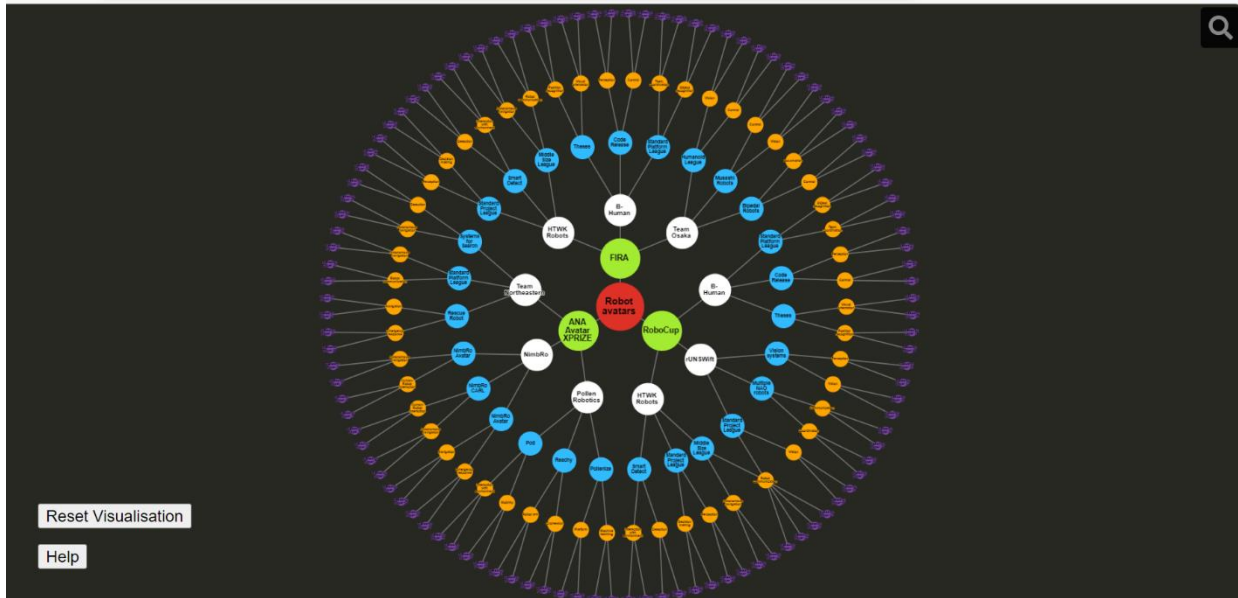


Figure 64 HiFi prototype - main overview of visualisation

This page says

Welcome to this interactive overview!

This tool is meant for people who are working in the field of robot avatars, or people who are interested in this field.

This overview is divided into 5 categories:
 Competitions (green), Teams (white), Projects (blue), Topics (orange),
 Research papers (purple).

More information can be found by clicking on the nodes (the circles).
 With some nodes, an extra explanation is given.

The search bar in the top right lets you quickly search for data.

Be aware: the data in this overview is not complete, and dummy names are used for the research papers.

OK

Figure 65 HiFi prototype - help button

The user can interact with the visualisation by clicking on the nodes. In Figure 66 an example is shown of the view when the B-Human node is clicked. The selected node becomes the biggest node. The parent(s) of the node is shown and all the connections to the children, grandchildren and further levels. From here the sizes of the nodes and fonts is applied again, with the selected node being the biggest, and the further layers getting smaller. All selected node and all its connections are highlighted, while the other nodes become faded. There is an animation where the overview has a smooth zoom from the full view to the highlighted nodes. In the top left of the screen there is an explanation about B-Human, and there is a link for more information to the search term on internet. Another important note is that there are links to multiple

competitions, even though the node that was clicked belonged to the RoboCup connection, also other nodes that have a relation with this node are highlighted, in this case the FIRA competition. This is also the case with other nodes, making it easy to see just the specific tree of the node, but also the connections to other parts of the visualisation. An example of this can be seen in Figure 67. Other interactions are zooming in, zooming out and dragging the visualisation over the page.



Figure 66 HiFi prototype - view if B-Human node is clicked

6.3 Conclusion of realisation phase

In the beginning of the realisation phase a MoSCoW requirements table has been made (Table 7). Most of this has been realised, there are only two elements that are not in the final HiFi prototype. One *should have* requirement is not fulfilled: ... have a way for the user to switch the central topic of the overview. This was not achieved because of time constraint. This function is explained and still evaluated upon in the evaluation interviews. The second requirement that was not fulfilled is a *could have* requirement: ...show more nodes when zooming in on the overview. This requirement was made for if there was too much data in the overview, the idea was to then have not all the nodes visible in the first glance, but when the users moves to layers that are deeper, they would see more nodes appearing. This was not needed, because of the small amount of data nodes used, and this function was not created because it was just a *could have* requirement.

For the rest all the requirements have been fulfilled and created to the liking of the researchers. The next phase in this project is evaluating the HiFi prototype.

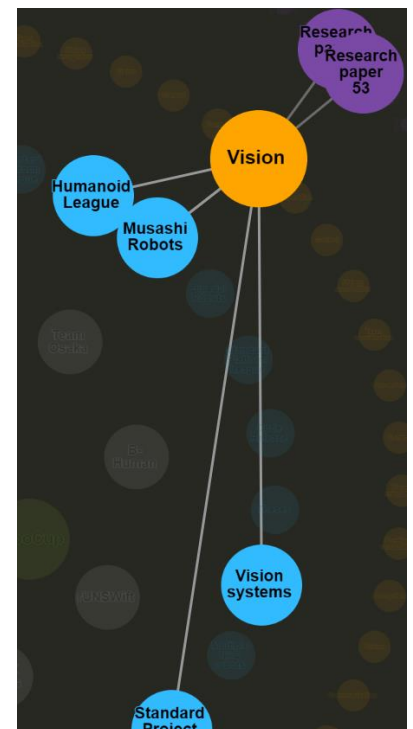


Figure 67 HiFi prototype - example of connections to other parts of the visualisation

7 - Evaluation

Evaluation of the HiFi prototype is done by five interviews with potential users. The aim of the evaluation is to find out if the final visualisation functioning in the way that is intended and if the goal of this project is fulfilled.

7.1 Structure of interviews

For the evaluation five semi-structured interviews were conducted, the structure of this interview was consistent for all of them. The interviews took between 20 and 35 minutes, depending on how much feedback the participant wanted to give. Every interview started with a brief explanation of the project and what had been done thus far. After signing the informed consent form, a brief introduction of the tool and explanation of the setup of the interview, the first part started. This part consisted of 5 questions that the participants had to answer. For finding the answers to the questions, the participants had to interact with the overview. The first question was *Which categories do the colours in the overview represent?*, this question was meant for seeing if the participants understood the general layout of the visualisation. The second question was *In which competitions did the team HTWK Robots participate?*, the answer to this question can be found in the first layer and meant to show the participants that the basic interaction. This would also give the user the concept of having multiple backlinks, directly seeing that all the relevant information is highlighted with selecting the node. The third question is *Which project is focused on making a robot arm?*, this question can be answered by looking at all the topic nodes, but more likely the user will use the search function. The fourth question is *Which projects have autonomous navigation?*, this will show the user a lot of different backlinks and giving the user the idea of how this tool may be useful in finding a lot of projects with the same topic. The last question is *Which team has a project about mobility?*, this question combines three layers, the teams, projects and topics. Therefore if the user selects the mobility node, only the project node is highlighted. They have to click on this project to see the connection with the team. This question is made to test if this is an intuitive step. The participants could either say out loud what they were doing or thinking, or they could do it in silence and they would be observed. The answers to the questions were given verbally and if an answer was wrong they would be nudged to the right direction. After all questions were answered there was a conversation about how easy or difficult the information retrieval was. The list of questions was prepared, but if interesting point emerged in the conversation, follow-up questions would be asked. The questions were:

1. What is your first impression of the tool?
2. How easy or difficult did you think finding the information was?
3. Do you think this tool is useful for you?
4. Did you need the help function at any point? Why?
5. Is there any information or categories that you think is missing from this visualisation?
6. Do you have any recommendations for improving this tool? Anything you would like to add remove or change?
7. From the LoFi interviews there was an idea for letting the user switch which category would be in the centre of the visualisation. Do you think this is needed?
8. Do you have any final remarks or other things you would like to say?

The interviews were conducted with five potential users, some participants were already interviewed in earlier phases of the project (the LoFi evaluation interviews or the user requirements interviews), but there was also a participant that did not yet see anything about the project.

7.2 Results of interviews

The overall response from the interviews to the visualisation is really positive. All the information that the participants had to find in the assigned tasks was found quickly. The only question that the participants were unsure about was the first task, about which categories the colours represent, in particular the blue nodes

were not clear to some. The other categories were easy to deduct. The evaluation and the answers to the questions after the tasks were finished was also generally the same across the five participants. An overview of the important points from the answers of all participants is in Appendix B – Results of HiFi interviews. In this section a summary and comparison of the results is made.

The general first impression of the tool was that it is easy to work with, only one participant thought that there was a bit too much information in one view. The other four participants, however, either said that this was the perfect amount of information, or that even more information could be added. All participants said that the tool is useful for them and that they would use it in their work. Different usages were mentioned, either as a replacement of normal internet search, or as an addition to find more connections between projects. The help button was not used by most of the participants and they said that the tool was intuitive to use, however, two participants did need the extra guidance. None of the participants mentioned that they thought that there was information missing, but two participants did say that the 'More information' link that now leads to a general search output of the node is not useful and they would rather have a link to a specific website. To the general recommendation question, two of the participants responded that they would like to see compound or grouped nodes when there is more data added to the overview. Once the user clicks on one of the further layers, these grouped nodes would then ungroup and all nodes would be visible. Another recommendation from another participant about having less information on the screen is to start in a zoomed in position and only show the first three layers, the other layers being faded. And only when the user clicks on a further layer, new layers would appear. However, they also immediately mentioned that then it would be a difficult balance between having a focus on a specific part of the visualisation or seeing the whole picture with the full visualisation. Another recommendation is to add a legenda for which categories the colours represent. This is now explained in the help section, but an additional legenda that is always in view would be appreciated. A problem that two participants mentioned, but did not have a definite solution for yet was that there are duplicate nodes and that may cause ambiguity and confusion in the overview. A thought was to only have one instance of a node but then have multiple edges leading there, however a new concern was raised about then not being able to see the full top down tree for one section. Another recommendation was to only show one node in the search results list, currently, because there are duplicate nodes, multiple nodes are shown in the list. This causes confusion, only having one node and a potential drop down of the different connections would be useful. The last big recommendation is to make the tool more inclusive, for example for colourblind people.

Making a function that switches the view and the category that is in the centre of the visualisation, was not present in the HiFi prototype, three participants said that this was not necessary. Two participants mentioned that this could be a nice addition, but that then it was only needed for centering the topics, other categories do not have to be centred.

8 - Discussion and future work

This chapter provides a discussion of the project by providing its strengths and limitations. Also, an evaluation is made by comparing the HiFi prototype to the goals and requirements that were stated at the start of this project. Based on this, recommendations for future work is given.

8.1 Discussion

This discussion is divided into the development process and the project result, both elements are discussed based on the limitations and strengths.

8.1.1 Limitations

A limitation of the development process is that interviews were conducted with a small number of participants. And the majority of participants of the evaluation of the HiFi prototype were already interviewed earlier in the process. In total fifteen interviews were conducted with seven different participants. Even though these participants are all in the potential user group, this limited amount of interviewees can not give the full overview how this tool will be received generally. A second process limitation is that due to the time scope of this projects not all suggested features from the interviews could be implemented. It could be that these features would have improved user experience or have a better effectiveness. However, these were not created so only other features could be properly evaluated. A third process limitation is that different interviewees indicated having contradictory preferences. Because the LoFi prototypes were only evaluated with two participants, not more opinions could be asked. Resulting in the researchers making the decisions based on their own preferences.

Limitations of the HiFi prototype is that only a small set of data was used to visualise with the tool. The goal of the project never was to put in as much data as possible, but just to create a good structure for easily finding information. This has been achieved, but adding more data might have an effect on the ease of use of the tool. This is an element that has not been evaluated. A second limitation of the HiFi prototype is that in the current state, there are still some elements that can cause confusion to the users. For example, the categories that the colours represent and the duplicate nodes. The third limitation of the result of this project is that it might not be accessible to people who are colourblind, need a text to speech function, or other accessibility features. These features were not included in the development process and was mentioned during the evaluation interviews.

8.1.2 Strengths

The strengths of the process is the structure of the project, where a lot of evaluation interviews were conducted. There were multiple rounds, where the feedback was immediately implemented and brought back to evaluation. This iterative process made it possible to understand the user's needs and adapt to that. The second strength of the process is close connection to the potential users from the targeted user group, this in-depth involvement of the user group makes the project fit the user's requirements.

The strengths in the HiFi prototype is that all five interviewees indicated that the tool was easy to use. This was the main goal of the project. The potential users indicated that the information was easy to find and that they would use it in their own work.

8.2 Evaluation

In the start of the project interviews were conducted with potential users. From these interviews an understanding of the user's needs were made clear, based on this, MoSCoW requirements were created. In this section an evaluation is done by comparing the HiFi prototype to the requirements that this project started with.

During the interviews information was gathered about which information sources the potential users

currently use, what content of information is needed and the current struggles that they face, while gathering this information (this can be seen in Table 2). The information sources that are included in the HiFi are the research papers and the internet search. The deepest layer of the network are research papers and the nodes all link to the internet search of that node. The content of information that is needed for the users and that is a part of the overview are projects and hardware in projects. The struggles that this overview might solve is that the information that is needed is too niche, because very niche information can be found, but then there are still backlinks to how these topics are applied in different projects. It can be stated that also the structure of information is improved based on the evaluation interviews of the HiFi prototype. Not a lot of prior knowledge is needed for understanding the information in the overview because every node has an information box for explanation. Quite a view of the user's needs are met, however not everything is addressed with this tool. For example, there is no information about specific people or even functions of people. In the overview only teams are described, but no information about individuals is given. But there is also information in the overview that was not initially mentioned by the users that they need this, for example the competitions. These were added, however, to give the overview structure, which in turn is a user need. Some struggles that are not addressed in this tool is the quality and credibility of the information and showing the newest updates. Creating a balance between which struggles can and can not be addressed in the tool in the scope of this project is a decision that is made by the researchers.

The MoSCoW requirements that were made for the tool in Table 5 are partially met. All the requirements in the Must section and Won't section were completed, however most of the requirements in the Should and Could section were not. This shows that the focus of the project has shifted as the different phases of the project progressed. This is not necessarily a disadvantage, because potential users from the target user group were closely involved in the project, allowing the project to be dynamic. However, the most important requirements (Must have...) and the goals that were stated in the beginning of the project were still successfully achieved.

8.3 Recommendations for future work

Based on the strengths and the limitations that are identified and the evaluation of the user's requirements, some recommendations for future work are proposed.

The first recommendation is to implement the extra features that were proposed during the HiFi prototype evaluation interviews. Here is a list with points of improvement:

- Adding a legenda for clarification of the colours and categories.
- Limiting the confusion of the duplicate nodes, for example by highlighting the same nodes while hovering over a node or removing the duplicate nodes and adding more edges.
- Changing the links of the nodes that lead to internet search to more detailed pages.
- Introducing grouped or compound nodes to collapse and expand certain parts of the overview.
- Adding an option for the user to switch the central layer to the topics.
- Adding accessibility features to allow more people to benefit from this tool.

Some recommendations for the project as a whole, not specifically focused on the HiFi prototype is to evaluate the tool with more potential users and adding more data to the overview.

Beyond these recommendations for the projects within the current scope, a broader look can be taken at some other elements that were not in the scope of this project. In future work of the project these elements are possible other views from which this project can be approached:

- Automation of data gathering
- Verifying correctness of data
- Privacy regulations for publishing data
- Keeping the information in the overview up to date
- Addressing ethical responsibility that comes with the creation of the tool
- Scalability and adaptability
- Adding the information or addressing the struggles identified as user's needs (see Section 8.2)

By addressing the recommendations, strengths and weaknesses discussed in this chapter, this project can develop further and making it a valuable tool for people working in the robot avatar field.

9 - Conclusion

In this chapter the conclusion of the project is drawn by summarizing the project with which the main research question is answered. The main research question was *How can a tool be created to give an overview of the latest developments in robot avatar technology?*

The goal of this project is to develop an interactive web-based tool that allows the users to easily find information about robot avatars. The target group is people that work in the field of robot avatars. First a background research was done where a look at the ANA Avtar XPRIZE competition taken to understand robot avatars. The definition found for robot avatar is a system that transports a human's senses, actions and presence to a remote location in real time. Besides this, also a research to the state of the art is made. No existing projects could be found with the same goal as this project. Therefore, a broader look at the state of the art was taken, where general visualisations with big amount of data was explored and individual visualisations were looked at. From this background research seven sketches for visualisation ideas were made. These were evaluated with potential users from the target group, another goal of these interviews was to identify the current ways of information retrieval and the benefits that the users would get from the tool that is developed. After conducting interviews with potential users in the target group, the user requirements were identified. The goal of the users that want to use this tool is to quickly find information that is structured, credible and updated, without having to spend a lot of time researching. The information that the users would like to have access to differed among the participants, but the main three categories are people working in the field, hardware possibilities and/or already existing projects. Three visualisations were chosen but based on the insights from the interviews the focus of these visualisations were changed. These were the sense-based diagram, the topic evaluation and the network diagram.

For each of these visualisations LoFi prototypes were created and evaluated by three rounds of interviews with two participants each. The feedback differed each round but the main topics were improving navigation, access of information and layout of the information on the page. Because the focus of two of the visualisations overlapped these were combined. This combined visualisation was the visualisation chosen for developing the HiFi prototype. This prototype was created with Cytoscape, where Excel was used for storage of the data and JavaScript and other coding languages to create the visualisation, interactions and webpage. The HiFi prototype was evaluated with five interviews with potential users from the target group, which was well received and the goal of easily finding information about robot avatars was achieved. To further clarify the outcomes of the research, the sub-questions are shortly addressed:

1. *What is the goal of the users for using this tool and what information would the users like to have access to?*

The goal of the users wile using this tool is to quickly find relevant information in a structured way about hardware, projects, technologies, people, competitions and teams in the robot avatar field, without needing a lot of prior knowledge to understand the data.

2. *Which type of visualisation(s) can communicate the relevant information in a good way to the users?*

The visualisation that can communicate this information in a good way to the users is a graphical visualisation which allows the user to see a tree view of the data for every node in the graph, but also keeping in backlinks to other parts of the visualisation to understand the relationships between different components in the field.

3. *Which interactions can be added to the tool to make the information retrieval easier?*

The interactions that were added to the tool to make the information retrieval easier are zoom in and highlight functions, allowing the user to only focus on the information that they need, and introducing a search bar to quickly find specific information.

Appendix A – Conversion of exported file to elements.js

Structure of exported networks.js file (actual data is deleted in order to keep the overview):

```
var networks = {"Matching from scratch": {
  "format_version": "1.0",
  "generated_by": "cytoscape-3.10.2",
  "target_cytoscapejs_version": "~2.1",
  "data": {
    "shared_name": "Matching from scratch",
    "name": "Matching from scratch",
    "SUID": 14241,
    "__Annotations": [ "" ],
    "selected": true
  },
  "elements": {
    "nodes": [ {
      "data": {
        //All nodes here
      },
    },
    "edges": [ {
      "data": {
        //All edges here
      },
    ]
  }
}}
```

Structure of the elements.js file (actual data is deleted in order to keep the overview):

```
const elements = {
  "nodes": [
    {
      //All nodes here
    }
  ],
  "edges": [
    {
      //All nodes here
    }
  ]
};

// process data
elements.nodes.forEach((n) => {
  const data = n.data;

  data.NodeTypeFormatted = data.NodeType;
});
```

```
// save original position for use in animated layouts
n.data.orgPos = {
  x: n.position.x,
  y: n.position.y
};

// zero width space after dashes to allow for line breaking
data.name = data.name.replace(/[-]/g, '\u200B');
});

export default elements;
```

Appendix B – Results of HiFi interviews

1. What is your first impression of the tool?
2. How easy or difficult did you think finding the information was?
3. Do you think this tool is useful for you?
4. Did you need the help function at any point? Why?
5. Is there any information or categories that you think is missing from this visualisation?
6. Do you have any recommendations for improving this tool? Anything you would like to add remove or change?
7. From the LoFi interviews there was an idea for letting the user switch which category would be in the centre of the visualisation. Do you think this is needed?
8. Do you have any final remarks or other things you would like to say?

	Participant 1	Participant 2	Participant 3	Participant 4	Participant 5
Q1	Fantastic and easy to use	The back links are nice and it is easy to understand what it can do.	It has a nice visual appeal.	Comprehensible and pleasant to use.	A bit full, but nice.
Q2	Easy because of the search function, however there were duplicate in the list of results, which was confusing.	It is really easy to find information.	It is easy to find information.	It is easy because of the relationships and associations through the whole visualisation.	It was easy to find, but some instruction was needed.
Q3	Yes, I could use it during a lecture, to understand the full overview of the field.	Yes it is great for mapping domains to technology, which I do in daily work.	Yes, only if it is complete in data. I would use it instead of traditional ways of finding research papers. Or to find connections to things I already know.	Yes, I would prefer this over a normal internet search because the connections are visible.	Yes, if the data is complete.
Q4	No.	Yes, I did use the help button. But just out of curiosity.	Yes, I did not read the full text. But checked back quite often for which colour is	No.	No. But if it would have taken longer for me to figure out how to use the tool, I would

			which category.		have.
Q5	No, all the current levels are fine.	Information that is not full are the links from the nodes to more information. Right now they go to a general internet search. This can be more targeted.	No.	No, the routes between the current categories are very clear.	No.
Q6	When more information is added, it is nice to have groups of nodes that can group and expand.	When more information is added, it is nice to have groups of nodes that can group and expand.	There are duplicate nodes, maybe another way to display this is having only one node, but multiple edges to it. Also adding a legenda of explaining the colours and categories would help.	Linking to a specific website would be nicer than linking to a general search term.	Start more zoomed in, and make only the first three layers highlighted. This guides the focus of the user more.
Q7	No, with the search function all levels are easily accessible.	Currently not necessary, maybe when there is a more complex dataset.	Yes, however the only other view that sounds useful is the topics as the center. The other categories don't need the separate view.	No not necessarily.	Yes, also an addition where you can see in one sight all the papers from one team is nice.
Q8	There is an ambiguity in the visualisation because of the duplicate nodes, this may cause confusion. And to really be	No.	The styling can be more equal throughout. The help and reset button don't match with the rest of the styling. Also it is nice if the	Think about how to make it more accessible and inclusive (colourblindness, speech,...)	Have a legenda for the categories and introduce a sorting option on the side.

	useful it is important that the data is up to date.		duplicates in the search results are removed.		
Additional remarks from observation	-	Clicking around and interested in all other information found in the overview.	Only used the search function and did not look at the nodes.	Did not use the search function, just looked at all the nodes.	Immediately interested and trying to find specific information related to their own field.

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