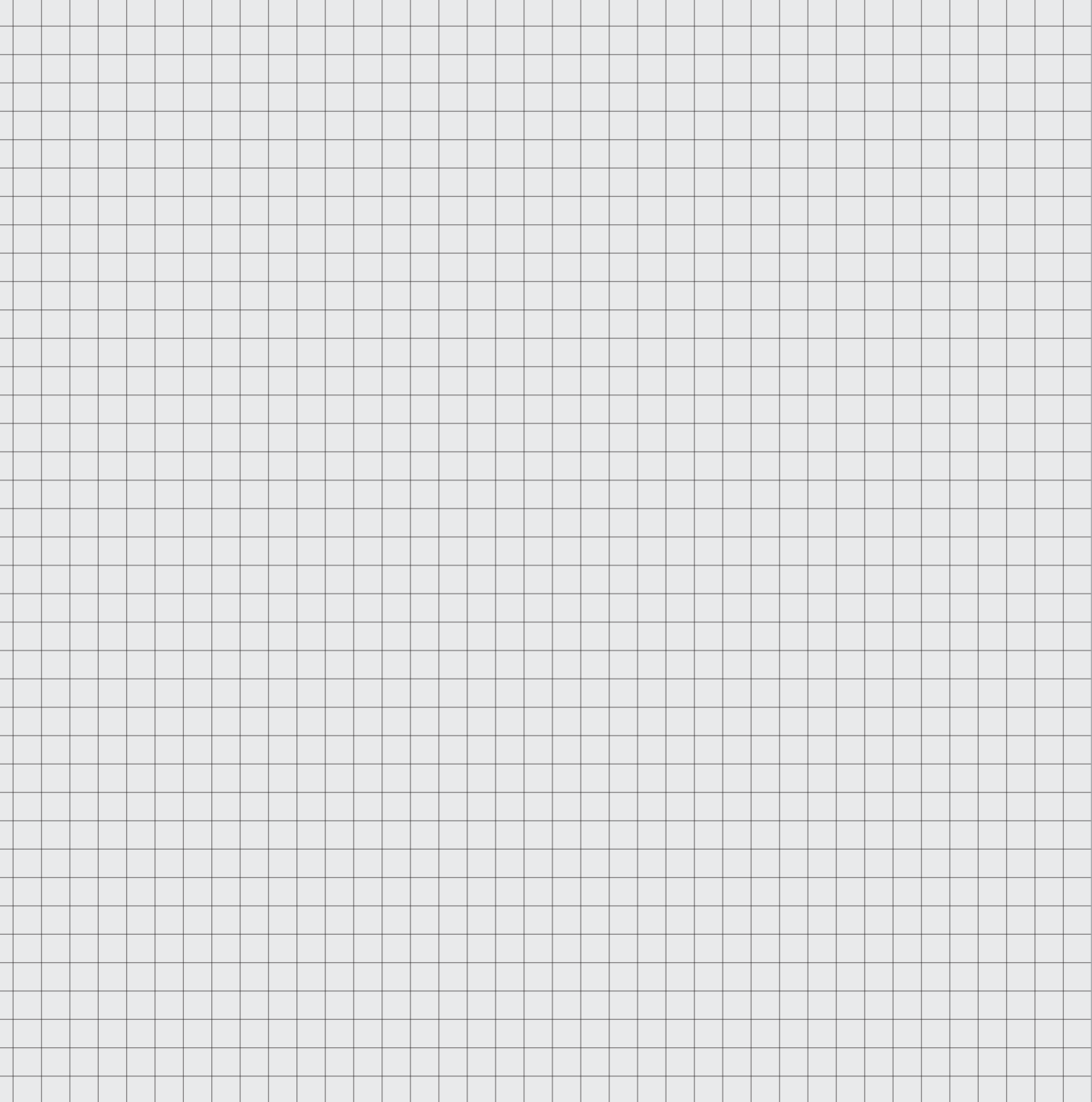
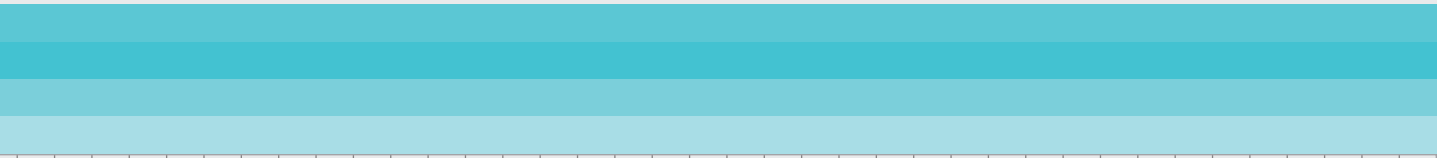


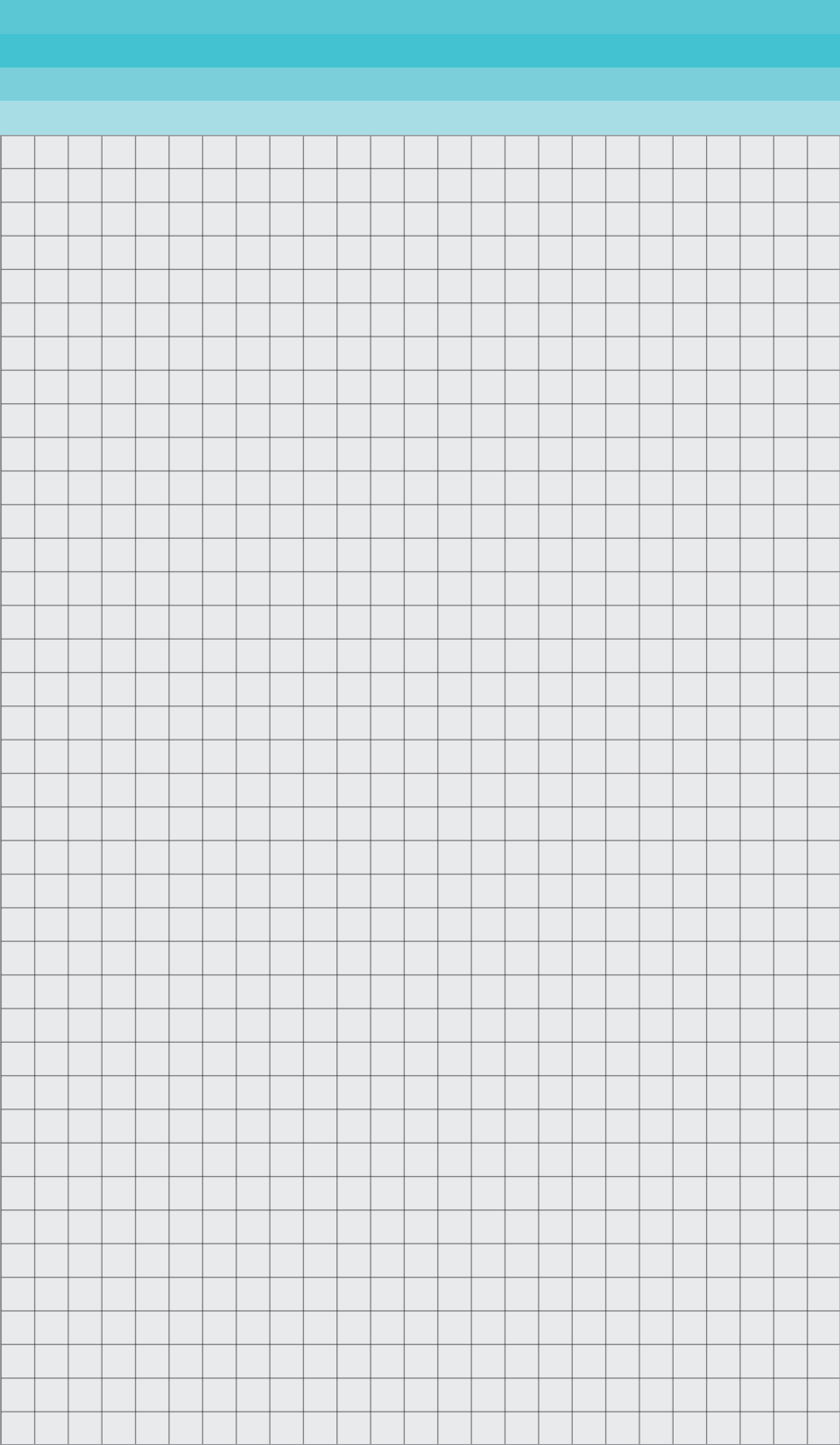
VR COMPOSITE HAND LAY-UP
COLLABORATION FOR VIRTUAL
TEAMS



CONTENTS

5	Assignment		101	Product Evaluation	
	Design Case	7		Research Goal	102
	Project Introduction	8		Hypotheses	102
				Methodology	103
11	Literature Review			Results	105
	Composites	12		Conclusion	105
	Mental Models and Achieving Common Ground	14		Discussion	106
	Virtual Reality	22		Requirements Evaluation	108
	Collaboration	24			
	Key Terms and Insights	30	111	Project Conclusion	
	Knowledge Gaps	31		Project Summary	112
				Project Conclusion	115
				Future Work	116
33	Contextual Analysis				
	Composite Production Analysis	34			
	Composite Production Timeline	36	121	References	
	Collaboration Techniques Analysis	46			
	Analysis Conclusion	56	125	Appendix	
				Project Brief	126
61	Conceptualisation			Current State Of Vr	133
	Requirements	62		Collaboration Study Questionnaire	136
	Interaction Vision	63		Collaboration Study Follow Up Question Guide	141
	Ideation	64		Hkj Ideation Results	144
	Holistic Concept	68		RITE Qualitative Questions Guide	150
	Prototyping Plan	74		Quesi Questionnaire	151
	Evaluation Plans	75		Written Description Of Lay-Up	152
				Qualitative Results RITE	154
77	RITE Prototyping			Blueprint Code	162
	RITE Methodology	78		Evaluation Of Requirements	166
	Prototyping Steps	80		Individual Quesi Results	168
	Final Prototype	85		Questionnaire Final Evaluation	169
	Prototyping Implementation	87			
	Quantitative Results	90	183	Confidential Appendix	
	Conclusion of RITE	91		Confidential Composite Production Timeline	184
	Recommendations	91		Final Evaluation Data	194
				Personal Reflection	200
93	Knowledge Recorder				
	Made For Lay-Up	95			
	Made To Make Knowledge Traceable	96			
	Customer Journey	98			





In the assignment chapter, the design case is introduced. An overview of the project and how the design case was solved is given in a project summary on page 8.

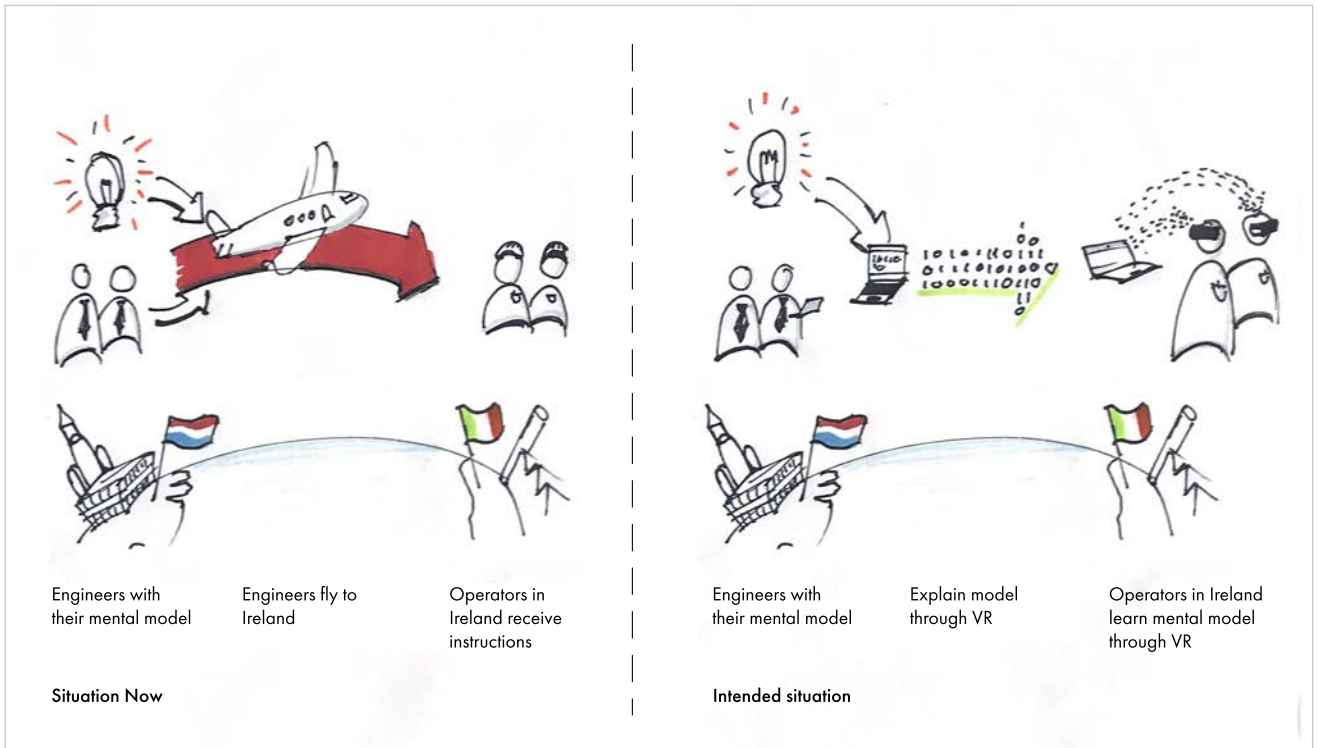


Figure 1: Current situation and Desired Situation

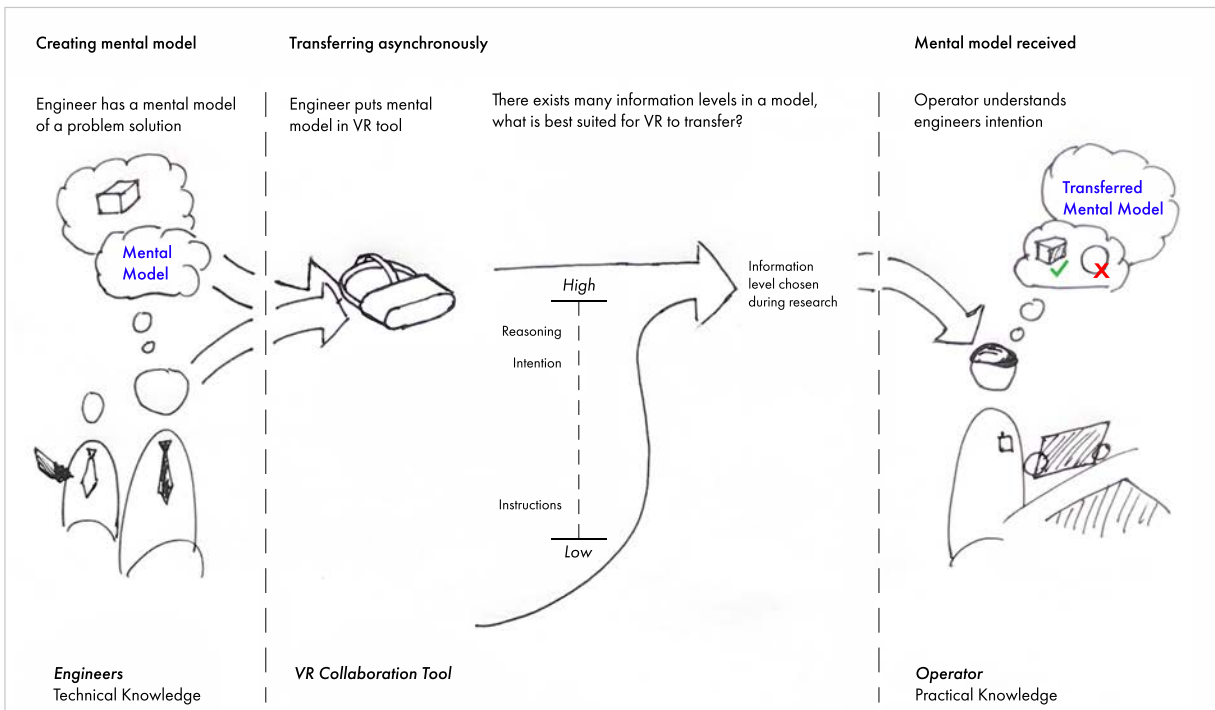


Figure 2: Solution Framework

Enabling long-distance expression of complex Mental Models for asynchronous collaboration within Circular Grid-stiffened Composite Hand Lay-up Production through Virtual Reality.

PROBLEM STATEMENT

ATG Europe is a space engineering company in Noordwijk, the Netherlands. They do projects mostly for the European Space Agency but are also developing their own products, such as grid-stiffened composites.

ATG has two teams working on grid stiffened composites, illustrated in Figure 1. They have an engineering team in the Netherlands and a production team in Ireland (called operators). The engineers have theoretical knowledge and the operators have practical knowledge. This means establishing Common Ground on a shared Mental Model of a problem can be challenging.

ATG found that their engineers, working in the Netherlands, could not rely only on reports, email, and Skype in order to collaborate with the operators, working in Ireland. In order to solve this problems the Dutch engineers fly back and forth to Ireland quite often.

In between those two methods, a lot of information is lost and the high amount of flying has a big impact on the environment. Ideally, a tool should exist to reduce this reliance on flying.

SOLUTION

Virtual Reality was deemed to be a potential solution to this communication problem. In this project, it will be determined how Virtual Reality should be used to enable engineers to share their Mental Models with the operators, without being present. Activities in this project include exploring not only the possibilities that VR brings but also understanding composite production and communication. Combining that knowledge into a build prototype for a VR tool, which can be used to establish easier communication and better collaboration between teams. Leading to a reduction in the need for flying.

This solution framework is illustrated in Figure 2 on page 6.

PROJECT INTRODUCTION

In order to arrive at the proposed concept as a solution to the design problem several design steps and studies were done. These are outlined in this report. In this section the report is summarised as a reading guide.

LITERATURE REVIEW

First a literature study was done, in which four main things were explored. First, the concept of Mental Models and Common Ground was introduced. This can be read in section "Mental Models and Achieving Common Ground" on page 14.

Secondly, Virtual Reality itself and the affordances it provides was analysed in section "Virtual Reality" on page 22, The current state of Virtual Reality is analysed in Appendix 02 on page 133. The current literature on collaboration was reviewed in section "Collaboration" on page 24. This introduced the concept of communication bandwidth on page 26. Additionally, a review of current VR collaboration tools was also done in this section.

This formed the theoretical basis for the project and the conclusion of which were summarised in section "Key Terms and Insights" on page 30.

CONTEXTUAL ANALYSIS

After the literature review it had become quite clear that there were two knowledge gaps. The first one being the composite production process was still not understood by the researcher. This meant it was unclear how the process went and what could work well with the affordances of Virtual Reality. Secondly, it was unclear what current collaboration tools were used in ATG and how and why they were used.

To gain insight into the production process, an immersion exercise was done in which the researcher did the actual production process. This study is described in section "Composite Production Analysis" on page 34. The results of this analysis were made into a timeline found in section "Composite Production Timeline" on page 36. The main conclusion from this explorative study was to focus on the alignment phase of the process.

A generative study was done to determine the use of each collaboration tool used by the composite at ATG. This is described in section "Collaboration Techniques Analysis" on page 46. The results of these interviews were then clustered and made into a comparison which can be found on page 48. The main insight was that a traceable and high bandwidth tool did not exist yet, but would be very useful. This presented an opportunity for VR. This is explained in section "Analysis Conclusion" on page 56.

CONCEPTUALISATION

For the conceptualisation, requirements were created based on the previous studies. These requirements can be found on page 62. Together with an interaction vision, page 63, an ideation exercise using HKJ's was done. This is documented on page 64. From these ideas a single concept direction was created.

CONCEPT DIRECTION

The concept direction, found in “Holistic Concept” on page 68 is a Virtual reality tool that does two main things. First, it records sketches, objects and the engineers’ position and voice in 3D over time to capture Mental Models. Secondly, by organising those Mental Models in a clear project structure that makes the Mental Models traceable and findable in a persistent project.

Having these two features addresses the two main insights from the contextual analysis and resulted in a prototype that satisfied the requirements.

RITE PROTOTYPING

To embody this concept direction, an almost fully featured prototype of the concept was build using a method called RITE (Rapid Iterative Testing and Evaluation). This method allows for multiple iterations of the prototype to be made and evaluated. This method is further explained in section “RITE Methodology” on page 78. The iteration process itself is documented in section “Prototyping Steps” on page 80. How the prototype was build is explained on page 87.

FINAL PROTOTYPE/CONCEPT

The final prototype is the embodiment of the concept direction explained on page 68. This final prototype is detailed on page 85 from a more technical standpoint. The final prototype is explained in chapter “Knowledge Recorder” on page 93. A customer journey explaining how the prototype works is detailed in the same chapter on page 98.

CONCEPT EVALUATION

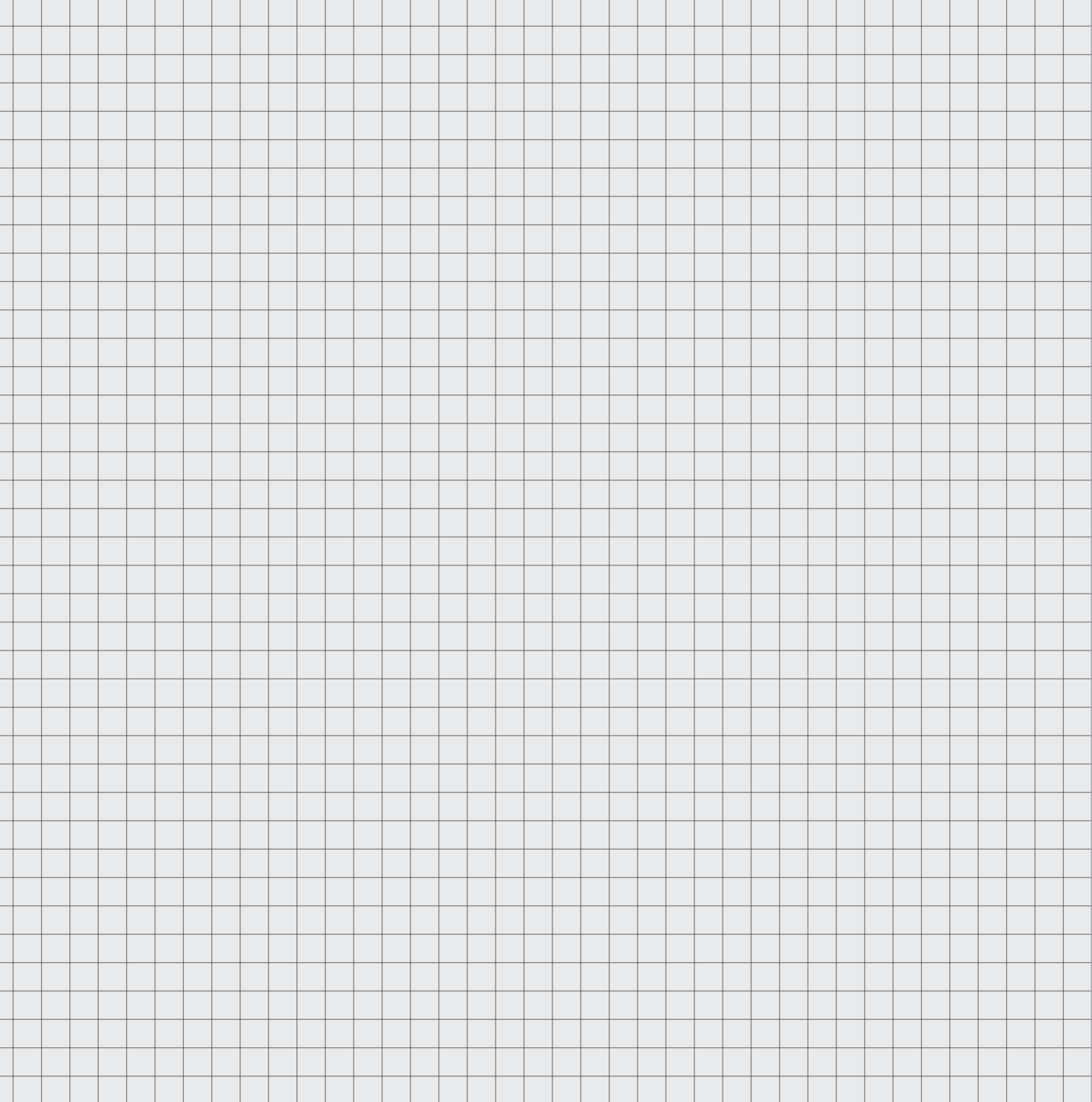
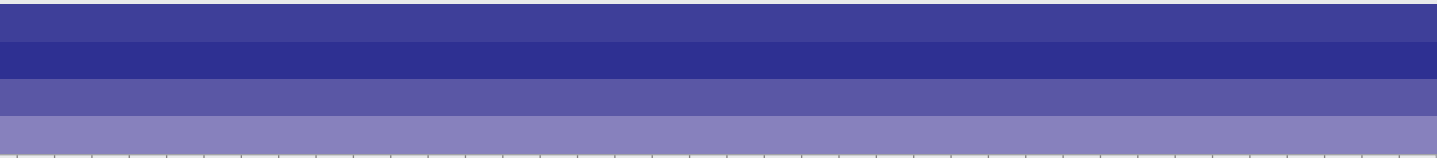
A between-group study was done to evaluate the prototype on its ability to transfer Mental Models. Participants were shown either a video of the tool or a written description of the process. The participants were then quizzed on the process. Furthermore, they were asked about their perceived understanding of the domain before and after the questionnaire, as well as their opinion on the experience. This is described on page 102.

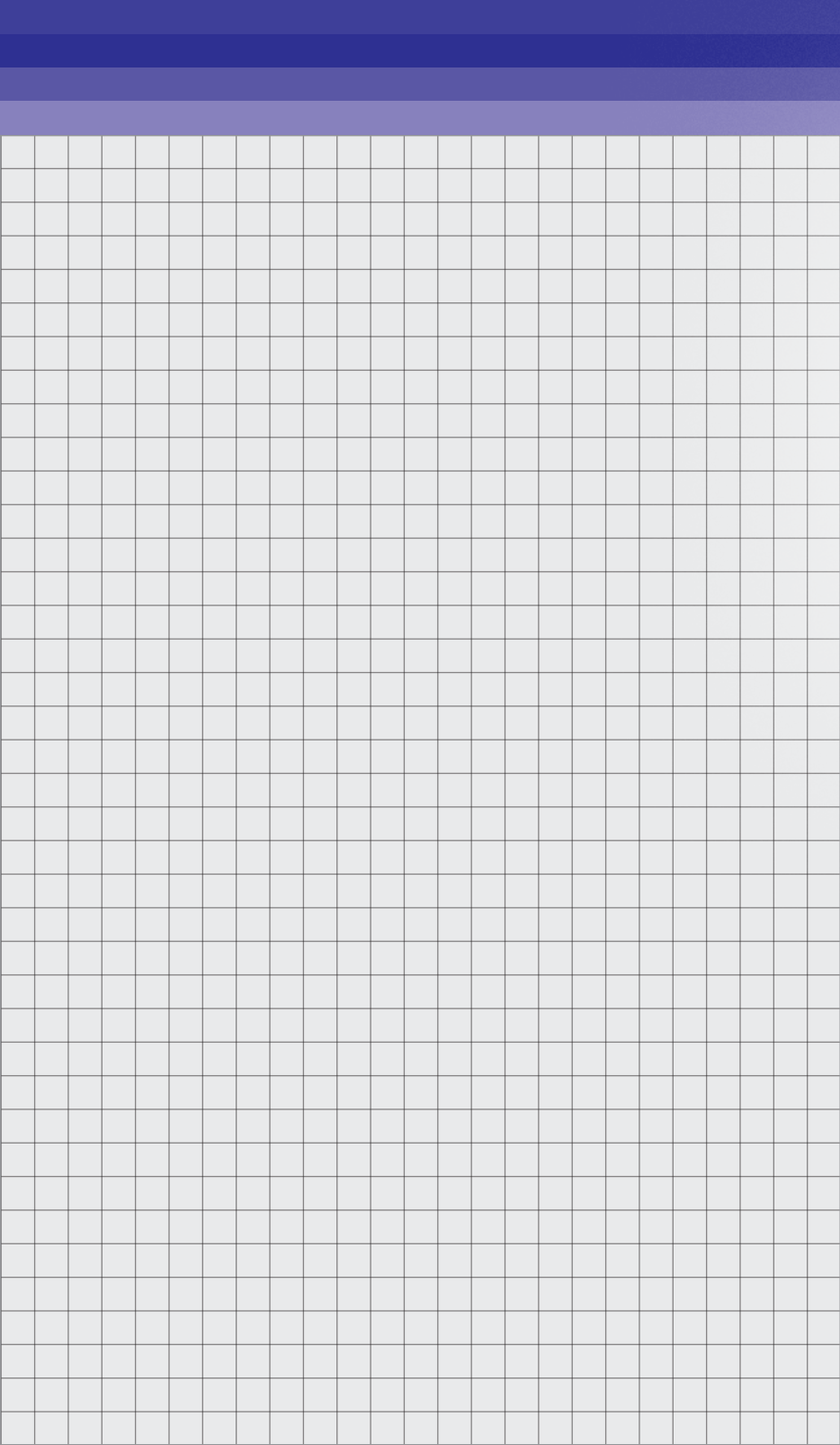
The results came back mostly insignificant but the video of the tool of VR did perform better on clarity and experience. It performed slightly higher but not significantly so on the score and the perceived understanding. That is still a promising result as preparation time was lower and the VR tool is traceable. An evaluation and discussion of the requirements is done on page 108, which were largely fulfilled.

PROJECT CONCLUSION AND RECOMMENDATIONS

In the final chapter the project is summarised again in section “Project Summary” on page 112 then concluded in section “Project Conclusion” on page 115. At that point, this project will have laid a solid foundation for future research on using VR for long distance collaboration. The prototype itself was quite complete and it was tested thoroughly with RITE. It will have shown that VR can be used to transfer knowledge and by extension Mental Models as well as, if not better than, a detailed document.

This is followed up by recommendations future studies and design directions in section “Future Work” on page 116.





In this chapter, a literature review will be done for Mental Models, Common Ground, collaboration and information sharing. In addition, an analysis of current collaboration tools will be done. An analysis of the state of Virtual Reality can be found in Appendix 02 on page 133.

At the end of this chapter, all important terms will have been analysed and defined based on existing literature. That creates a theoretical foundation on which the rest of the project rests.

COMPOSITES

WHAT ARE COMPOSITES?

According to Hull and Clyne (1996), many materials are effectively composites. They define composites as “needing to consist of load-carrying material and a binding component which results in a material with better properties than those of the individual components.” This includes materials such as wood. However, in this project, only continuous high-performance fibre reinforced composites will be considered. These generally consist of fibres and a binding component. Abramovich (2017) states that these composites’ main advantages are their high strength and stiffness, combined with low density. This allows an engineer to reduce the weight of a component. This is highly valuable in high-performance applications such as aerospace where saving weight has a large impact on the cost of a mission.

AUTOMATED OR HAND LAY-UP

There exist many different techniques for producing composites, which can be categorised into two main categories “Automated Production” and “Hand Lay-up”. Hand lay-up is

laying down individual layers of a form of reinforcement by hand. According to Elkington et al (2015) “The hand layup process involves manipulating each layer (ply) into shape by hand”. Using this method, high-quality complex features can be produced with relatively low start-up costs. This means the shape is easily changeable when project requirements change, which makes it ideal for manufacturing unique parts. However, due to the cost of both materials and labour, it is not a good fit for mass manufacturing. Additionally, hand lay-up means less reliability and larger tolerances due to human operators. They simply cannot achieve the reliability, repeatability and precision of a machine. However, this does mean automated production has the disadvantage of having high start-up costs. When mass manufacturing a part, these costs can be offset due to a reduction in labour costs and the optimisation of the manufacturing process. This results in automated production being cheaper for mass-manufactured parts. Whether hand lay-up or automated production is best should be determined on a case-by-case basis.

ATG’S COMPOSITES

ATG has developed a specific type of composite grid structures. They have developed a method of producing flat sheets using hand lay-up and are now working on developing Cylindrically Shaped Grid Stiffened composites. These composites make use of strips of material rather than large sheets. By laying down these strips in a grid pattern a large weight saving can be achieved while still creating a very strong composite. Understanding the production process of these composites will be the focus of the next analysis phase.

A single part will be used as a reference during this project. The production process of this part will be studied and solutions will be designed for it. This is done to keep the project manageable. This part, pictured in Figure 3 on page 13, was chosen because it represents the most complete cylindrical part available right now. It requires not only cylindrical manufacturing techniques but also covering techniques.

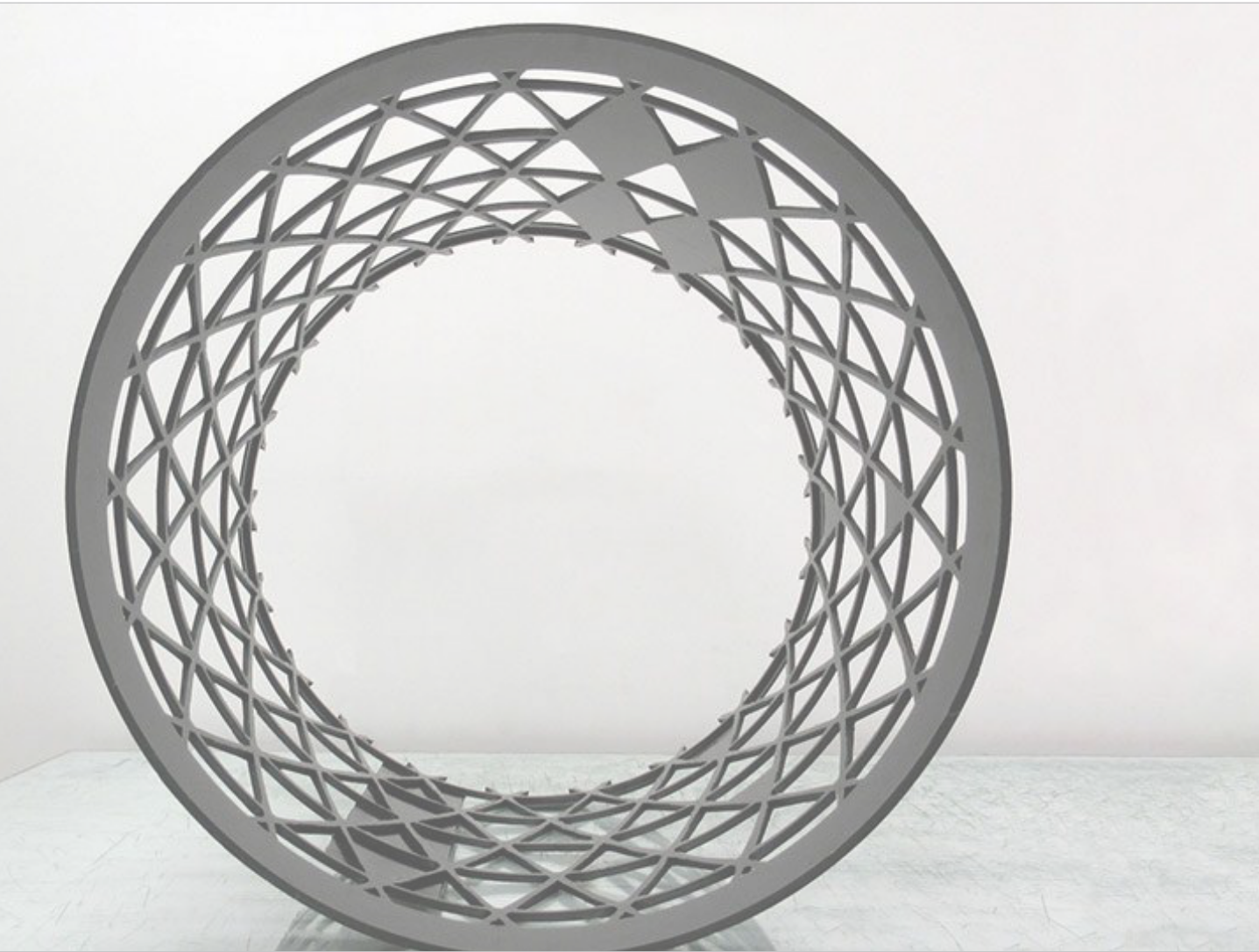


Figure 3: The cylindrical part that will be used as a reference during this project.

Source ATG-Europe

MENTAL MODELS AND ACHIEVING COMMON GROUND

Throughout this graduation project, the term Mental Models and Common Ground will be used. Therefore they will be introduced in this section. After introducing them, the different types of Mental Models found in literature will be described. In addition, it is explored why it is important to share Mental Models in a collaboration process. This section will be concluded with an overview of current literature on how to establish Common Ground.

MENTAL MODELS: AN INTRODUCTION

Mental Model's as an idea has had a long history in philosophy. With the first paper on the concept being written by Kenneth Craik in 1943. However, until the 1980s Mental Models were not used. This changed with the development of the field of cognitive science when Mental Models were reintroduced by Johnson-Laird (1980). Johnson-Laird (1980) proposed Mental Models as the basis of human cognition. He stated that "Human beings do not apprehend the world directly: they possess only internal representations of it."

It was suggested by Rouse and Morris (1986) that research on Mental Models should be studied for each domain separately. This is because the knowledge that they contain and their purpose, which is domain-specific, should be considered. That leads to the question: how do Mental Models relate to design or more specifically interaction design?

Don Norman, the writer of the book "The Design of Everyday Things", wrote this about Mental Models in 1983. "In interacting with the environment, with others, and with the artefacts of technology, people form internal, Mental Models of themselves and of the things with which they are interacting. These models provide predictive and explanatory power for understanding the interaction." This supports the view of Johnson-Laird that Mental Models are our interpretation of the world. Suggesting that Mental Models are not only important for observation but also influence the way we interact with the world.

On the other end, Badke-Schaub (2011) stated: "Mental Models are simplified representations that people produce and adapt for the sake of quick reactions performing acts, as well as for gaining understanding, predicting, assimilating and processing new information and new situations.". Combining this suggests that Mental Models are what allows us to interpret and understand our world. They directly influence the way we behave and the decisions we make. Logically this also means that newer Mental Models are influenced by older Mental Models, i.e. experience or background. This is the definition that will be used during this project.

COMMON GROUND

Because Mental Models are influenced by context, experience, background and many other factors people tend to interpret the same concept or situation differently than others. That means that your Mental Model on a concept can completely differ from someone else's.

Even though you were observing or talking about the same concept. In that case, you have no Common Ground.

Then, what is Common Ground? First, it is important to understand that there are many terms used in literature, such as shared understanding, shared Mental Models, shared belief, and shared knowledge. These have a lot of overlap with Common Ground and in the case of shared Mental Models are very comparable. However, only the term Common Ground will be used to avoid confusion .

Common Ground is having a shared or similar Mental Model with another person. It is important to note that 100 per cent certainty that someone has the same Mental Model can never be achieved, as argued by Lee (1998). He introduces three different types of Common Ground with different levels of certainty. The first type is "established Common Ground". In this case, it is known that people have the same Mental Model because it is established through interaction.

The second case is "Assumed Common Ground, not established", where Common Ground is assumed, because of an assumed similarity of background. This background is often only assumed by people through other sources of evidence and prior interactions. The third type is "as though Common Ground, not established", where new information is shared as though it is already part of the Common Ground. To illustrate Lee (1998) gives an example of the Little Mermaid in Copenhagen. Even if the other party has never heard of the Little Mermaid it can be assumed that they would be able to find their way there. In other words, it can become Common Ground but is not yet.

TYPES OF MENTAL MODELS

Similarly to Common Ground, there are also three types of Mental Models. Originally it was proposed by Johnson-Laird (1983) that there were two types of Mental Models, task and team Mental Models. Casakin and Badke Schaub (2013), add to this by introducing process Mental Models for

design and engineering teams. Badke-Schaub et al (2011) define the different tasks as follows:

TASK

When team members have to arrive at a common solution for a design task, task Mental Models should be shared. This is about how users individually interpret the task at hand, which might differ due to different backgrounds and context. Task Mental Model's are about how the task can be completed, the different design stages, and making decisions about the task.

PROCESS

According to Casakin and Badke-Schaub (2013), Process Mental Models are about an understanding of the steps, strategies and procedures that teams need to take to complete the task. When it comes to non-standard procedures, establishing a shared Mental Model on how to complete a task is essential. Team members that agree on how to work together, to solve a problem and to structure the procedure, will very likely perform better than teams that do not.

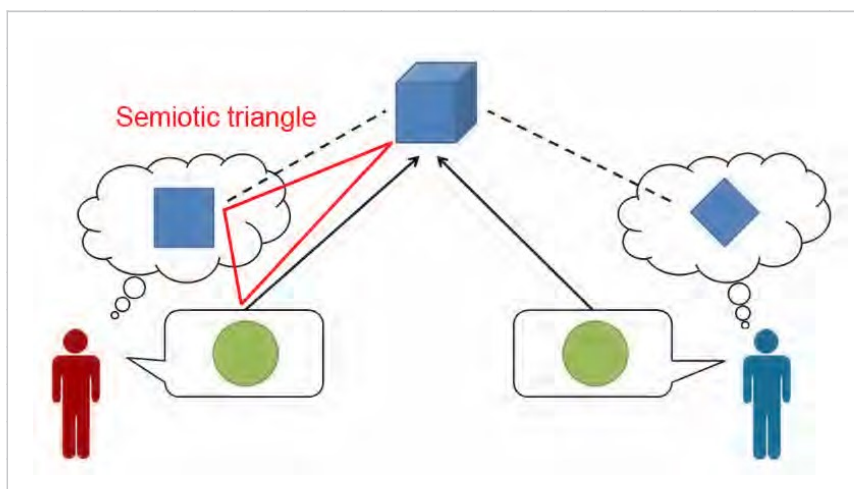


Figure 4: Image Illustrating Mental Models Source: Aschenbrenner (2017)

TEAM

Badke-Schaub (2011) defines Team Mental Models as “Team Mental Models are representations related to the team and its members. These are fundamental for coordinating between team members and enable collaborative work.”. This is necessary for allocating roles and responsibilities in the team and understanding what kind of knowledge team members have. Both of which help a team achieve its goals. This also concerns the team climate. Team climate is influenced by the willingness to work together, mutual respect, and other factors. However, this latest point falls outside of the scope of this project.

Other literature fits on types of Mental Models fit within these categories. To give an example, Cannon-Bowers (1993) defines shared Mental Models as “knowledge structures held by members of a team that enable them to form accurate explanations and expectations for the task, and, in turn, to coordinate their actions and adapt their behaviour to demands of the task and other team members”. This underlines the importance of taking these different types of Mental Models into account in the analysis phase.

WHY SHARE MENTAL MODELS?

This leaves the question, why are Mental Models interesting for this project and why should ATG strive to create a shared Mental Model in their teams.

DISTRIBUTED KNOWLEDGE

ATG has its engineers in the Netherlands. They have the technical knowledge required to produce composites. They understand how a grid-stiffened composite gets its strength and which conditions need to be met. Furthermore, they can calculate the amount of tension required in the composite and they are the ones who create the shape of the composite. However, they have little practical knowledge of how to manufacture composites. To give an example, the engineers might understand why a composite needs to be shaped in a certain way but an operator would understand why a specific shape might be impractical to produce. This is what is called distributed knowledge.

ATG has perceived a problem in their current reporting methods. The engineers have trouble conveying all necessary information to the operators,

necessitating frequent visits to Ireland by their engineers. This is a problem that has also occurred in literature. DU (2013) writes that: “Some information is vital to creating shared understanding on the aspects [of a project], including the reasons behind a mechanical design decision, the justification for it, the other alternatives considered, the trade-off’s evaluated, and the argumentation that led to the decision. However, this critical information is not recorded explicitly in technical documents.”.

Shared Mental Models can support the composite production process. Mental Models make this information implicitly understandable by other team members but if that is not the case they increase the understanding of “who knows what”. According to Badke-Schaub et al (2007), it is essential to create a shared team Mental Model to use distributed knowledge. This makes sure team members understand what knowledge is available in the team. Furthermore, it seems likely that a shared Mental Model of the roles and responsibilities in the team facilitates teamwork.

Shared understanding

Another term that is found quite often in literature is “Shared understanding”. How does shared understanding relate to a shared Mental Model and what is it. Kleinsmann (2006) defines it as “a similarity in the individual perceptions of actors about either how the design content is conceptualised or how the transactive memory system works.” Transactive memory system being a term introduced by Wegner (1987) as “a set of individual memory systems, which combines the knowledge processed by particular actors with a shared awareness about who knows what”. In other words, Shared understanding in a team is that members have an understanding what others know. As such, it seems to be similar to the team Mental Model as described by Casakin and Badke Schaub (2013).

EASIER COMMUNICATION

Shared Mental Models allow for easier communication between team members. They allow team members to draw on similar representations and coordinate actions more efficiently (Bierhals et al, 2007; Badke-Schaub et al, 2011). Additionally, Mathieu et al (2000), found that "shared Mental Models are important for coping with tasks with difficult communication. Team performance can benefit from shared Mental Models in situations with a high need for information exchange in the team. In situations, where only limited communication is possible shared Mental Models were found to be most valuable". This also relates to work by Kleinsmann (2008), who defined a set of barriers and enablers for reaching a shared understanding or Common Ground. For example, the higher the ability of actors to make use of different communication methods the easier it is to come to a shared understanding.

PREDICTIVE BEHAVIOUR WITH DISTRIBUTED KNOWLEDGE

Having a shared Mental Model seems to increase the ability to better predict team behaviour. This is supported by Badke-Schaub et al (2007), who states that: "Commonly held Mental Models are thought to provide a set of organized knowledge of the task and the team from which predictions about team member behaviour can be drawn.". Additionally, Stout et al (1999) state that "Shared Mental Models are important for tasks that require highly coordinated actions between different team members. [team] members have to act according to their predictions of each others' understanding of the task demands

and their behaviour.". This suggests that shared Mental Models allow a single user to better include factors from outside their field of expertise when making a decision. For example, an operator can better understand why and engineer wants a specific amount of tension applied and can take this into account in a manner that suits his process. In this project, that could potentially lead to better, more desirable, results faster with less back and forth.

TEAM PERFORMANCE INCREASE

In addition to making it easier to use distributed knowledge, it is well documented in literature that creating shared Mental Models in a team leads to better team performance in general. This is supported by research done by Lim and Klein (2006), Marks et al (2002), Mathieu et Al (2006) and Smith-Jentsch et al (2005). They have shown that similarity of Mental Models between team members has a positive effect on team performance. This increase in performance is partially due to the aforementioned reasons.

INFLUENCE OF MENTAL MODEL TYPE

It is of note that the type of Mental Model, which needs to be shared, seems to be dependant on the task at hand. Badke-Schaub et al (2007) states that: "Depending on the type of task, Operational tasks with clear procedures need a highly shared task model. Whereas tasks that require individual decisions might be more reliant on highly shared team models.". This will be important to consider later on in the project.

ESTABLISHING COMMON GROUND

We can create a shared language by increasing the ability of the engineers to make a transition of knowledge, or their Mental Model of a problem, to the operators. This is done by increasing the quality of project documentation, increasing the efficiency of information processing, and the equality of language used. Leading to a better understanding of each other's Mental Model or the creation of a shared Mental Model.

Two key pieces of work about the creation of shared Mental Models in engineering teams were found. First, Kleinsmann defined barriers and enablers for the creation of Mental Models. These work on three organisational levels which will be introduced. This is a theoretical study and does not provide any solutions yet. Secondly, there is the work of Goldschmidt, who presents the method of sketching as a way to create shared Mental Models.

BARRIERS AND ENABLERS

Kleinsmann (2008) defined factors, both negatively (barrier) and positively (enabler), on three different organisational levels to stimulate the creation of Common Ground. The three levels are the company, the organisation, and the project level.

These factors were derived from many observations during a single case study through clustering. Therefore, they may be incomplete for the case of composites. However, because of the clustering method used, most factors can be applied to composite production collaboration with varying degrees of applicability. Factors were selected that are thought to be most applicable to this project.

COMPANY LEVEL

Factors at the company level are mostly the resources available within the company and the organisation of the team and their knowledge. Together with proper allocation of tasks and responsibilities, this was found to be most influential by Kleinsmann et al (2010). Although this level falls outside of the scope of this project, it is important to mention.

PROJECT LEVEL

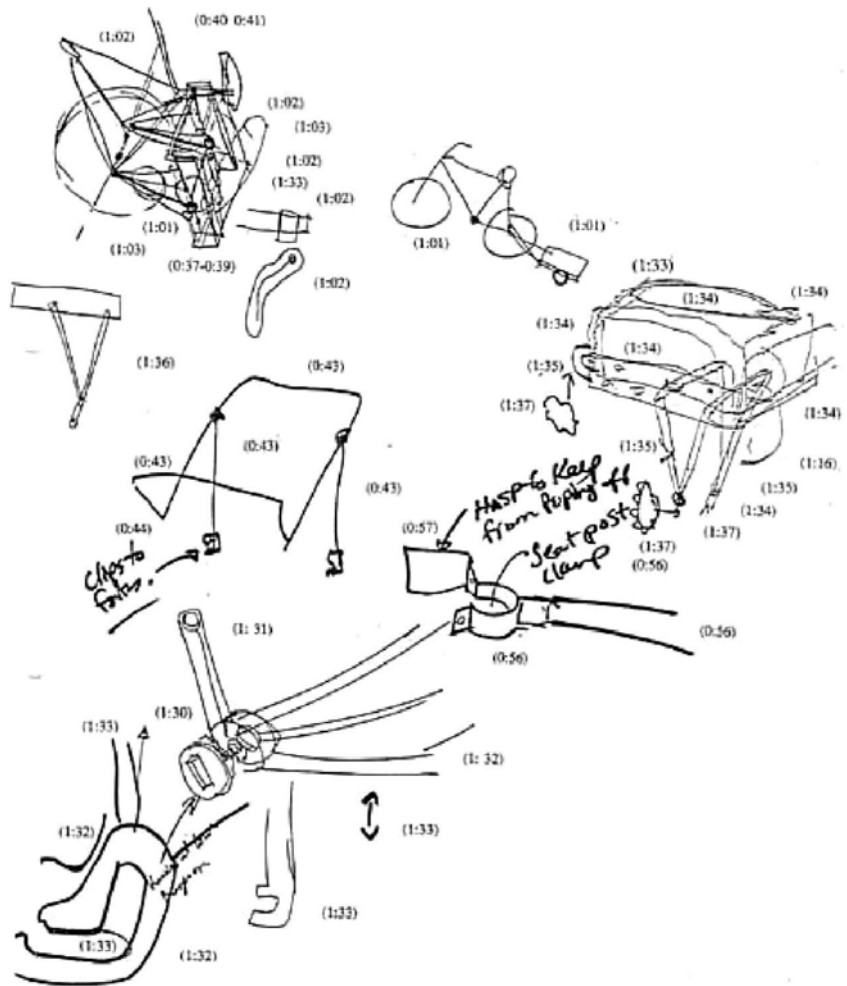
The project level mostly refers to factors within the team. These include the efficiency of information processing, the quality of project documentation, and the degrees of freedom within the design task.

For this project, it would be interesting to define the degrees of freedom for the process, seeing how it is of influence on the process. This is something that can be altered and thus will need to be accounted for in the final design. Improvements might be made in the quality of project documentation. Kleinsmann (2010) gives example causes, for instance, incomplete and continuously changing documents. The efficiency of information processing within the process and the quality of project documentation were found to be most influential for creating a shared understanding by Kleinsmann (2010).

ACTOR LEVEL

The actor level contains factors that are due to individuals, not necessarily team dynamics. Factors include the knowledge, ability, and experience of an actor relevant to the task and the equality of language used between actors. Also of importance is the ability of the actor to make a transition of knowledge. Potential improvements that can be made are in establishing a universal language that both the engineers and operators can understand. A certain intermediate language between practical and technical jargon. Additionally, actors can be supported in their ability to make that transition of knowledge. In other words, knowledge can be made more easily understandable for others.

Figure 5: Example sketch by Goldschmidt (2007)



ESTABLISHING COMMON GROUND IN PRACTICE

SKETCHING

According to Goldschmidt (2007), visual representations largely contribute to the communication between team members and aid in the development of a shared Mental Model. Creating visual representations is an iterative process that lasts until a team is satisfied that the representation captures the idea they're trying to communicate. In extension, this can then form the basis for the teams Mental Model.

Creating sketches, a form of creating visual representations, is especially useful. As they can be created rapidly and with simple means. According to Goldschmidt (2007) "It is an artefact that serves the [team member] to reason about [...] it can be easily transformed by adding, emphasizing or tracing over it". This makes the sketch an ideal means for representing and sharing knowledge. At the same time, sketches are also very rough and provide incomplete information. This forms an advantage when the object is still being developed but when detail is being discussed sketches might not be

a great fit. Goldschmidt's work shows that by using limited visual information, as an addition to other communication methods, makes it easier to establish Common Ground. Especially the process of seeing the sketch change, while being explained, is a promising method of establishing Common Ground.

VISUAL LANGUAGE

To understand how sketching can relate to establishing Common Ground in VR, it is important to first introduce Visual Language. Landman (2009) defines Visual Language as “tightly integrated communication units that are composed of word, images and shapes”. They can be used for “explaining individual MM to establish meaning”, “initiating negotiations of meaning” and “promoting group consensus”. This means that sketching is a form of Visual Language.

As stated earlier Kleinsmann (2010) found that the equality of language, or lack thereof, was a factor in the creation of Common Ground. It can thus be argued that the use of visual language will help with the creation of Common Ground because it is a more universal and equal language compared to the use of jargon. This is supported by Landman (2009), who

found that Visual Language supports the creation of Common Ground.

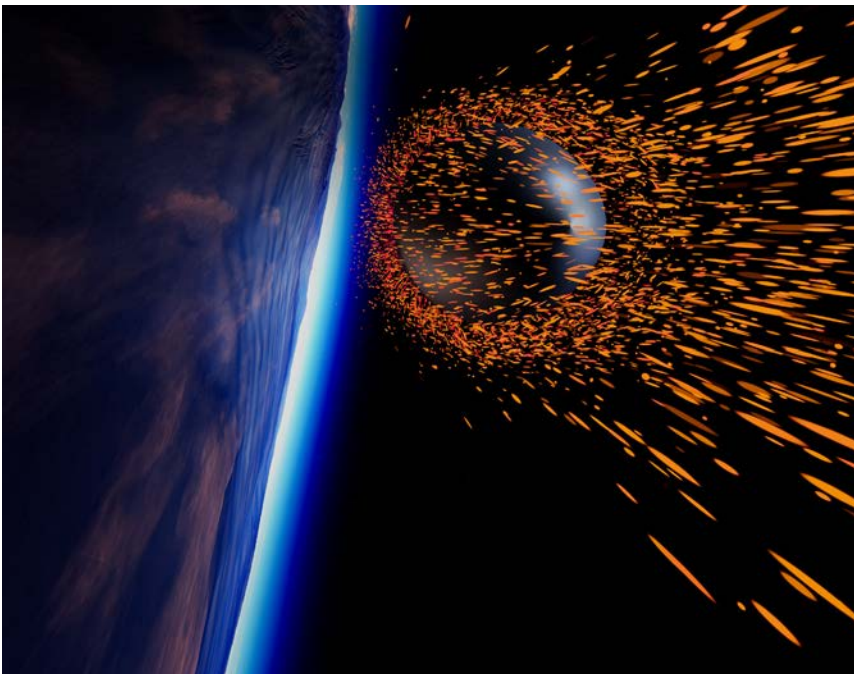
Evidence exists that VR allows for the creation of Mental Models in a similar manner as sketching. Sketching mediates the information exchange between users by supporting a vocal exchange with visual information. Bekebrede (2015) experimented with a simulation game of the development of the second Maasvlakte in Rotterdam. In this game, multiple users would receive different roles and they would need to collaborate and coordinate to build the second Maasvlakte as efficiently as possible. It was found that the game created “an environment with incentives to share Mental Models”. Users would not only share knowledge about the simulation but would also explicitly discuss and share their Mental Models on the real-world system. Results indicated that this impacted the perceived Mental Models of others.

For, Bekebrede (2015) that meant the simulation game had proven its validity and usefulness for the development of experience and understanding of complex systems.

This example emphasises two things about visual language in VR. First, it can be more than just sketches or a single visual, for example, visual language can be the implicit information of how systems influence each other. To give a more concrete example, the weight of an object can be deduced in VR by dropping it. In short, visual language can also be the feedback received on an action taken. Therefore Visual Language in VR can entail more than just text, images and shapes, but also motion, spatiality, user decisions, and feedback. This comes from the affordances of VR, which will be explained in the next section. Secondly, the visual language within VR will still be in support of other communication methods, be it vocal or textual. In the case of Bekebrede (2015), in support of vocal discussion.

Many papers are written on specific visual information or visual aid designs in VR and AR. The work of Radkowski is notable to mention. Radkowski has researched different visualisation options for assembly and work instructions, for example, how object position can be made clearer with occlusion. However, this research is very specific which means that within the time constraints of this project it is impossible to provide a complete overview. That is why research in this area will be revisited later in this project based on the design decision made after the analysis phase.

Figure 6: Example Visualisation of vehicle re-entry in VR. Source ATG Europe



MENTAL MODEL AND COMMON GROUND SUMMARY

In this section, it was first defined what a Mental Model and Common Ground is. To reiterate Mental Models, are what allows us to interpret and understand our world. They directly influence the way we behave and the decisions we make. Common Ground is having a shared or sufficiently similar Mental Model with another person.

Next, it was explained why the creation of Mental Models and the establishment of Common Ground is interesting for engineering and design by doing a literature review. From this, it was concluded that having Common Ground improved communication, allowed other team members to better make predictions and thus work faster, and improve team performance overall by increasing understanding of tasks.

Then, a review of the literature on the creation of Mental Models was done. Two key pieces of literature were found. There was the work of Kleinsmann (2008), who found a set of barriers and enablers on three different project levels (actor, project and company). Second, the work of Goldschmidt (2007) put forward sketching as a method of establishing Mental Models. More importantly, it showed that limited visualisation together with explanation can lead to establishing of Common Ground.

Lastly, Visual Language was introduced as a term for visuals created in support of the creation of Common Ground. This builds on the idea of sketches, showing that VR can in theory be used in support of other methods in order to share Mental Models. It can do so using not only words, images and shapes, as proposed by Landman (2009), but also motion, spatiality, user decision and feedback.

As mentioned earlier Rouse and Morris (1986) stated research on Mental Models should be done for each domain separately. This also applies to the creation of shared Mental Models in collaborative work for composite production. The literature presented in this chapter is relevant but remains inconclusive. It is a goal of this project to add to this research.

VIRTUAL REALITY

Virtual Reality, or VR for short, is a technology where a user can immerse themselves completely in and interact with a virtual environment. This allows for unique possibilities and affordances. These will be explored in this chapter.

CURRENT STATE OF VR

There are currently many different visions of what VR should be and how it should be. Nevertheless, VR seems to be moving in two directions. First, you have companies creating more capable and cheaper headsets. Thus lowering the barrier of entry. Secondly, high-end headsets are becoming ever more capable while still maintaining a relatively high barrier of entry. A detailed analysis is presented in Appendix 13 on page 133.

AFFORDANCES

VR has different affordances compared to reports or teleconferencing. Johnson-Glenberg (2018) writes that VR has two profound affordances. The first of these affordances is "the feeling of presence". Presence being "the feeling that you are at a location in the virtual world". Another term that comes to mind is immersion. VR enables a designer to immerse his user in the virtual world. This suggests that VR can have you feel like others are present in the same room as you. For example, an engineer can feel like the operator is present at a meeting even though the operator is in a different country.

The second affordance of VR, according to Johnson-Glenberg (2018), is "the embodiment and the subsequent agency associated with manipulating content". This is a slightly confusing term but in my opinion, it is best described as "the freedom that VR affords the user to control or manipulate the VR content" or "freedom of interactivity". This is supported by another quote "The ability to control and manipulate objects in the 3D environment is perhaps a different and deeper form of agency [rather than controlling through gaze] with many more degrees of freedom."

In any case, this type of freedom in interactivity combined with immersion does not seem to be possible to achieve in any other type of medium. To give an example, films can be very immersive but they do not allow for more interactions or agency than play, pause, and rewind. Additionally, the only way for the story to make sense is to watch a film from start to finish.

Apart from these two affordances, Dalgarno and Lee (2010) state 5 additional affordances of Virtual Environments of which 4 are relevant for this project. Because there is no perceived problem with motivation, the fifth one "engaging" is not relevant.

CREATING SPATIAL UNDERSTANDING

VR can be used to facilitate learning tasks that lead to the development of enhanced spatial knowledge representation of the explored domain" (Dalgarno and Lee, 2010). Because VR headsets render a stereoscopic 3D image, that moves according to the movement by the user, a user can more easily infer information about the scale and position of objects in the Virtual Environment.

IMPRACTICAL CONTEXTS PRACTICAL

"VR can be used to facilitate experiential learning tasks that would be impractical or impossible to undertake in the real world" (Dalgarno and Lee, 2010). It is easy to create situations that would be impossible in the real world as normal constrictions such as the laws of physics or a need for life-support need not apply.

IMPROVED LEARNING IN CONTEXT

"VR can be used to facilitate learning tasks that lead to improved transfer of knowledge and skills to real situations through contextualisation of learning" (Dalgarno and Lee, 2010).

STRONG COLLABORATIVE LEARNING

"VR can be used to facilitate tasks that lead to richer and more effective collaborative learning" (Dalgarno and Lee, 2010).

AFFORDANCE SUMMARY

Every VR headset provides a basic set of affordances, due to the unique capability to allow the user to interact with spatial data within scenes. This allows for visualisations that immerse a user in contexts that would be impractical in the real world. Which can lead to improved transfer of knowledge and skills and more effective and richer collaborative learning.



Figure 7:
The Oculus Quest in use

COLLABORATION

What is collaboration and why is it necessary? Collaboration is when people work together to achieve a single goal. This has the benefit of pooling resources and having different actors with different backgrounds available. For Kleinsmann (2006) collaborative design was "the process in which actors from different disciplines share their knowledge about the product design process and content". This emphasises the advantages of collaboration.

ASYNCHRONOUS COLLABORATION

Asynchronous collaboration refers to teams collaborating on the same project but not at the same time and in a different location. Related terms are "distributed collaboration", which specifically refers to being in a different location, and Virtual Teams, a popular term for a distributed team. To illustrate this, a Face-To-Face (FTF) meeting would be an example of non-distributed synchronous collaboration. During an FTF meeting, feedback is immediate and direct. On top of which, additional information such as facial expressions and tone is also shared. In comparison, users collaborating over email can potentially wait days to receive a reply. Even more so with written reports. Sending a report to a client can mean receiving feedback on many different issues days if not weeks later. However, it is not the case that synchronous collaboration is by definition better. Asynchronous can afford users time to think, and it might not always be feasible for every team member to be in the same place. That is why you often find asynchronous tools being used in support of synchronous

collaboration, or vice-versa. To give an example of the former, asynchronous tools can be used to capture information generated during a synchronous activity. The captured information can be accessed later or sent to other team members.

Collaborating asynchronously affects different factors during the collaboration process. The first factor is the level of participation. This was found to be more equal between users than collaborating synchronously by Dubrovsky et al. (1991) and Taylor and MacDonald (2002). Additionally, Hammond (2001) states that due to this no clear leader would establish itself during the process. This also seems to be true for Computer-Mediated Communication (CMC) as Bordia (1999) states that "CMC, when compared to FTF, is a more egalitarian medium, with greater equality of participation, relatively less intense normative pressures and higher incidence of uninhibited behaviour". Secondly, time to completion seems to take longer with asynchronous collaboration. It is also harder for group members to reach conclusions than FTF teams according to Ostergaard (2003) and Bordia (1999). The amount of conclusion they make is also lower.

Furthermore, Chiu (2000) found a difference in the collaboration tools used by designers between the two types of collaboration. Chiu (2000) stated that "During asynchronous communication, design representation included verbal description, sketches, tables and photographs. In synchronous communication, participants preferred the use of visual

presentation plus oral communication.” It must be noted that FTF was not taken into this comparison.

Currently, most applications in the VR and AR collaboration industry are targeted towards synchronous Collaboration, see “Existing Solutions”. Likewise, that is where most research seems to be focussed. However, other non-VR methods of asynchronous collaboration exist. To give a couple of examples, reporting, email and tools like Trello are all methods of computer-supported asynchronous collaboration.

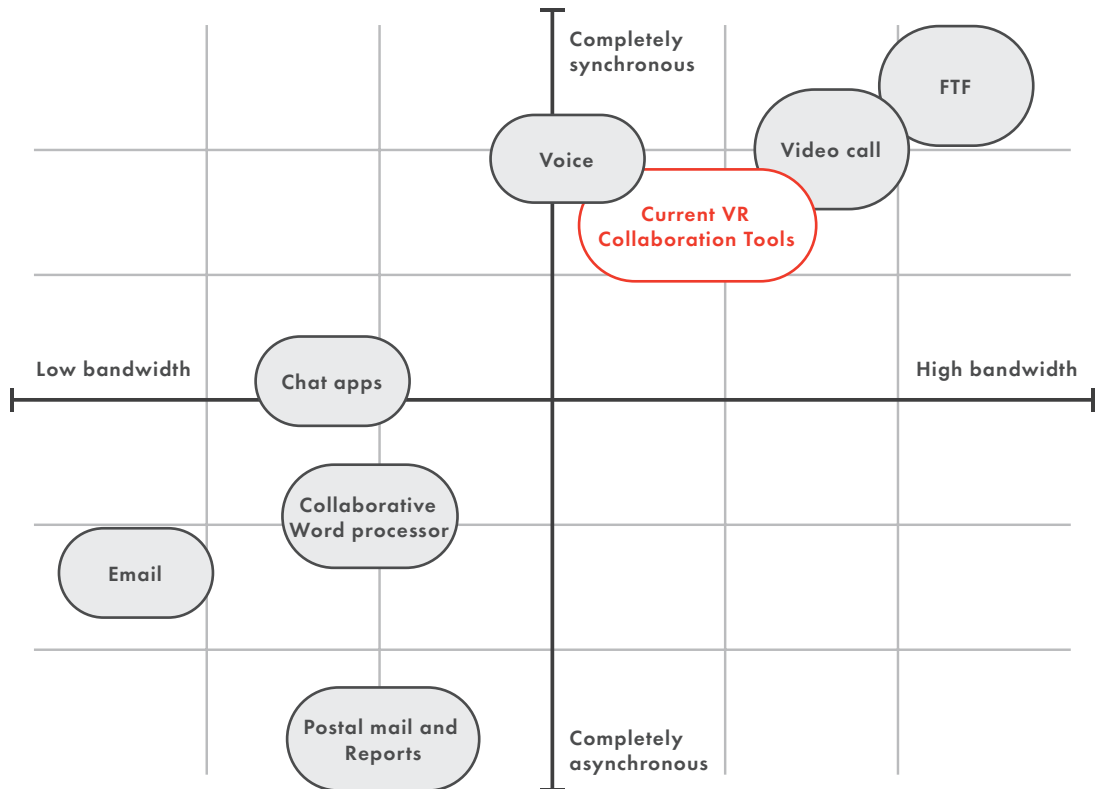
COMPUTER SUPPORTED COLLABORATIVE WORK

Today, there are many different methods to communicate and collaborate in a project group. Not only can people work together in person but a lot of online solutions exist as well. These solutions are generally grouped by the name Computer-Mediated Communication (CMC) or Computer Supported Collaborative Work (CSCW). Each method has its advantages and disadvantages. In this chapter, a review of the literature that currently exists about different CSCW and CMC methods will be done.

There are numerous CSCW methods. Examples include but are not limited to, email, chat services such as WhatsApp or Slack, task boards such as Trello, video conferencing like Skype or facetime, and even services such as Google Docs that allow you to work on the same document at the same time. All these solutions are used to achieve different goals in a collaboration process. However, they can be categorised using two metrics, synchronicity and communication bandwidth. An overview, using these two metrics, was provided in Figure 8 on page 25.

Figure 8: Different methods of CSCW

Bandwidth on the x-axis, synchronicity on the y axis



Collaboration Tools

1. Postal Mail and Reports
Does not seem to be considered as a form of communication or collaboration in literature so far. Most literature is interested in email or chat. This leaves a gap. Textual least effective.
2. Collaborative Word Processor
Think of tools like Google Docs and Office 365 that allow users to work on a word file at the same time. These allow for limited communication but are synchronous.
3. Email
A well understood collaboration tool. Generally not used synchronously. The medium invites longer times between responses
4. Chat apps
This includes apps like Slack and Microsoft Teams. These are more synchronous because they are more conversational compared to email.
5. Task Boards
Can be both CSCW or a physical location. Allows users to coordinate their actions.
6. Phone calls
Can be over internet or landlines. Often times one user can speak at a time, also no text or visuals can be used. This leads to reduced bandwidth.
7. Video calls
Allows users to see each other while talking. However, some details might be lost. Is more synchronous if both users can speak at the same time.
8. Face to Face
Strictly non-CSCW. This allows for full freedom, and has the highest bandwidth.
9. Current VR Collaboration Tools
See chapter existing tools

SYNCHRONICITY

To understand Figure 8 the two metrics must first be defined. Synchronicity is a nominal scale of 0 to 7 where zero is completely asynchronous and 7 is completely synchronous collaboration. Asynchronous was introduced earlier in this chapter. To illustrate this scale, postal mail, received a low score as there is no opportunity to communicate during collaboration. Where-as email would receive a higher score because it takes less time for an email to arrive. Reducing the time between messages and making it possible to send a quick message. Chat scores higher as information is sent before and after a message is sent. For example, typing indicators and delivery checkmarks.

COMMUNICATION BANDWIDTH

Communication bandwidth was introduced by Hammond et al (2001). It states that the fewer opportunities for interaction a method provides, the less information can be shared by a user.

To give an example of how this impacts meetings Oostergaard (2003) states that "Face-to-face discussions can provide signals to other participants of the group via the five senses. However, in the other communication [methods] the potential bandwidth is reduced, resulting in a decreased efficiency in information transfer.". Reduced bandwidth has an impact on communication. Oostergaard (2003) then goes on to state that "As this information exchange decreases, group members alter the nature of communication processes and they seek to maintain a comfortable level of communication by utilizing compensating mechanisms, such as increasing mental effort or limiting

the amount of data considered". Compensation within communication is supported by Bordia (1997), who found that "groups in CMC take longer than FTF groups in completing a task, and produce fewer remarks in a given period.". This illustrates reduced bandwidth being compensated with fewer results in more time.

In the same paper, Bordia also found 2 more consequences of reduced bandwidth. Firstly, they found frustration with the method if it proved to be insufficient for what they were trying to do. Secondly, they found users compensating but using more task-oriented language rather than social-emotional language. It must be noted that Walther & Burgoon (1992) found that "given enough time [users were able to] adapt to the new technology, [and began showing a] pattern of social-emotional conversation".

For bandwidth an ordinal scale with 3 types, text-only, speech-only, full freedom in communication (including use of visuals) is proposed. This is based on work done by Oostergaard (2003) who found that full freedom was most effective, highest bandwidth, followed by speech-only. Text-only was found to be least effective.

EXISTING VR CSCW SOLUTIONS

Currently, there are already many solutions for synchronous VR collaboration on the market, with more being developed every day.

There seem to be 3 main categories of VR collaboration tools. Engineering review tools, meeting tools and architectural visualisation tools.

All of these tools are focussed on synchronous collaboration. Additionally, another interesting category is social VR tools. These are interesting because even though they are not focussed on workplace collaboration they are also about sharing information and (social) experiences. Social VR tools are also comparatively developed products. Some of them with big-name brands behind them such as Facebook.

MEETING TOOLS

MeetinVR, Rumii, Glue, Dream

These tools are mostly meant to hold meetings and give presentations. Both within a company (collaboration) and externally (sales). Their main advantage is the feeling of presence of other users. Rather than seeing a 2D image of someone through a Skype call, users can now interact with a 3D representation of other users within a contextual environment. Second to this is to present context in 3D. A

user can make use of 3D objects in his presentation as well as traditional presentation sheets. Other content such as websites can also be shown and interacted with by multiple users. Some of these platforms also support training simulations but they do not seem to be specialised in it. Therefore, it is questionable how often used and effective these tools are.



Figure 9: MeetinVR Collaborative Session.

Source: MeetinVR Twitter

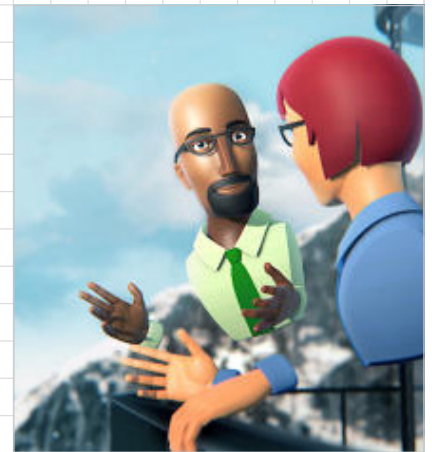


Figure 10: Glue Avatars

Source: Glue Collaboration

SOCIAL TOOLS

Facebook Horizons, RecRoom, VR Chat

These focus on the feeling of presence of other users, similarly to meeting tools, however, they are meant to be more informal and playful. They are more focused on allowing friends to socialise rather than users being able to hold presentations in a formal setting. You will not find these tools in an office context although they could technically be used as such. Additionally, they have a large focus on interactions between users. Offering many different games that can be played together, and even offering multiple users the ability to build a game themselves. Another important feature is voice chat. Voice chat is the ability to talk with other users through a microphone. This enables direct communication between users.

ARCHITECTURAL VISUALISATION TOOLS

The Wild, IrisVR

These tools are mostly focussed on showing and immersing inside of structures and designs. These tools are concerned with conveying the spatiality and looks of designs in different conditions. Some of them only allow for importing of a design, others allow for making dynamic changes within VR. A good example of this is how *The Wild* allows an interior designer to quickly change the placement of furniture.

Figure 11:

Facebook Horizon Characters Source: Oculus

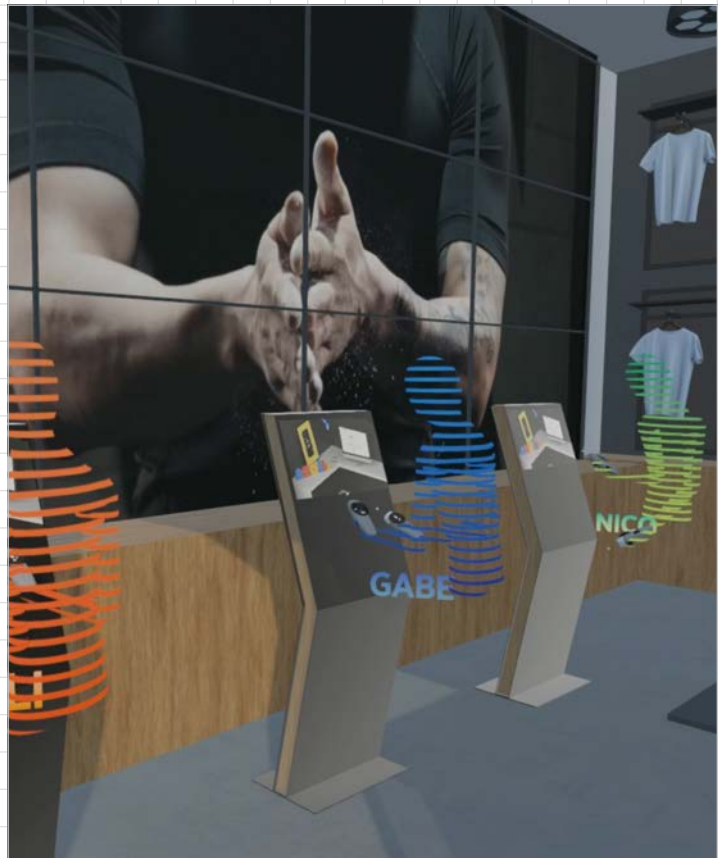


Figure 12:
The Wild

ENGINEERING REVIEW TOOLS

Improov, Vizable, Techviz and VisionXR

These tools are generally targeted towards reviewing a model with multiple people in VR. They are very similar to the architectural visualisation tools but are more focussed towards products and mechanics rather than buildings. They are also not concerned with the form of the reviewed object but more its function. Examples of tools that are available to the user are measuring distances, points of interests, drawing tools, cutting plane, screenshot, a geometry extrusion tool and virtual mannequins with model collision detection.

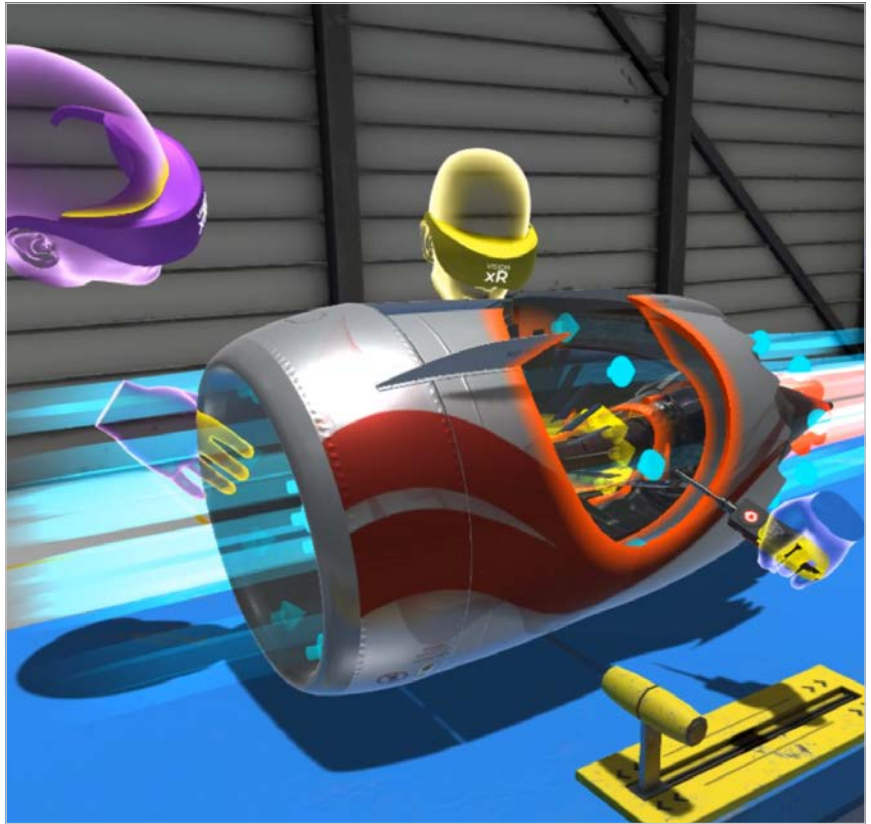


Figure 13: People reviewing an engine in VisionXR
Source: VisionXR

SUMMARY

In this chapter, it was defined what asynchronous collaboration is, namely users collaborating on the same project but at different times and different locations. Working asynchronously has a big impact on the process and results of a project. Asynchronous collaborations are more egalitarian and a clear leader is less likely to establish itself. However, with current methods, there is a reduced bandwidth between project members which leads to fewer results and less consensus. There is also a difference in language and methods of expression used between asynchronous and synchronous. The bandwidth of interactions and the synchronicity of

the tools was plotted, in Figure 8 on page 25. From that figure, it was understood that there seem to be **no asynchronous VR collaboration** tools. That leaves a gap on the market for a full freedom asynchronous collaboration tool.

Literature is scattered and comparing individual parts and thus it was difficult to form a complete overview of current collaboration techniques. Additionally, It is not yet known what type of information and Mental Models people prefer to share over what medium. This is a gap in the knowledge that needs to be filled.

KEY TERMS AND INSIGHTS

In this chapter a theoretical foundation for the research and prototyping later on was created. Multiple terms were defined that will be used throughout this project and conclusions were drawn from them. These terms and conclusions are summarised in this section.

VIRTUAL REALITY

VR is a technology that allows a designer to visualise and immerse a user in contexts that would be impractical otherwise. While also affording their user a high amount of agency to go through the scenario. Which leads to improved transfer of knowledge and skills and richer and more effective collaborative learning. There are currently two directions in which VR is moving. First, lowering the barrier of entry for VR with cheaper more capable headset and second creating higher-end headsets that push the capabilities of VR, and what they afford a user, forward.

MENTAL MODEL

A Mental Model is the internal representation of an object, concept or problem that a user forms in his head. Mental Models, are what allows us to interpret and understand our world. They directly influence the way we behave and the decisions we make. There are three types of Mental Models, task, team and process.

COMMON GROUND

If Mental Models between users are sufficiently similar then we speak of Common Ground. Similar to Shared Mental Model and Shared Understanding. Establishing Common Ground within a team leads to improved communication, allows other team members to better make predictions, and improve team performance overall by increasing understanding of roles and tasks. A set of barriers and enablers was found in literature. A potential method of establishing Common Ground through sketching was also found.

COLLABORATION

Collaboration is when people work together to achieve a single goal. This has the benefit of pooling resources and having different actors with different backgrounds available.

VIRTUAL TEAMS

A team collaborating on the same project but at different locations. Often their main form of communication is online with CMC. In that case they are doing Computer Supported Collaborative Work, or CSCW.

ASYNCHRONOUS

It is when users collaborate on the same project but they do so at different times and different locations. Examples of asynchronous collaboration tools are email, reports, and chat services. Currently no asynchronous VR collaboration tools seem to exist. Thus a gap on the market could exist.

COMMUNICATION BANDWIDTH

The bandwidth of interactions or communication is the amount of information a user can share using a given tool. There are 3 main types in order of low to high bandwidth; Text-only, speech-only, and full freedom. If a tool offers low bandwidth users generally compensate by using different language and producing fewer results.

COMPUTER SUPPORTED COLLABORATIVE WORK (CSCW)

A term often used in literature in order to indicate a computer was used to aid a collaborative process. Examples of CSCW tools include Skype, email and VR collaboration tools.

COMPUTER MEDIATED COMMUNICATION (CMC)

Similar to CSCW, however this term is not about collaboration but about communication. That is admittedly a very fine line but in general CMC is in support of CSCW. Any tool that mediates communication through a computer is called CMC. Examples include, Skype, email, and synchronous tools.

FACE-TO-FACE (FTF)

FTF is when a meeting is held in person. This allows for the highest bandwidth of communication. It is the goal of this project to reduce the need for Face to Face collaboration within Composite Production.

COMPOSITES

Composites consist of a matrix material and a binding component. Which results in a material with better properties than those of the individual components. This includes materials such as wood. Composites main advantages are its high strength and stiffness, combined with low density.

HAND LAY-UP

Hand lay-up is laying down individual layers of a form of reinforcement by hand. Using this method of composite production operators can produce high quality products with complex features and relatively low start-up costs. The method is suited for manufacturing one-off and unique parts.

GRID-STIFFENED

The type of composite developed by ATG. Rather than using large sheets it makes use of small strips of material. This allows for a weight reduction while maintaining strength. The production methods of this composite type will be studied during this project.

KNOWLEDGE GAPS

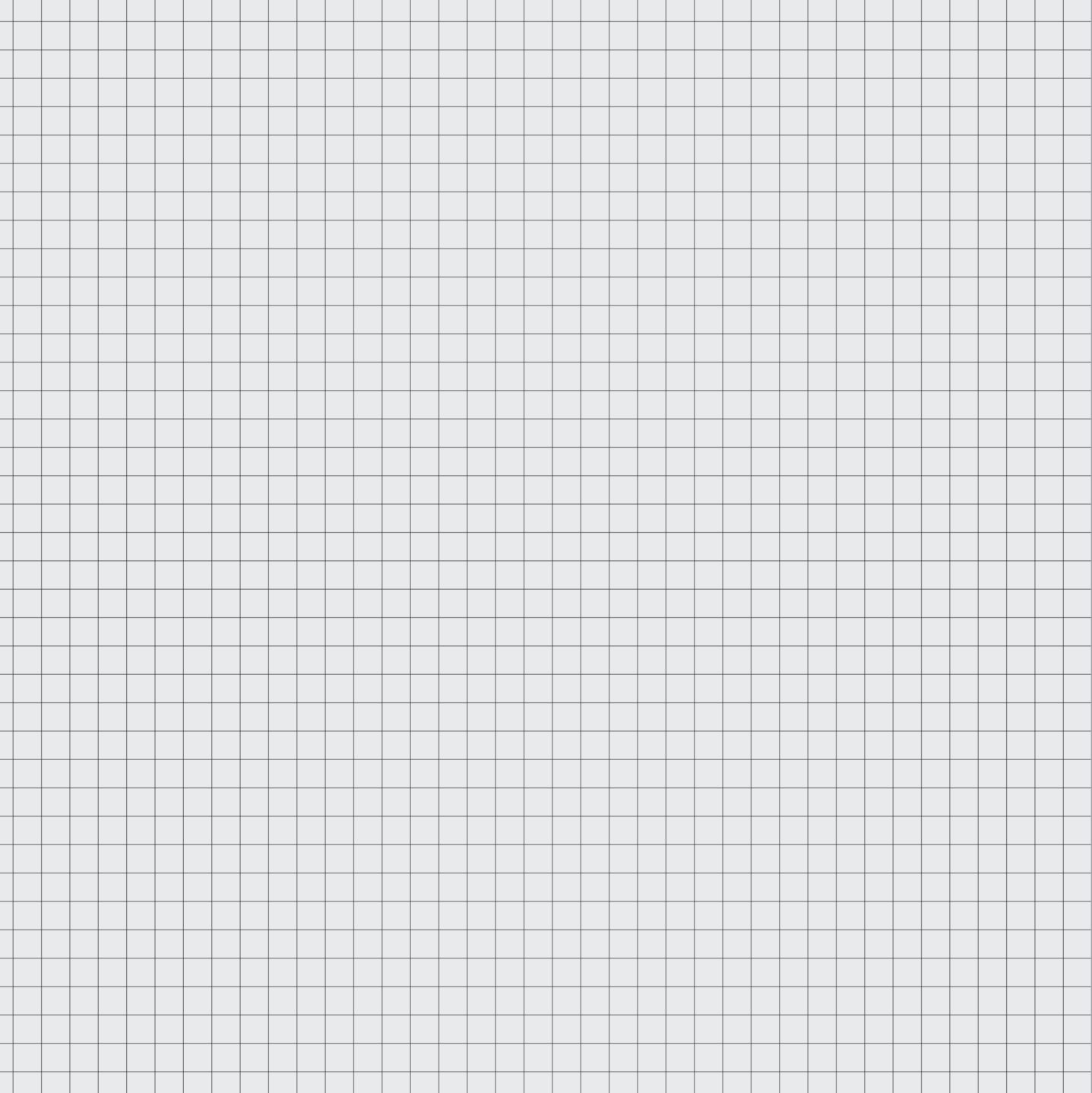
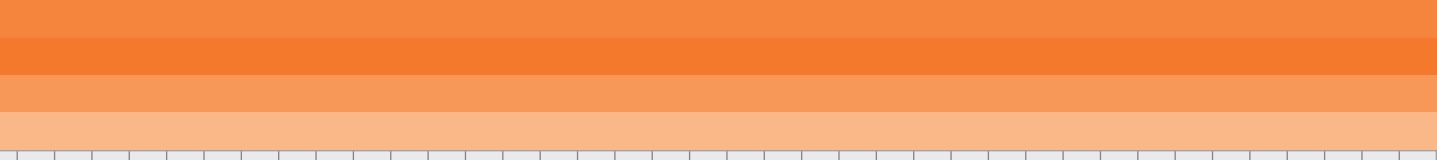
For the next chapter, two main knowledge gaps in the literature were identified that need to be addressed during the analysis. These are the following:

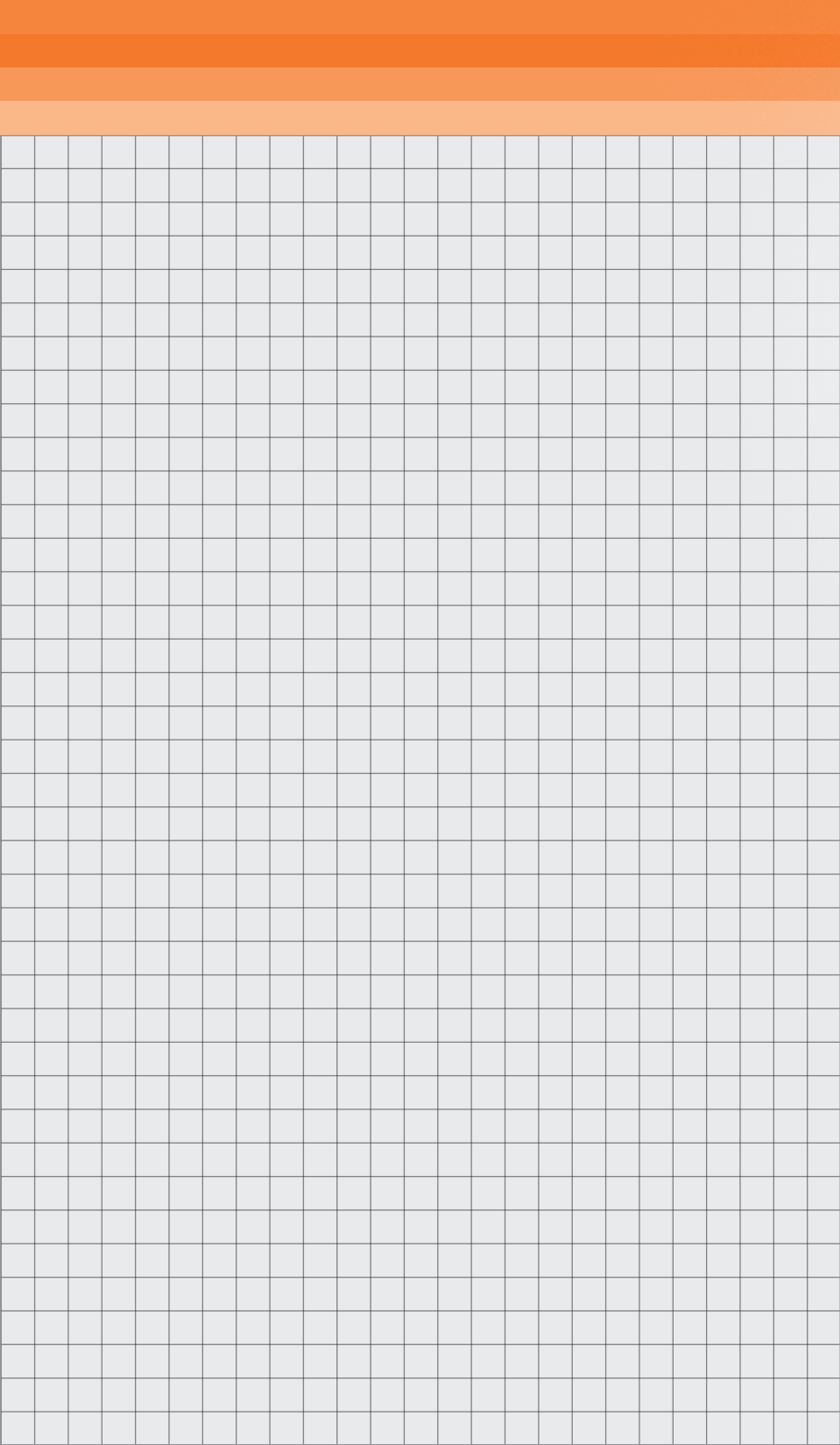
INFORMATION SHARED IN DIFFERENT COLLABORATION TECHNIQUES

In this chapter, an initial evaluation of the usage of different collaboration tools was done from literature. However this is not sufficiently elaborate. In order to understand what the impact of reducing the number of FTF meetings would be, it is necessary to know what kind of information or Mental Models is shared through FTF and other methods. The plan is to do generative session based on the method from Sanders et al (2012) in order to generate insights on the different methods.

ATG'S SPECIFIC COMPOSITE PRODUCTION PROCESS

In order to design for ATG's unique composite production type. It is necessary to understand this process and the complications it brings.





In this chapter, the composite production process will be analysed and captured in a timeline. Furthermore, research into current collaboration methods will be done. The results of these two categories will form the basis for the design requirements and concept in the next chapter.

COMPOSITE PRODUCTION ANALYSIS



To understand the design context an analysis of the composite production process needed to be done. This will be done in this chapter.

RESEARCH GOALS

This generative study had as goal to define the composite production process. This includes defining which steps need to be taken and how.

A secondary research goal was to define what kind of information is exchanged between the engineer and the operators during the composite production process. This is especially relevant for the separate collaboration analysis.

METHODOLOGY

It was not possible to observe the composite production process in Ireland, as anticipated in the assignment. ATG was able to provide access to the engineers and their

smaller scale composite lab in the Netherlands. This provided the opportunity to do two activities. First, a lay-up activity to create a composite production timeline followed by an interview with the main engineer to validate the timeline. It is argued that this has given a clear and validated overview of the composite production process.

ACTIVITIES

Layup

To learn about the steps taken in the composite production process, the researcher immersed himself in the composite production process by doing a hand lay-up activity, see Figure 14 on page 35. This activity took 3 hours, during which one of the composite team members explained how to create a composite. At the end a grid-stiffened composite was delivered and left to cure.

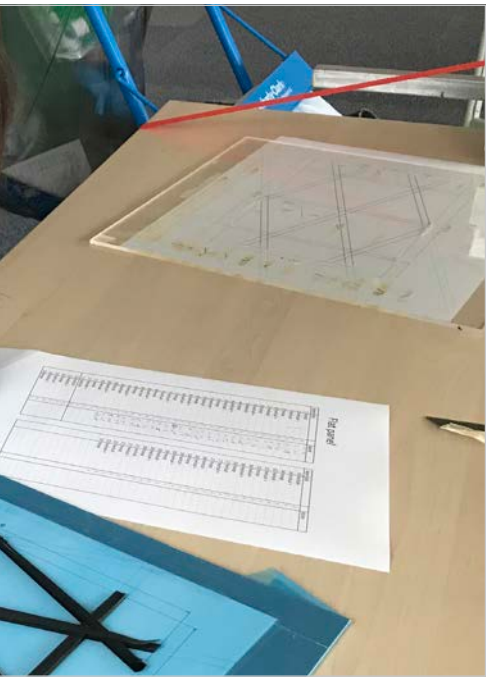


Figure 14:
Composite Lay-up Process

During the lay-up activity, the focus was on creating an understanding of the process and gathering information about nuances. Data was recorded by filming the activity and additionally notes were taken. After the activity, the initial impressions on each phase were written down. Then by reviewing the film footage a first version of the timeline was created. This timeline is based on the researcher's experience in the Netherlands and are therefore qualitative self-reported results. A second activity was deemed necessary to apply these results to Ireland.

Discussion of timeline

To understand the differences between the lay-up in the Netherlands and Ireland the timeline was discussed in a creative session with the composite team in the Netherlands.

First, the timeline was talked through to familiarise the team with the findings. Using a graphical example can help with remembering details, anecdotes

and other memories. With the timeline as a sensitizer, the composite team was encouraged to identify errors or omissions. The team could place sticky notes and draw on the timeline to capture ideas. Next, the process in Ireland was discussed. Key questions to answer were how the process in Ireland differed and what issues came up in Ireland that did not occur in the process. The results of this discussion were added to the timeline in order to get a final result that reflects, as much as possible, the composite production process in Ireland.

DATA RECORDING

Video-recordings of the lay-up activity were made. During the activity notes were also taken. For the discussion of the timeline, sticky-notes were placed and drawings were made directly on the timeline. In addition, an audio recording of the entire discussion was kept. The results were self-reported by the engineers of ATG.

RESULTS

As mentioned earlier, a timeline was created to capture the composite production process. A timeline was chosen specifically because it allowed showing the step order in the process as well as alternative paths and background information.

COMPOSITE PRODUCTION TIMELINE

In general this timeline reads from left to right, the **red line**. A new phase in the composite production line is denoted by a header and a break in the red line. The **black lines downward** are steps within the same topic.

Notes with **blue** borders are general information, **orange** borders means it is an insight into communication gained during the process.

To protect the intellectual property parts of this were moved to Appendix 14 on page 184.

PREPARATION

PREPARE PREPREG

Take prepreg out of freezer

PREPREG

Prepreg is pre-pregenerated material. These are the fibre strips which already contain the binding component. The binding component still needs to harden (curing), which it does not do when kept frozen. The material will harden after defrosting but often it is cured in an oven to melt the binding material together. Once it is cured it is no longer sticky.

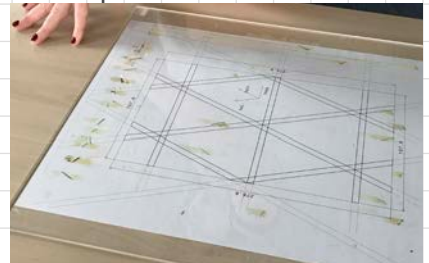


HANG PREPREG

A construction is build to hang the prepreg on. This is to keep the prepreg from sticking

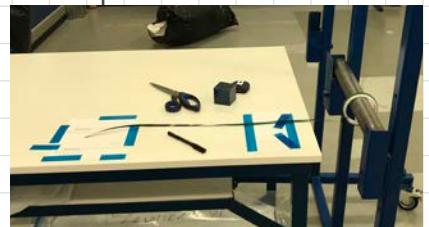
PREPARE CUTTING TEMPLATE

A cutting template is prepared beforehand. This contains the length of every piece that needs to be cut.



PLEXIGLASS

The cutting template is placed under a plexiglass sheet on which will be cut. The plexiglass is to protect the table but the paper might also stick to the prepreg otherwise



CUTTING ON TABLE

Composites can also be cut directly on a table.



PART DEPENDENT TEMPLATES

The cutting templates differ for parts.

CUTTING

PREPARE LAYER UP TEMPLATE

A template for the placement of the fibres is also created beforehand.

PLACE TEMPLATE ON METAL SHEET

The template is placed on a metal sheet and then taped in place so that it cannot move. No tape should be placed where the template is placed.



APPLY ANTI STICK FILM

An anti stick film is roughly cut to size and placed on the template. The anti stick film prevents the prepreg from curing to the metal and the paper.



CUT TO SIZE

The anti stick film is cut to size and taped to the metal sheet. This makes it a moveable setup, which is useful to get to a better angle. This is not possible in Ireland. Where a round rollable mould is used.

TERMINOLOGY

Toes, a toe is a single strip of prepreg that is cut to size. The length and cutting angle can differ for each toe.

Plies, a ply is a set of toes that all go in the same direction. There were three types of plies hoops, helical+, and helical- but more types are possible.

Layers, a layer is a set of plies that form a single layer. Which can then be repeated. A full composite exists of 20 or so layers.

ALIGNING THE PREPREG FOR CUTTING

LAY DOWN PREPREG ON SHEET

Take the prepreg from the reel and place it on the cutting template.



CHECK ALIGNMENT

Before cutting the long sides must be properly aligned to the long sides of the cutting template.

MAKE SURE IT IS FLAT

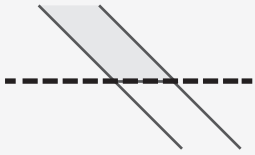
If the prepreg is not flat on the material it could introduce waviness.

CHECK ALIGNMENT FROM ABOVE

Because of the material thickness this must be done from above.

CUTTING (CONTINUED)

MAKING THE FIRST CUT



CUT THE OUTER EDGE FIRST

You first want to make sure that the outer edge is correctly cut. Cut on the outer line on the cutting template.



CUT IN CLEAN STRAIGHT LINE

It is important to not hesitate, you want to cut all the fibres in one go and not rip or tear any. If fibres tear the composite loses strength and you can introduce bumps.

PRACTICE REDUCES HESITATION

After cutting a bunch of these, you'll notice that you'll do it faster. This suggests it is due to confidence.



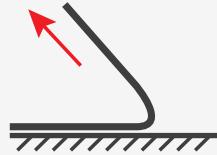
CUT INNER EDGE SECOND

Now cut the inner edge in a similar manner. This creates a toe.

REMOVING FROM CUTTING TEMPLATE

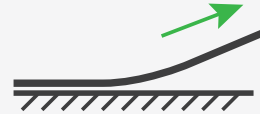
STICKINESS

Straight from the freezer the prepreg should not stick to the surface of the cutting template too much and removing should not be a hassle. However if it does not want to come off there is a wrong way and a right way.



WRONG WAY

Do not lift it up straight and backwards. This makes the material bend and could tear fibres. It will also pull other material with it.



RIGHT WAY

Carefully, pull on prepreg in the horizontal direction. This will lift it up without bending it improperly.

WAVINESS

Bending the material makes it harder to keep the fibres straight within the middle section. Straight fibres are thought to lead to stronger composites.



EXTRA HELP

If the material still sticks then a knife can be used to pry it loose a bit. It is important to only go parallel to the material otherwise you could accidentally cut it.

FIRST LAYER

ALIGNING



ALIGN OUTER EDGE FIRST



USE YOUR THUMB TO GUIDE THE PREPREG DOWN

Using this technique it is easy to follow the guides on the alignment template.



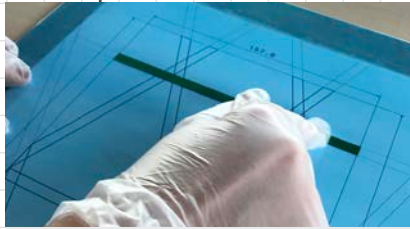
CHECK ALIGNMENT FROM ABOVE

Make sure the prepreg is properly placed from above. This gives the best view whether or not it is between the lines.

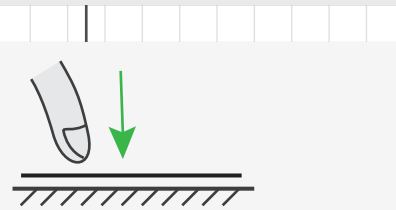
DO NOT HESITATE TO TRY AGAIN

The first layer is extra critical because all other layers align to it. The first layer should not obscure the guide lines. Lifting procedure is similar.

FASTENING

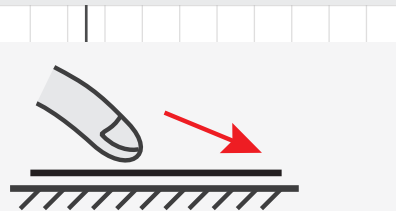


The first layer can still quite easily get loose. This will become less when more layers are added. For now it helps to press it against the surface.



STICK IN PLACE BY PRESSING REPEATEDLY

You can keep it in place by repeatedly pressing it against the surface. This ensures it will stick better and keep it from shifting.



DO NOT SLIDE YOUR FINGER OVER THE MATERIAL

You only want to apply a downwards facing force, by sliding your finger you introduce a sideways force that could potentially shift the toes. On the first toe this is not a problem but when you have a couple overlapping plies this could ruin your progress.

FIRST LAYER (CONTINUED)

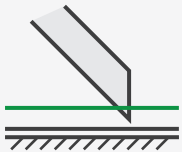
REMOVING PROTECTIVE FILM



PROTECTIVE FILM

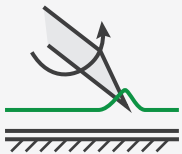
The prepreg comes with a protective film on top. This stops it from sticking to itself on the reel.

Before the next ply can be placed the protective film needs to be removed from the toes. This can be done with a scalpel.



STICK THROUGH MATERIAL

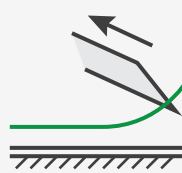
First use the point of the scalpel to stick through the film but not the material.



ROTATE A BIT

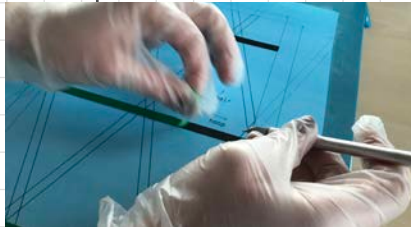
Rotate the scalpel point to get the film to lift up a bit but make sure your point stays underneath. It is possible to tear straight through it.

REMOVING PROTECTIVE FILM (CONTINUED)



PULL UP WITH FILM

If your scalpel point is still underneath the film you should now be able to carefully pull up the film. Once you have a good start you can go faster.



PULL AWAY WITH HANDS

Once you have a start you can grab it with your hands and just pull it.

MAKE SURE YOU DON'T

ACCIDENTALLY RIP THE PREPREG

Sometimes the sides of the prepreg can rip off together with the protective film. In that case stop pulling cut the torn prepreg at that point and make sure you don't pull any more prepreg up. You leave the torn fibres on the material.

TRICKY MOTION

This is definitely tricky to execute but it is also difficult to explain in words. It is a motion you need to be shown in order to learn.

ADDITIONAL LAYERS

KNOT PLACEMENT

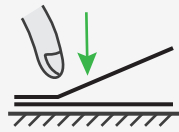
For every new layer, every next layer needs be taken into account.



ALIGN NEW TOE TO OUTSIDE OF PREVIOUS TOE FIRST

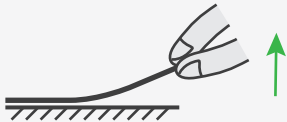
Push down on the first knot to stick the toe into place. A knot is where the different toes cross each other.

HOW TO PRESS



STICK IN PLACE BY PRESSING THE KNOT

The stickiness of the prepreg will from that point on keep the material in place.



KEEP PREPREG UP WITH OTHER HAND

Make sure the prepreg is properly placed from above. This gives the best view whether or not it is between the lines.

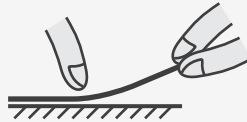
KEEP TENSION

The prepreg does not stretch, still it is important to pull on the material to keep it straight. If the material is not kept straight. There were a couple techniques observed.



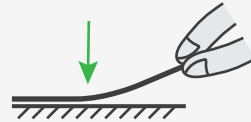
PULL 2 SIDES

Pulling on 2 of the outsides help keep the material stretch when aligning from above



.2 PUSH PULL

Best method if prepreg is not super sticky. Keep finger in place on last played knot.



.2 PUSH PULL

If material is sticky enough, you can free up a hand by removing it from the material and gently pulling with the other hand.

ADDITIONAL LAYERS (CONTINUED)

NO MORE KNOTS

BEFORE NEXT KNOT CHECK PLACEMENT FROM ABOVE

Is it correctly placed and is the prepreg still straight and going in a straight line?

YES (GOOD PLACEMENT)

MORE KNOTS?

NO (BAD PLACEMENT)

DOES IT MOVE WITHOUT MOVING
OTHER LAYERS?

NO

CHECK HOW STUCK IT IS BY PULLING SLIGHTLY

Pull away from the previous knot. Do not pull upward otherwise the fibres might break. Make sure the previous layers do not move.

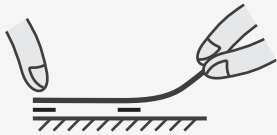
YES

Great! Keep pulling until it is sufficiently loose to apply again

FREEZE SPRAY

Cool down the prepreg using a freeze spray. This reduces the stickiness of the material so the glue let's go a bit.

Make sure not to cool the whole knot down too much, just the top toe.



SCALPEL TO SPEED IT UP

You can stick a scalpel between the layers in the air gaps. You can then slide the scalpel underneath the prepreg to help pry it loose a bit. Use the blunt edge to do this to prevent cutting.

PULL OUTWARDS, LIFT UPWARDS

Same techniques as always try and lift the prepreg of the knot.

PRESS FINGER ON PREVIOUS KNOT

In order to keep the previous knot from moving, place your finger on that knot.

SCALPEL IF HARD TO GET

You can stick a scalpel between the layers in the air gaps. You can then slide the scalpel underneath the prepreg to help pry it loose. Use the blunt edge to do this to prevent cutting.

PROBLEM ILLUSTRATIONS

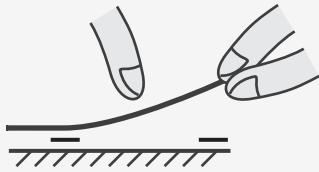
As you can see for this section I've used mostly text and graphics. It was hard to get the right information across without using simple graphics that focus on the problem at hand.

WARM UP BEFORE REAPPLYING

The prepreg needs to warm up a bit for the glue to regain its stickiness. That is why you have to wait before you can reapply it.

→ **PLACING THE NEXT KNOT**

KEEP PULLING ON STRIP TO KEEP TENSION



SLIDE THUMB OVER STRIP TO NEXT KNOT

With the other hand slide over the prepreg until you reach the next knot. Then press down. Be careful not to press down in the middle.

WRITE DOWN THE TIME WHEN TOE IS DONE

Write down the time when a toe was finished to keep track of progress.

TIMELINE INSIGHTS

EIGHT PHASES AND PREFERENCES

Eight different phases were found in the composite production process. A preparation, cutting, damming, first layer lay-up, additional layers lay-up, silicone tooling, curing prep and curing phases. These phases do sometimes overlap or can be done by multiple actors at the same time. For example, one actor can cut the composites to size and another can do lay-up in the meantime.

Most of the phases have a set step order, with minor alterations based on production context. For example, some steps differ slightly for cylindrical lay-up. Techniques are reported too, these can differ from person to person as personal preference seems to have a strong influence. The goal that users have when applying a technique is similar for different users, i.e. more efficient composite production.

FINESSES AND THE CORE PROBLEM

This composite production process mainly differs in the steps that need to be taken from a conventional production process. Like a conventional process, it exists of many small techniques or finesses however the conventional wisdom and techniques cannot be applied to the ATG process. This forms the core of the design problem. A good example, of this, is how in a conventional production process you would not leave any air gaps between the different layers. However, due to the thin strips of composites, this is now actually desirable and requires special attention.

FOCUS ON PHASES

Without understanding these finesses and techniques it is difficult to successfully create a high-quality grid stiffened composite however they also form for a very small design problem. This is an interesting dilemma. On the one hand, these finesses individually are relatively simple to explain but explaining all of them, Even with experience with composites, is very hard without being present during the process. Additionally, choosing just one would be too limited of a design scope but all of them too broad of a case. With the former, the design would become too focussed on something that is too small. The latter would take too much time since the composite production process exists of so many different finesses.

For these reasons, the focus should not be on designing for a single step designing for a phase. This expands the scope to include multiple finesses. More importantly, it also expands the scope to include the sharing of a Mental Model on the relation between steps and the reasons for taking them. For example, allowing an engineer explaining the goals of a phase. Showing the flow or relation between small steps. Creating this shared Mental Model of background knowledge on the phases should, according to the theory, lead to a reduction in mistakes and easier collaboration between operators and engineers.

INTERESTING PHASES

Two interesting phases were identified based on the steps that are required to complete them.

First layer, and additional layers

These two phases are mostly focussed on the alignment steps. Together they create an interesting scope due to four reasons. This would require visual cues in 3 different domains:

The first domain is that this phase has a very clear step order. Steps cannot be taken out of order but there are multiple paths to be taken dependent on the context. These “branches” require an understanding of the reasoning behind the process, or in other words, they require a transfer of a Mental Model of the engineers perspective on the process. Additionally, they do also allow room for an operator to develop their preferred technique. This means that even though the execution order of steps is fixed the execution itself allows for room for creativity, This underlines the importance of Mental Model transfer as a rigid explanation of the steps would not work.

Second, the finesses that are of importance in this process are mostly spatial problems. For example, the methods of alignment of composite strips but also body posture are spatial problems. These are of course specifically suited to be solved with VR, playing into the strength of VR to show content in the 3rd dimension. Another interesting step is removing the foil, this is a certain trick that you need to learn which is hard to put into still 2D images

and even harder to put into words. It is however fairly easy to show in motion.

Third, there is a requirement for the operator to emphasize certain elements. In this, there are elements with a higher priority than others. To give an example it is paramount not to lean on the composite. Working on allowing an engineer to express the importance of these more clearly would be a useful challenge to tackle.

Finally, some of the finesses that need to be shown are differing in interesting manners from a traditional composite production process. A good example of that is the difference with keeping air between the composite strips.

Damming

The damming of cylindrical composites is another interesting phase to consider. The key problems to consider is conveying how the dams are placed and why they are like that. This keeps being though for people to understand the reasoning without them having felt it or having seen it.

There is also a high variety to the steps. To give a couple of examples. there are pressure plates, thermometers and dams that need to be placed. One of the most interesting aspects of the placement of these parts is that they require movements difficult to capture in a report. Similarly to the alignment phase, some motions are hard to explain in words. A good example is the slotting motion of the pressure plates. Next, the dams need to be screwed progressively tighter together

at different moments. It is especially paramount to understand when to tighten and by how much. Visual cues that could be interesting to visualise would be showing compression. Also, there is a problem of vacuum sealing that requires an understanding of how to properly place it. This makes for an interesting scope, however, it could also mean that the finesses are too different requiring a different solution for each three. It would be preferable to offer a single solution for multiple solutions.

FOCUS ON ALIGNMENT PHASES

Unfortunately, the damming process happens only in very limited form in the Netherlands. Meaning many interesting steps were not observed during the lay-up. Therefore, it would be better to design for the two alignment steps. The knowledge that was captured in the timeline is more detailed and of higher quality, because it was observed first hand.

TARGET GROUP

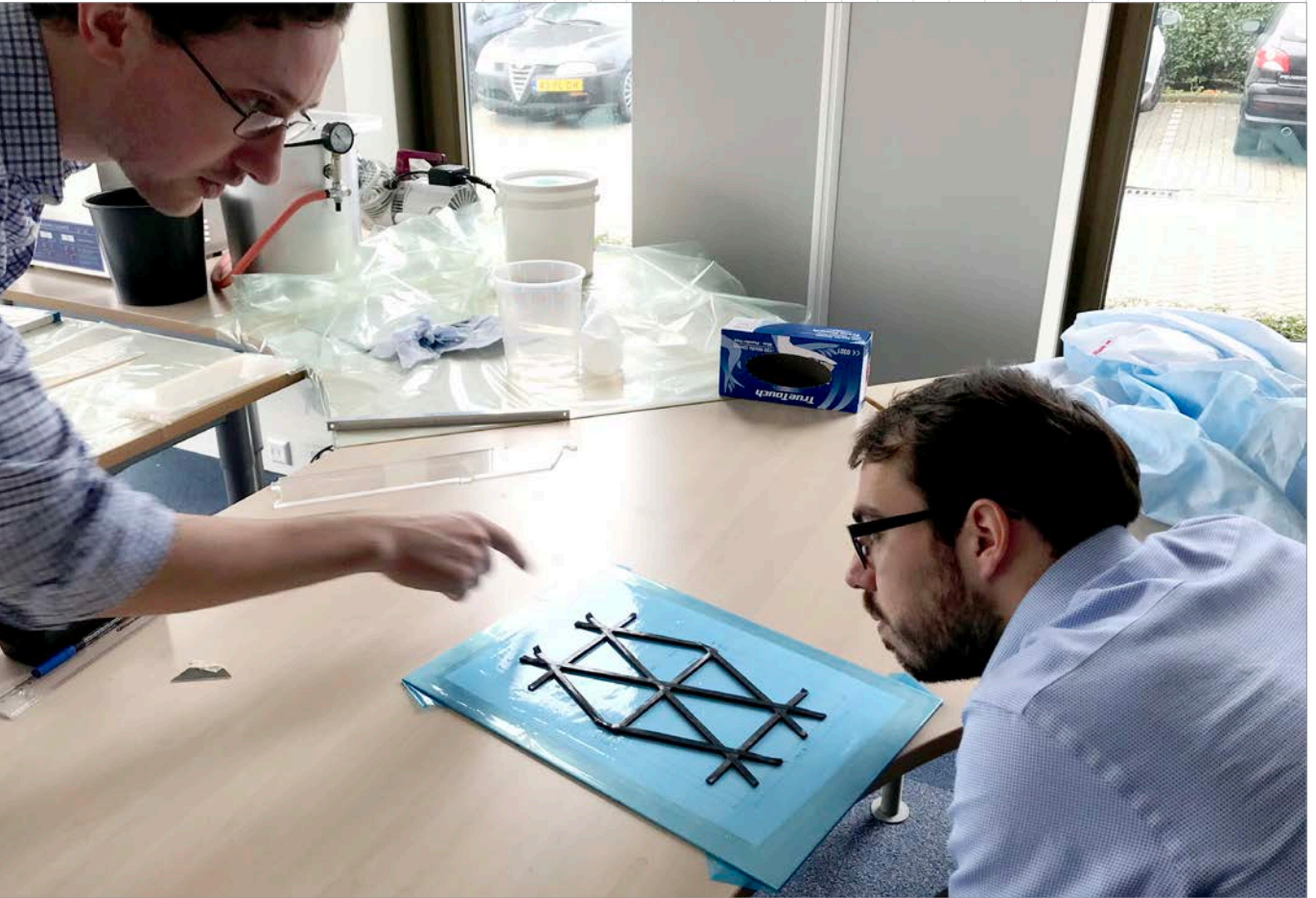
The potential danger with these categories is that the target group does not need help or a tutorial. Composite operators are highly trained and most often already have a good understanding of the way composites work. This means that they have a preferred way of working. That is why the design should focus on allowing an explanation of the differences with the normal composite production process.

COMPOSITE PRODUCTION ANALYSIS CONCLUSION

Due to the many small finesses, which each form a small design problem too limited in scope for a graduation project, the focus of the project should be on an entire phase. The most interesting phase is the alignment phase. A design solution for this phase needs to be concerned with spatial alignment, showing the relation between and reasoning behind the steps that need to be taken, and to enable an engineer to emphasize information. Another interesting phase would be Dam placement. This phase has a high amount of variation in its steps and presents some unique motions. Both phases represent a manageable amount of steps and finesses, all working towards the same goal. However, the damming phase was not directly observed thus it is best to design for the alignment phase.

Finally, it would be desirable for a solution to allow engineers to share Mental Models themselves rather than being a solution that can only be used once.

COLLABORATION TECHNIQUES ANALYSIS



In order to create a new collaboration tool, it is important to first understand how and why people use current the collaboration tools. From that information, it can be found where a VR tool can support current collaboration processes. To get this information, exploratory interviews were held. This is described in this chapter.

Figure 15: ATG engineers collaborating on a lay-up review

RESEARCH GOALS

This exploratory enquiry was meant to gain an insight into two main research questions. The questions were:

1. The first goal was to gain an understanding of collaboration methods used by engineers and the information that they share using the different methods. This is to establish where a VR tool might differentiate or supplement current collaboration methods.
2. Second, the theory states that lower bandwidth methods should lead to less information shared, it was the goal of this research activity to see how lower bandwidth would manifest within the composite production context.

So far, the theory on this has been unclear, it is hypothesised that is due to it being domain-specific and thus research for the composite or VR domain is lacking.

TECHNIQUES

Five main co-working methods were of interest in this research enquiry. These are the most used methods of collaboration within ATG and they represent a broad range of interaction bandwidths. From high to low bandwidth these were:

1. Face-to-face meeting (full bandwidth)
2. Video meeting (face, voice and 2D images)
3. Phone call (voice only)
4. Email exchanges (text only, short form)
5. Report writing (text only, long form)

METHODOLOGY

The research was done in two steps. During the first step, participants were asked to fill in a questionnaire to sensitize them to the topic. Next, a follow-up interview was done which used the answers of the questionnaire to guide the interview.

QUESTIONNAIRE

The topic is difficult to discuss in an interview so participants needed to be primed (or sensitized) beforehand. That is why a questionnaire was delivered to the participants well before the interview. This method was inspired by the generative research method by Stappers (2012).

In this method sensitizing booklets are used to immerse the participants into the topic beforehand. It was decided that a sensitizing booklet would not be a great fit for the target group instead a questionnaire was made. The participants were encouraged to take multiple days for this questionnaire. The questionnaire can be found in Appendix 03 on page 136. Participants were asked to recall and describe earlier memories, the follow-up interview would then require them to further dive into these memories.

INTERVIEWS

To get usable results, the questionnaire was followed up with an interview with each participant. These interviews took between 0:45 and 1:10 hours.

For the interviews, additional questions were created. These questions were focussed on finding the properties of a method and the intention of use, specifically what kind of information

do the participants share using this method and why. To better prepare the researcher for the interview a guide to the interview was written. This was made by writing down expected answers and based on that follow up questions were created. This allowed the researcher to more easily keep the participants on topic. The interview questions combined with the guide can be found in Appendix 06 on page 150.

PARTICIPANTS

10 ATG engineers (2 for each category) were asked to participate in the enquiry. The participants were all ATG engineers specifically because of the domain specificity of the method used. However, the composite team within ATG was not large enough to achieve an adequate sample size thus other engineers were interviewed as well.

DATA COLLECTION

Questionnaire results were collected in a spreadsheet. For the interview recordings were made, an automatic transcript was generated and notes were taken by the interviewer.

COLLABORATION TECHNIQUE

ANALYSIS RESULTS

In this section, the conclusions for each method are presented. They will be discussed in a later chapter.



Figure 16: Gathering round or whiteboard paradigm

FACE-TO-FACE

Face-to-face meetings are any synchronous meetings held with all persons present. This can either be in a group or one-on-one. This section is mostly focussed on meetings with external parties.

High preparation time

Due to the requirement for people to be in the same room at the same time this method has a fairly high preparation time with external parties. Mostly due to the time, it takes to schedule and travel to a meeting.

High bandwidth

In general, these meetings afford the highest bandwidth available as the full range of interactions are possible. Examples include facial expressions, spoken and written words, body language, images, and even touch.

This means it is possible to find out contextual information. For example, you can see if someone is interested and change your story accordingly. With synchronous methods, you can infer someone's background knowledge when talking about a topic based on their reactions and adapt your story to it. For example, if someone is struggling with a subject you can go into more detail.

This works two ways, others can read your facial expressions as well. To give an example of how this changes the dynamic, pacing is less important compared with a voice-call because people can see you think about an answer.

Immediate non-verbal information

As stated before, you can adapt your story halfway through based on non-

verbal clues such as body language or facial expressions. This high bandwidth immediacy allows for faster discussions and decision making. This is the main reason why people prefer working together using this method.

Gathering round

Face-to-face meetings are nearly always supported with visual information at ATG. This can be both a prepared presentation or sketches made during a presentation. One of the things that kept coming up during the interviews is the whiteboard explanation. This is similar to the idea of Goldschmidt (2007) of making sketches to support an explanation. This “gathering round” a visual representation while explaining proves efficient at sharing Mental Models. Together with the aforementioned 2-way communication, it means that parties can bring together their different knowledge sets to solve a common problem. In other words, the visual representation allows them to establish Common Ground. This gathering round process is not easily captured in a different form.

Relationship building

The more direct contact that FTF affords is important to build a professional relationship with the client. A better relationship leads to a better understanding of each other. Where it would be easier to anticipate what someone would and easier to understand their explanation. This means FTF meetings build team Mental Models.

Distance

When the distance to a person is small it can be the most convenient way

to quickly get some information from someone. These meetings are generally very short and not prearranged. This is only valid for very short distances within the company itself. Meetings like this with external parties rarely occur.

Used for Important moments

Because of the aforementioned reasons face-to-face meetings are mostly used for important moments during a project, for example, a kick-off. When it is important to correctly and quickly convey a lot of information FTF meetings are best.

However, due to the preparation time, it can sometimes become a multiple day commitment, especially with larger design reviews with many stakeholders.

Not traceable

This method is not inherently traceable like email or a report is. If it needs to be traceable extra steps are taken through other methods, like note-taking. In these cases, everyone must agree on the recorded information, email is frequently used to arrange for this due to its traceability.

Interruptive

Informal chats with colleagues are technically face-to-face meetings. It must be noted that people can feel like they are interrupting when asking something of a colleague.

Fewer misunderstandings

In general, misunderstandings happen less using this method. If it is noticed that a misunderstanding has occurred they can immediately be rectified.

VIDEO-CALLING

This method is very similar to face to face meetings. Everything that was written on FTF is true for video-calling as well. There are, however, a couple of key differences which will be highlighted in this section.

Distance

Key to understanding this method is that this method is the most similar to face to face meetings. That is why you often find that this method is often used when an FTF meeting is not possible or impractical due to distance or other factors. Using this method important decisions that require immediate high bandwidth reactions can still be made but over a longer distance.

Visual information

A video-call is a visual collaboration tool, showing facial expressions and body language similar to FTF meetings. However, it was found that it does this not as clearly as FTF meetings. There are 3 key methods you can use to show visual information during a video-call, these are:

- Facial expressions and body language
- Presentations
- Screen sharing and mouse placement

These are lacking in a couple of manners. First, a user often loses their face image when sharing their screen. Thus you lose the ability for people to see and read your face. Second, it is also more difficult to point something out on the screen nor can you easily confirm people are looking at the thing you are pointing at.

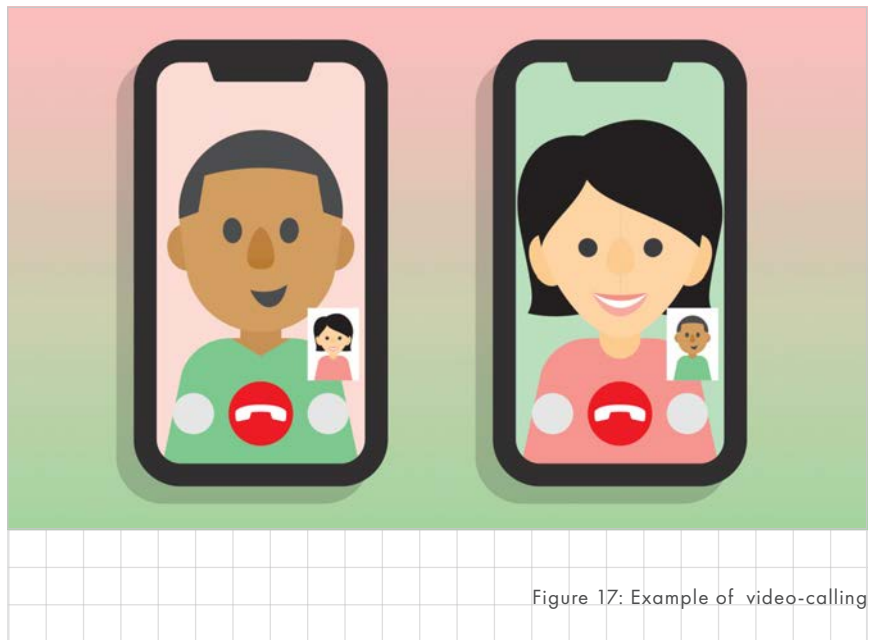


Figure 17: Example of video-calling

Third, it is difficult to easily draw with a mouse as the input method is not suited for it. Simple and rough drawings can be made but are often avoided. Due to this, explaining a concept during a video call is seen as more difficult than explaining the same concept during a face-to-face meeting.

Preparation time

It takes time to set up a video-call. It can be experienced as intrusive if unannounced thus needs to be set-up. A video call requires preparation. First, a moment needs to be found where everyone can attend. Next a service to video-call with needs to be decided on. For example, you might use Skype but someone else might prefer Zoom, so if you decide to use Zoom you need to create an account and test if everything works beforehand. Then a space needs to be found within the office as video-calling outside a meeting room is seen as intrusive.

VOICE-CALLING

Voice-calling is used to quickly reach someone for small discussions or quick information retrieval. It only requires audio and thus has little set-up. It is mostly used in one-on-one settings. It is efficient, with low preparation time.

Voice-calling requires little preparation apart from preparing questions. The engineer can easily pick-up the phone and reach someone immediately if they're available. This call does not need to be announced, however, often a phone call is agreed to beforehand.

More personal than email

When making a phone call it is perceived as more important and personal than email. This has the advantage that users are inclined to respond faster and give you the information you need. It can also help you build a connection with the receiver.

Intrusive

When calling someone on the phone you are requiring people to stop whatever they are doing. People feel required to stop what they're doing and take the phone. However, because you can't know if the timing is right the responsibility falls to the receiver.

Direct response

One of the main attributes of voice-calls is the directness of a call. It is possible to immediately receive and give feedback while on the phone. It is also possible to interrupt people while they are talking to steer the conversation.

On the opposite side, this also means you have to answer immediately. Any answer is final and you can't revise answers to filter out sensitive content or adapt it better to the context. When discussing sensitive matters with external parties this might form an issue.

Audio only

Due to the lack of any visual clues, verbal clues become more important. The most important being tone and pacing. This manifests itself in a couple of manners. First, with pacing you can hear someone hesitate or taking some time to think, so you can potentially rephrase the question.

Second, tone allows a person to change their message without changing the wording. For example, if something difficult or sensitive needs to be communicated then having the right tone can change the way it is received.

Used for quick information

Calling is mostly used to share smaller sized bits of information. The medium lends itself to get a quick answer due to the quick response and it is harder for someone to evade a question like you can easily do using an email.

Used for discussion (making agreements)

Due to the direct response, voice-calling is used for making decisions and agreements. Then often followed up with an email for traceability. The agreements that are made over the phone are of medium importance and can also include scheduling and project directions.

The advantage of calling over the phone to solve a problem is that everyone can pool their knowledge to come to a common solution. In other words to build a shared Mental Model and come to a common understanding of the issue.

Distance

Distance does not form an issue like it is with FTF meetings as there is no travel time. However, if the distance is great enough, time zones can still form a barrier.

Not traceable

Voice calling is not traceable without using other methods. A user can record a call but it is inconvenient to listen back to because it is hard to find the right information without labelling. Often recordings are solely used to refresh memory. Capturing information is mostly done through notes which might only make sense to the writer later.

EMAIL EXCHANGE

E-mail exchange is one of the most common forms of communication within the professional world. It is effectively used by everyone. With email you can send a limited amount of text and images to someone's mailbox, additionally, you can attach small files or use an external service for larger files.

Creates misunderstandings

The communication in an email exists predominantly of text, sometimes supported with images. This means the bandwidth is very low, making it hard for a user to express nuances.

It is hard to convey tone, pacing and emotion through email without using a lot of text. Even in that case, an email can be read with a different tone than it was written. To summarise, an email can express tone and emotion but it is hard to control the interpretation of the receiver leading to frequent misunderstandings.

High traceability and convenience

One of the main reasons emails are used is due to their traceability. Once an email is sent you can assume it will reach the person. There is no way of knowing, for sure, that a person has read it. The responsibility to read the email falls with the receiver. The sender of an email can always say that they have sent an email thus they should know what is in it. This means it is a convenient way to share important information. This information can include:

- Agreements made during other methods. By sending them over email a version of what was said becomes traceable. You send it over email because both parties agree to it.
- Information requests
- Information deliverables

Information deliverables

Important information is shared through email if it needs to be delivered in a traceable manner. This sometimes means an email can be a deliverable. However, in those cases, less information overall is shared because you cannot capture the same complexity as a report with less text. You would not use long texts because you run the risk of someone not reading the entire email.

In addition to shorter explanations, Email is suited to deliver test results, like numbers or graphics. Especially if follow-up tests need to be done, email is a convenient medium to discuss this need. Small decisions will be made over email, larger decisions often escalate to meetings.

Impersonal

When sending an email the author does not always know their audience. Nor does email provide an opportunity to get to know them over time. This makes it even harder to find the right tone.

Focus through limits

By limiting the amount of information in an email a user can convey importance. However, within the text itself conveying importance is much more difficult.

Convenient for groups

Using emails was found to be especially convenient to reach large groups. Other methods require a form of one-on-one interaction (except reports) but email can be sent to many people at once without being problematic or really changing the dynamic.

Unintrusive but slow to respond

Sending an email is a very non-intrusive way to communicate with someone. The receiver can choose their own time to reply and there is no pressure to do so immediately. Some people try to respond relatively quick when receiving an email however even then a reply takes a couple of hours. This is also partially because an email is seen as less important than a call.

REPORT WRITING

Reports are the overall results of a project and thus often required as a deliverable at the end of a project. They contain a large amount of information mostly in textual form.

Very slow due to overhead

Writing a report was considered the slowest method by far. It was described as taking a lot of time to tell a story which can also be told in 5 minutes using other methods. This is because it is often the requirement to describe the entire process in detail in the report. This means a lot of time is spent capturing details that would not be communicated using other methods because they would be irrelevant to the story. Most of these details are because they need to be shown in a standard test method. This leads to a lot of overhead, that needs to be captured for traceability, more on that later, but is not necessarily immediately relevant for the main conclusion of a report.

Overhead is also worsened because it is obvious that stakeholders do not necessarily read everything written. Rather skimming a document for the conclusions than asking stuff that is in the report later. The report is then written solely for traceability.

Creates misunderstandings

A report can create misunderstandings in 2 ways, a lack of understanding of author intent and a lack of understanding of reader background. This understanding cannot improve due to the low bandwidth and formal nature of report writing.



Figure 18: Example of report Writing

Slow due to review and revision

It takes a lot of time to write a report due to multiple reviews with internal parties. Taking a lot of revisions before a report can be sent. However, this also has a positive side because of the many reviews a lot of revisions are needed. These allow an author to think about exactly what and how he wants to convey information.

The tool used for this is the comment system in Word. It is the responsibility of the author to take the comments into account.

Very slow to get a response

It can take months to get a response from a stakeholder. This is in part due to the stakeholders needing to read a lot of information but mostly because it is often not a priority for many people. It is easy to not immediately respond when receiving a report. A report comes with no sense of urgency.

Lacks context of author intent

It often happens that the reader focusses on something the author did not intend thus missing the point of the report. It is hard for the author to show what is and what is not important when they need to show everything. In a report, generally, all information receives roughly equal importance. To prevent misunderstandings it can be best to limit information in the report.

Impersonal (receiver background)

When writing a report you often don't know your complete audience. If you do this might change at any time because reports can be easily shared. This makes it hard to find the right tone, which means it is mostly formal. More importantly, you can't always assume your audience has a certain amount of background knowledge.

Superficial influences

Aesthetics are also of influence on the reader. Better aesthetics give a more professional impression and can change how a reader views the rest of the documents. To give an example, if a document does not look professional this can lead to the reader to believe the contents of a document are also unprofessional.

Traceability

The document itself is also a deliverable. It is important to show that everything promised was delivered and you want it to be traceable so you can point to when a decision was made so that they could see that they knew this. It comes down to whose responsibility it is when something goes wrong. With a report there can be no doubt as both parties agree on it's contents.

Used to capture all result information

- Project process
Not all sub decision need to be captured but in general, the different phases need to be explained.
- Tests
This includes the entire process, the rationale of a test, the execution and the results of the test, then a discussion of the test results. Datasets, graphs and mathematical models included
- Project conclusions.
Of note is that conclusions that are in line with expectations are a lot easier to explain.

In general, all data that can be easily captured into text and 2D images are required to be in the report. No discussions are captured nor held.

CONCLUSION OF COLLABORATION TOOL ANALYSIS

In this section a short comparison of the different methods is provided. Report writing and email are cumbersome and take many revisions and relatively a lot of time to prepare. Due to the low bandwidth, it can then often still be confusing for the recipient.

Voice-calls do not allow you to refer to anything visual. Making it difficult to ensure someone is referring to the same concept.

An FTF meeting gives you the full breadth of explanation but it can be too hard to schedule due to distance.

Lastly, a video-call does not give you the spatiality and still requires both parties to be present. It is not inherently traceable either. A user can make notes, which create a biased interpretation of events, or it can be recorded. However, in that case, it takes a lot of effort to find the relevant information later.

KEY INSIGHTS

In this chapter, an overview of the different methods was created.

This capture the information shared and their intention of use. The most important insights are:

Traceability

Asynchronous methods are inherently traceable, this is not the case with synchronous methods. In the industry that ATG operates in, traceability is very important to prevent additional work or conflicts.

Visual information is stronger in person

Using visual information in an FTF meeting leads to better Mental Model transfer. This was found to be because users can more easily refer to parts of the image and because they can also expand on the image.

Decision making

Synchronous methods are more likely to be used for important decisions. This is due to the ease of explanation and the high bandwidth and direct response with synchronous methods.

Higher bandwidth synchronous

As expected bandwidth is higher for the synchronous methods due to audio and visual channels.

Influence of preparation time and distance

The preparation time of the synchronous methods can be very high, making them not always a viable method. Similar to distance. This is an important factor in choosing which method to collaborate over.

High response time asynchronous

Response time for asynchronous methods can be very high leading to some difficulties. For example, feedback can take long enough that an engineer has trouble understanding what they are commenting on.

Difficulties of synchronous

Direct response leads to other difficulties, most notable being that once a response has been made it cannot be taken back. This makes discussing sensitive matter difficult.

**ANALYSIS
CONCLUSION**

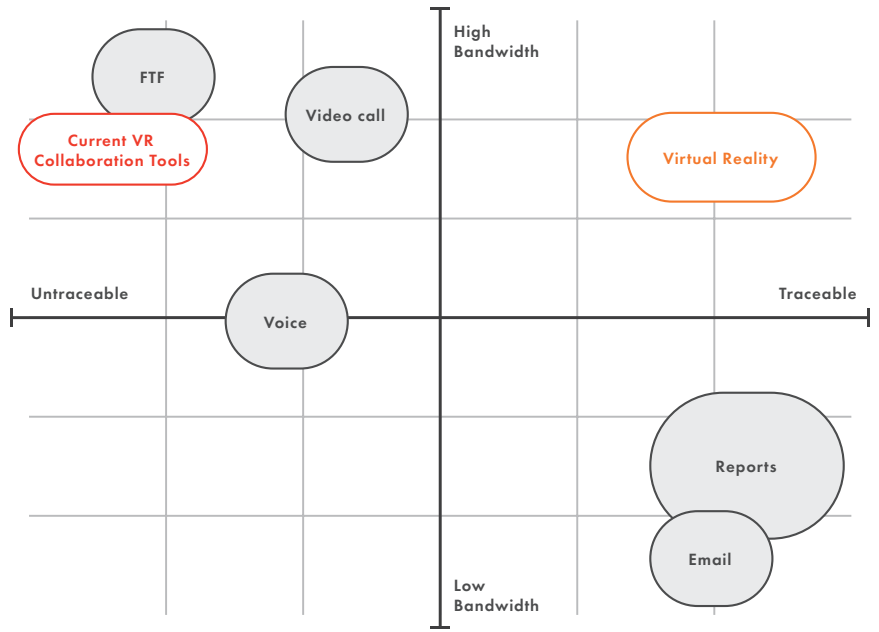


Figure 19: Perceived relative traceability on the x-axis, bandwidth on the y axis

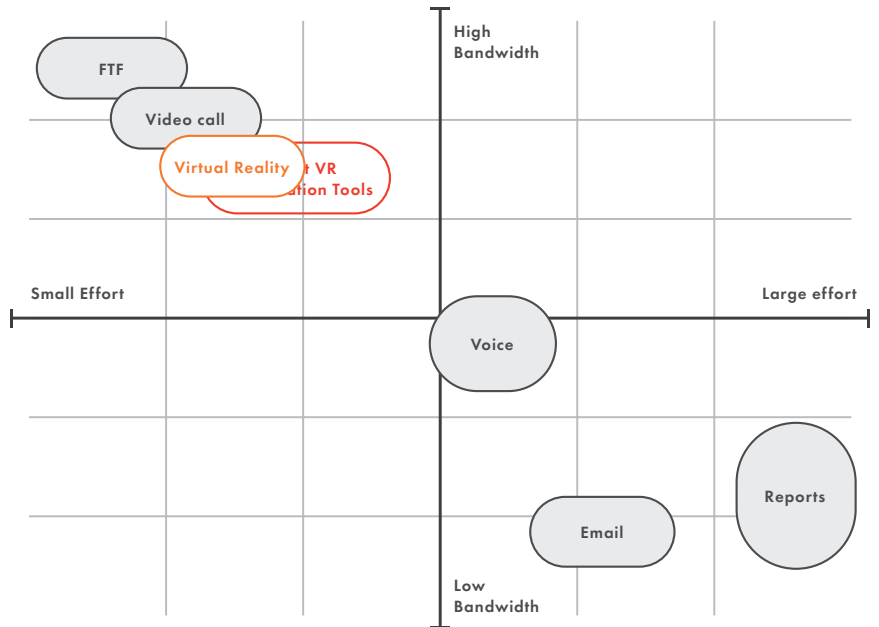


Figure 20: Perceived relative ease of explanation on the x-axis, bandwidth on the y axis

In this chapter the different methods were defined and compared. In this comparison it became clear that there is no flawless method of collaboration. Leaving room for an additional method.

An asynchronous VR setup could be a supplement to the analysed collaboration tools. For this, 5 important categories or scales were defined where VR is thought to be a useful addition.

INFORMATION

FOCUS ON EXPLANATION

The tool should have a focus on explanation rather than making agreements. Coming to an agreement on a topic was found to be mostly done through synchronous methods. Where as an explanation can be done through both methods and would benefit from an asynchronous approach.

Using the tool must make it easier to explain complex problems from the composite production process compared to using a report, email or voice-calling. In a sense, it is information that can be easily discussed during FTF meetings or video-calls but in a traceable asynchronous manner.

GATHERING ROUND

The whiteboard or gathering round paradigm could potentially be very interesting for VR. This would create a tool with high bandwidth where it requires little effort to explain complex subjects. This paradigm can be used as an interaction vision.

SIGNALLING IMPORTANCE

A user should also be able to signal importance within his explanation. Being able to lead a receiver through a story in a manner that highlights important information in a way hard to do in reporting. This so a shared Mental Model on important considerations is created between the two users. Leading to better cooperation and also more relevant questions later in the project.

REVISION

One thing that VR should allow for is revision. One of the main strong points of asynchronous collaboration tools was the ability to revise the information you share. This prevents confidential information getting out and makes for stronger explanations.

TRACEABILITY

Traceability kept coming up as one of the main reasons that people would use email or reports. Even going as far as making face-to-face meetings traceable by agreeing on what was said over email afterwards. As you can see in Figure 19, FTF, video and voice-calling are themselves inherently not traceable.

Traceability is important to ATG in two main ways. Keeping track of work done and agreements made. If their work is not traceable it means that a client could claim that something was not delivered as expected. Even if it was delivered or when it was never agreed to. It is also important to keep track of the knowledge gained and when changes are made, by whom and why? If a mistake was made then it can be

very useful to find out when they were made and who was responsible. With a traceable source they can easily pinpoint this.

For VR, there are a couple of things that could be made traceable more easily than current methods allow. These are motions or gestures, spatial information, relation between steps, and user intention. Finally, it could also make making sketches traceable as described by Goldschmidt (2007). The power of using sketches for explanation comes from the combination of talking about a subject while altering an image representing concepts in the explanation. This is currently not directly traceable but would be valuable if it was.

These items that can be made traceable fit well with the recommended phase from the composite production analysis. To reiterate the types of Mental Models that need to be shared are:

- Spatial alignment
E.g. how would you actually place down a toe? This is a task Mental Model, understanding the reasoning can help understand
- Showing (learned) motions
For example, the tricky motion of removing the foil. This is a process Mental Model, requiring an understanding of how steps build on each other.
- Showing the point of attention,
engineers need to be able to place special emphasis on different steps. This exists of both task and process Mental Models, sometimes a small thing needs to be emphasized other times

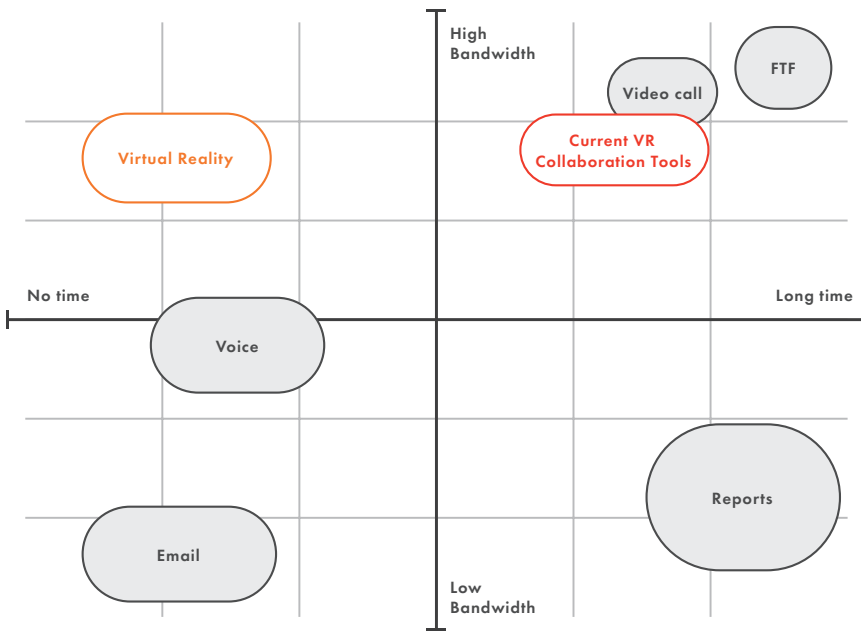


Figure 21: Perceived relative preparation time on the x-axis, bandwidth on the y axis

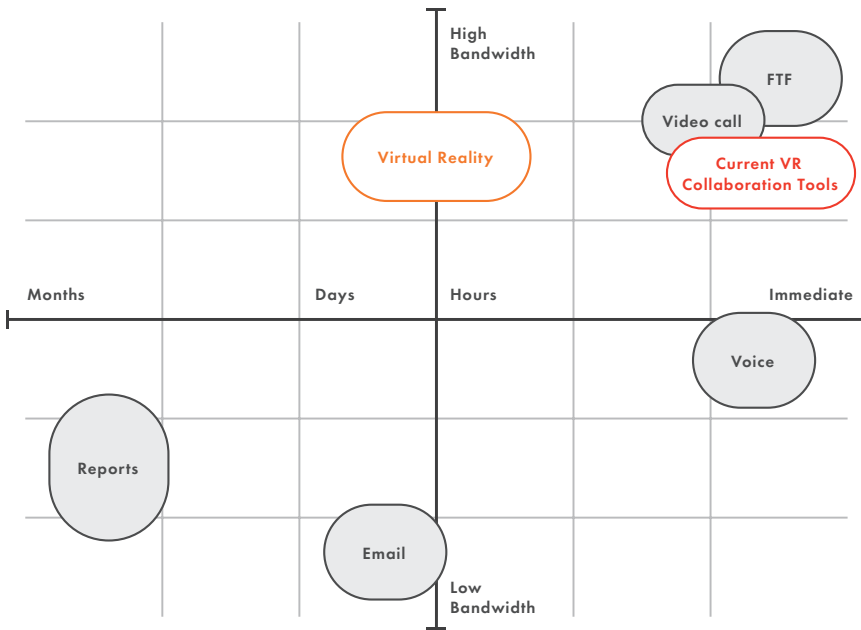


Figure 22: Perceived relative reaction time on the x-axis, bandwidth on the y axis

it is mindset that influences the process.

- Visualising process steps and the understanding behind it. This is a process Mental Model.

COMPARISON TO COMPETITION

It is important to create a clear difference from the current VR collaboration tools. These are nearly all synchronous and non-traceable. Differentiation on those aspects, will be the unique selling point of the final tool. With synchronous voice-chat, these tools emphasize creating team Mental Models. This will not be the focus of the VR tool. Rather the focus will be on task and process Mental Models.

PREPARATION TIME

Face-to-face or video-call meetings take a long time to prepare for. First, a date needs to be found then a venue or meeting room needs to be arranged and finally one or both of the parties needs to travel to that location. This, simply put, makes it so that a face-to-face or video meeting is something used mostly for important moments during a project even though a lot more information can be communicated easily. This is especially different compared to emailing or calling. These methods can be used at nearly any time and do not need to be arranged beforehand but have a low bandwidth.

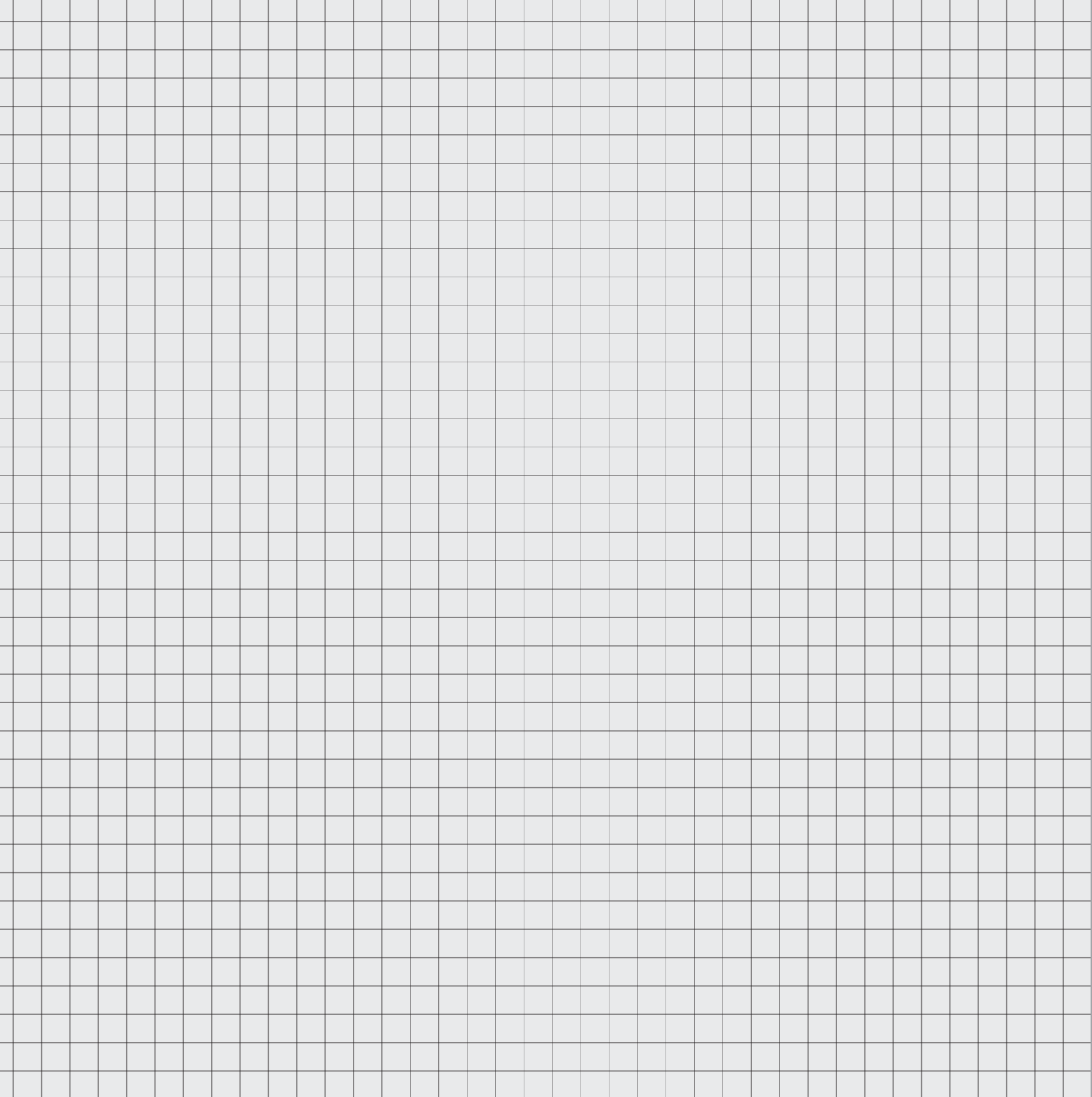
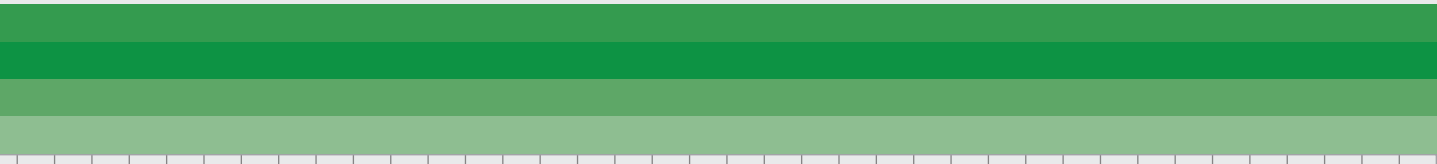
A Virtual Reality Collaboration tool can provide for a method that has low preparation time, as it is done asynchronously, but still a high bandwidth through movements, spatiality, voice, graphics and more, see Figure 21 on page 58.

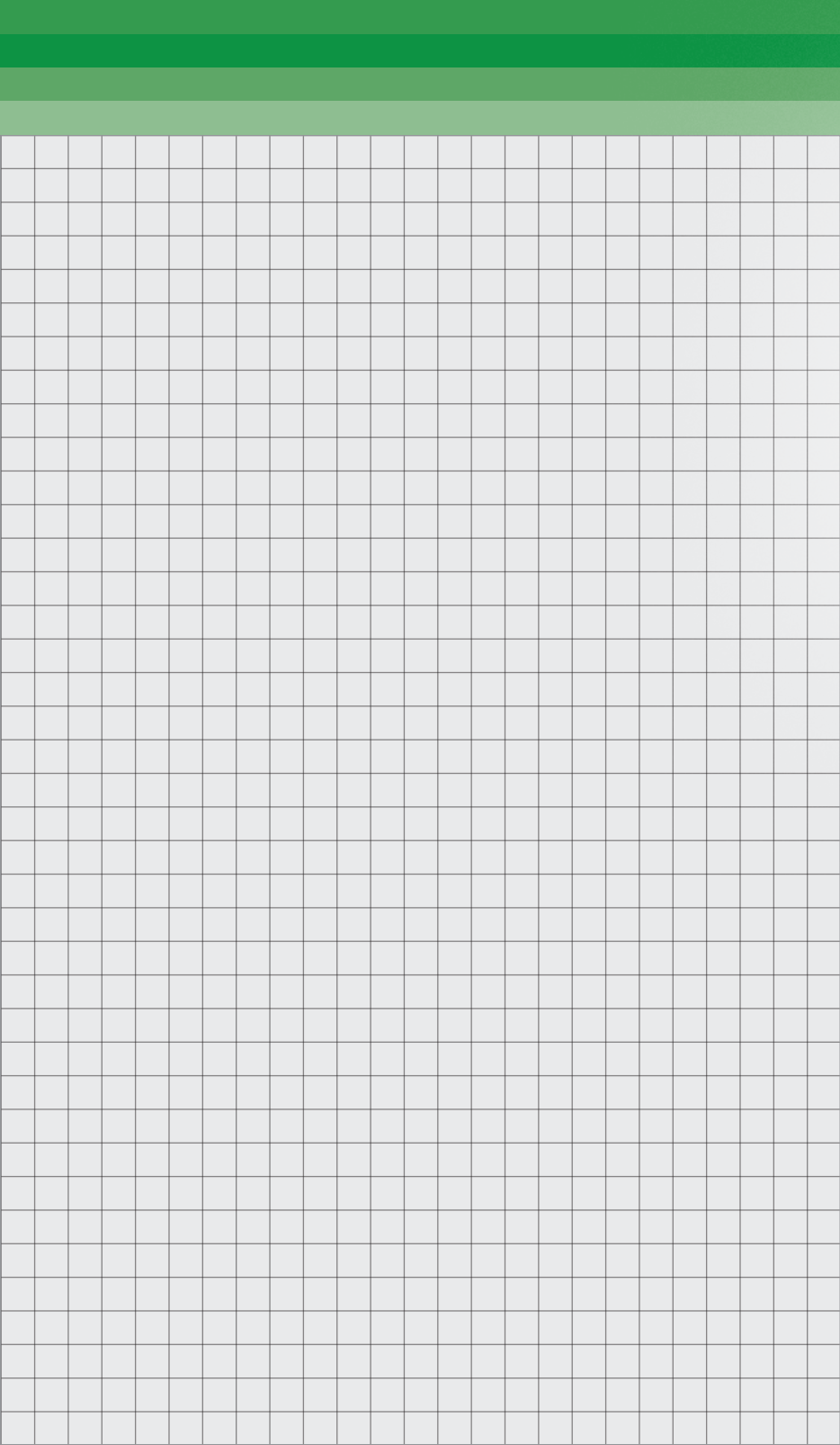
REACTION TIME

Because the tool will be asynchronous, it means the reaction time will probably be longer. This is because no two users can be in VR at the same time. The goal should therefore be to create something that makes a response easy but does not need to be responded to immediately, similar to an email (see Figure 22 on page 58). That is if a response is needed at all.

DESIGN DIRECTION

In conclusion, the VR collaboration tool should have **high bandwidth** to be able to explain complex concepts with the same ease as FTF or video-calling, see Figure 20 on page 56, but it should be also **asynchronous and traceable**, see Figure 19 on page 56. This makes for a tool that reduces the time needed to both prepare for and capture complex information in a manner that makes it easier to understand at a later date. Combining the best of both low bandwidth asynchronous methods and high bandwidth synchronous methods.





In the conceptualisation phase a set of requirements was created based on the research done. From these requirements questions were created that were used in a brainstorming session. The outcome of the brainstorming session was used to create a holistic concept. By creating a holistic concept in such a manner it was possible to have a relatively short conceptualisation process. This process will be outlined in this chapter.

REQUIREMENTS

A set of requirements were created by role-playing how the product might be used within the office setting in the Netherlands. This led to an array of interactions in the office which were defined into requirements.

INSTALLATION

1. Installing a headset should take no longer than an hour.
2. The tool should allow multiple users in an office to share a headset (not at the same time).
3. Hardware should come preconfigured with the software already installed.

LEARNING CURVE

4. An engineer should not need more than 10 minutes to learn the core concept.

ASYNCHRONOUS

5. The concept should be asynchronous, thus incorporating no live, or multiplayer, elements
6. Explaining a concept using the concept should take no longer as it would take to explain the same concept on a whiteboard with users present.

CAPTURE PROCESS EXPLANATIONS

7. A user should be able to convey Mental Models within and about 3D space better than a still image with description.
8. A user should be able to transfer a Mental Model on why a position is chosen.
9. A user should be able to transfer a Mental Model on why air gaps need to be kept.
10. A user should be able to transfer a Mental Model on how air gaps

can be kept.

11. The concept should show different steps of the process.
12. The concept should show how steps relate to each other.
13. A user should be able to see these steps independently of each other, not in one order.
14. Users should be able to draw the attention of the viewer to the desired subject only.

REVISION

15. The concept should allow a user to revise a recording.
16. A recording session should feel relaxing.

CREATE TRACEABLE INFORMATION

17. Mental Models captured in VR should be easily traceable during the project duration.
18. Users must be able to send the information recorded in the VR tool to other users.
19. Users must be able to reference the Mental Models recorded in VR in other mediums, for example a report.
20. Revisions to the process should be kept and be visible over different explanations. In order to understand when a parameter changed or when revisions were made to the explanations.
21. The tool should be able to show or allow an engineer to show their thinking process.

LOW PREPARATION TIME

22. From desk to VR should take no longer than 1 minute, to lower the barrier to entry.
23. Users should be able to prepare their explanation outside of VR and take this into VR.

24. Users should be able to reference information on their PC in VR.
25. A consistent project should exist to keep information permanently.

ALLOW FOR MEDIUM REACTION TIME

26. Users should be able to respond in VR to the Mental Model.

FINDABILITY

27. It should take no longer than one minute to find the right topic and no longer than two minutes to find the right Mental Model in a topic.
28. Information should be able to be kept permanently.
29. Information needs to be findable even for new team members or after half a year.

CONTEXT REQUIREMENTS

30. There should be the ability to import models from the desktop.
31. From desk to VR should take no longer than 1 minute.
32. Can be either used in a separate VR room or at a desk.
33. Must be able to transport the headset to make use of it in other settings.

WATCHING BACK

34. A user should be able to find the information that they are looking for within 1 minute.
35. A user must be able to skip information that is not interesting to them.
36. The explanations must take no longer than 5 minutes to watch.
37. Users should be able to take the information in VR to other mediums.

INTERACTION VISION

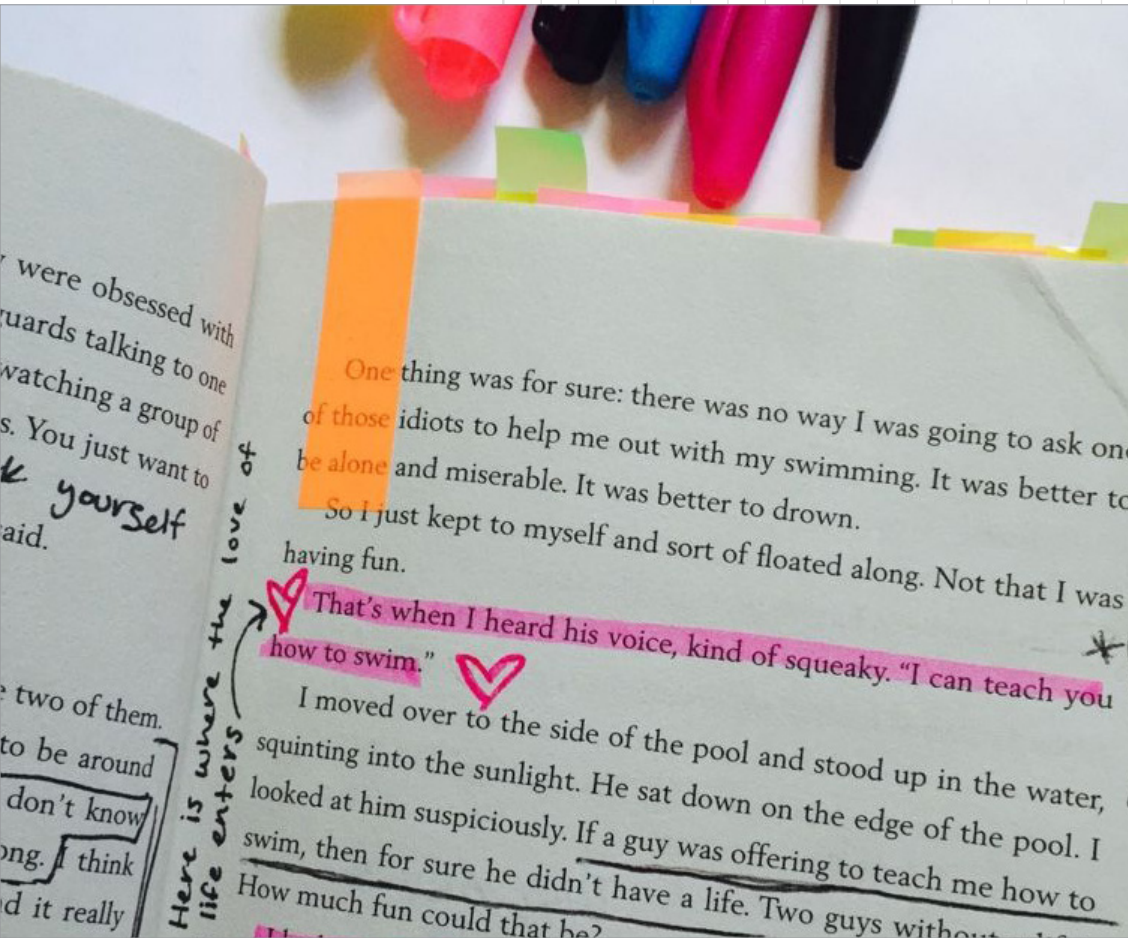


Figure 23:
Annotating a book,
interaction Vision

“Annotating a book you’ve read for someone who hasn’t”

The interaction should feel like you are sharing your expertise with someone who does not have that yet. You should feel like you’re adding small helpful bits of information to a model that are going to be very helpful to someone at sometime.

QUALITIES OF USE

1. Feel like the expert
2. In control
3. Helpful to others
4. Relaxed

IDEATION

A relatively quick ideation process was held. HKJ's (How Can You?) were created based on requirements formulated earlier and the interaction vision. These HKJ's ranged from being very general to quite specific.

A 6-3-5 brainstorming session was held at ATG with their engineers. They were asked to write ideas on the HKJ's for 3 minutes then passing it on to the next person. This allowed them to get inspired by other ideas and building on them as well as adding their own new ideas.

HKJ'S

In this chapter, the HKJ's, their origin and their goals are described with some key ideas highlighted. The full results of the brainstorming session will be in Appendix 05 on page 144.

LET USERS RESPOND TO OTHERS IN VR

Based on requirement 26.

This HKJ came from the requirement for medium reaction time. The idea was to establish more of a dialogue but was not used in the concept. Some interesting ideas were to give responders the same drawing tools as recorders and to have a virtual equivalent of sticky notes. These sticky notes would contain voice recordings or symbols, like emoji's.

LET PEOPLE REVISE CAPTURES OF INFORMATION

Based on requirement 15.

Promising ideas were to have a physical eraser as an undo button. But

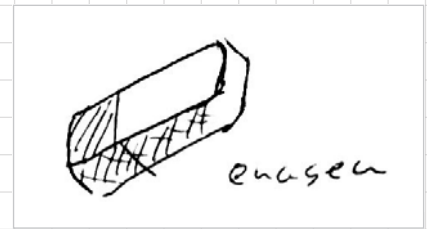


Figure 25: Eraser tool

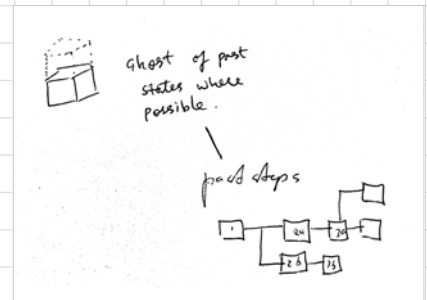


Figure 24: Ghost steps

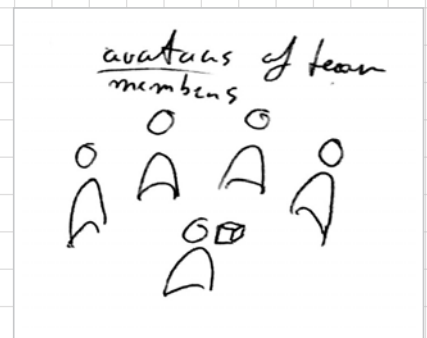


Figure 26: Ghost steps



Figure 27: Spotlight

the idea implemented was to break it into small chunks, to provide more of a video editing timeline experience. The goal is to make it easier to redo because you can redo less.

SHOW EVOLVING INFORMATION

Based on requirement 11, 12, 20.

Ideas included graphs being able to scrub through a timeline. One idea was to show ghost of previous states. Combing those two ideas led to the idea to keep a timeline of past steps.

WHAT KIND OF INFORMATION/ DATA/EXPRESSIONS CAN YOU CAPTURE IN VR AND HOW?

Requirement 7. This is the most general HKJ, it was meant to inspire a more broad set of ideas.

Ideas were audio, discussions, weight and material properties, position, drawings (2D or 3D), slideshows, re-enactments, visual avatars, models. These did not lead to any concrete ideas.

CREATE THE FEELING OF GATHERING ROUND WITH OTHERS THAT AREN'T PRESENT?

This HKJ ideates on how to achieve the interaction vision.

One of the first ideas was to have a virtual stage with avatars watching. In my opinion that would feel strange but the stage idea is good. This can also be implemented by using parts of it like the sound or by putting a spotlight on the user.

MAKE NON-VERBAL INFORMATION FINDABLE/ TRACEABLE FOR LATER USE

Based on Requirement 27, 28, 29.

The data flow structure was mentioned again during this HKJ. An idea that was mentioned was to use hashtags and colours in order to label information in the structure. Labels are promising because they can be short and easily reused. Typing long descriptions is suboptimal in VR.

Another idea that was presented was to have a graphical representation of a recording. Possible ways of achieving it were to show a mini version of the models (in motion) or to take screenshots of the scene and use them as thumbnails.

Other ideas that were found interesting but not feasible were for example creating a transcript from a voice recording and searching that.

DRAW ATTENTION OR GUIDE USERS EYES

Based on Requirement 14, 21.

The most useful but also fairly obvious idea was to allow users to point at stuff with their hands and record that. Vr, of course, has handtracking and the oculus controllers also allow for a bit of finger tracking so this seems fairly logical to implement.

A more interesting idea was to have spatial sound. Unreal can make sounds seem to play at a location rather, allowing the user to understand a location from sound. Maybe this can be done with sound effects that can be added or the voice recording.

Having a set of standard shapes could be a useful idea. However it could be

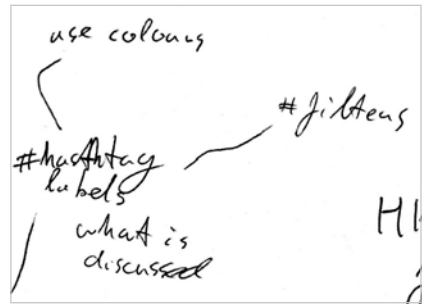


Figure 28: Hashtags

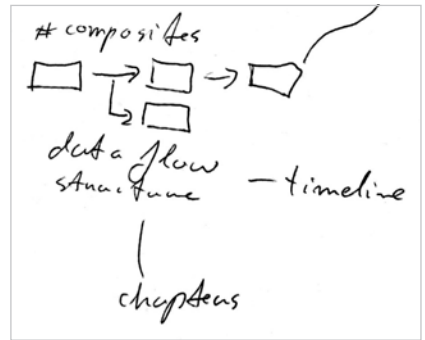


Figure 29: Structure

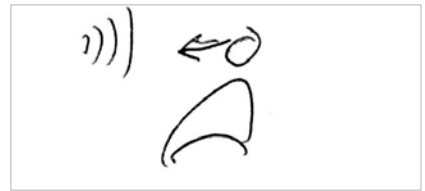


Figure 30: Spatial audio



Figure 31: Shapes

limiting, maybe allowing people to draw shapes would be far better. They could maybe also move the drawings to draw more attention towards them. For example, they can shake them.

There were other ideas, like using light. Save for using a spotlight, it is unclear how to use this. However, it might be interesting to try during the prototyping phase.

ALLOW USERS TO INPUT/MODELS OR IMPORT ANYTHING

Based on requirement 23, 24, 30.

The main ideas were to use some sort of shared folder, like Google Drive, or a shared project, like Trello. Users would be able to upload models from the pc and have them be available in the project.

Another idea was to have an email address or a WhatsApp that you could text and it would show up. By having the ability to email models would also mean there is a trace.

SEND AND RECEIVE SOMETHING IN VR

Based on requirement 18, 19.

There could be some kind of way to add people. Rather than typing in a name and email each time, the tool presents you with team members and you only need to select someone from a list. This could be in persistent project like brainstormed before. This is where the slack idea came from.

One other more concrete idea that was fun was a solution where you would throw paper planes at avatars.

Not really practical but it could be a skeuomorphic solution.

EXPORT VR TO OTHER MEDIA

Based on requirement 37, 19.

The idea that would fulfil the requirements while still allowing the most freedom would be to offer a virtual camera. Users could decide to watch it on a screen while being able to rotate the camera. It was also mentioned to have a camera switching method. Users could watch from the point of view of the engineer or control a camera themselves. The engineer could maybe also record the motion of a camera that can be watched. A simpler version would be to be able to render to video or GIFs. This would work well with email and meetings.

Finally there was an idea that 3d models could be exported. Maybe 3d models could be made up of mash-up of other 3d models, like gravity sketch, or a drawing tool could be implemented.

SHOW CONNECTION BETWEEN STEPS

Based on requirement 11, 12, 13.

A flowchart for the steps, showing branching paths for older revisions, was mentioned again.

Another interesting idea was to have two steps next to each other or to morph from one position to the next. Morphing between steps would only work if they were very small steps.

Otherwise too much information would be lost in between.

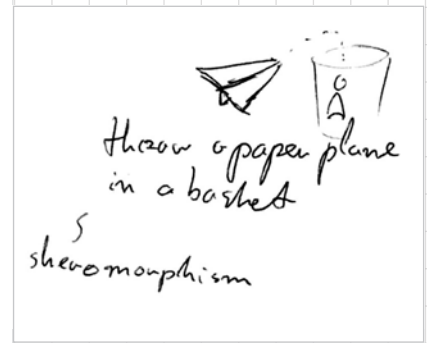


Figure 32: Paper plane, skeuomorphism

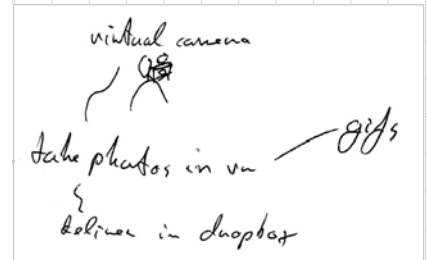


Figure 33: Virtual camera

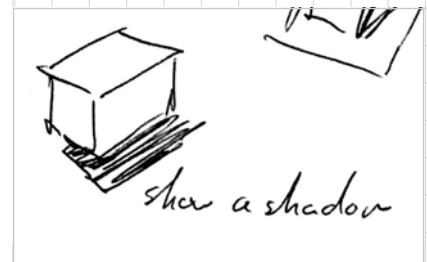


Figure 34: Shadows

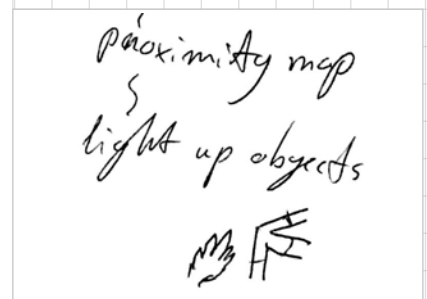


Figure 35: Proximity

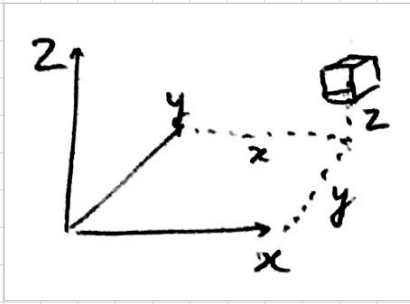


Figure 36: Grid plane



Figure 37: Ruler



Figure 38: Attention drawing light ideas

However, playing a step and then auto-playing the next one would already give you a good idea.

SHOW OBJECT LOCATION IN 3D SPACE

Based on requirement 7, 8, 9, 10.

Some of the main ideas were to make use of shadows. This is something UE4 gives you for free and will be quite useful to show distance between objects.

Another idea was to have measuring devices. Ideas included rules and grid planes. They could show absolute distance and would be interesting to try out during prototyping. Rulers could be combined with the drawing tool.

Final interesting idea was to use light (rather than shadows) in order to show location. Objects could light up based on how close they are to other objects. Maybe the floor could do the same, making for some kind of proximity map.

CONCLUSION

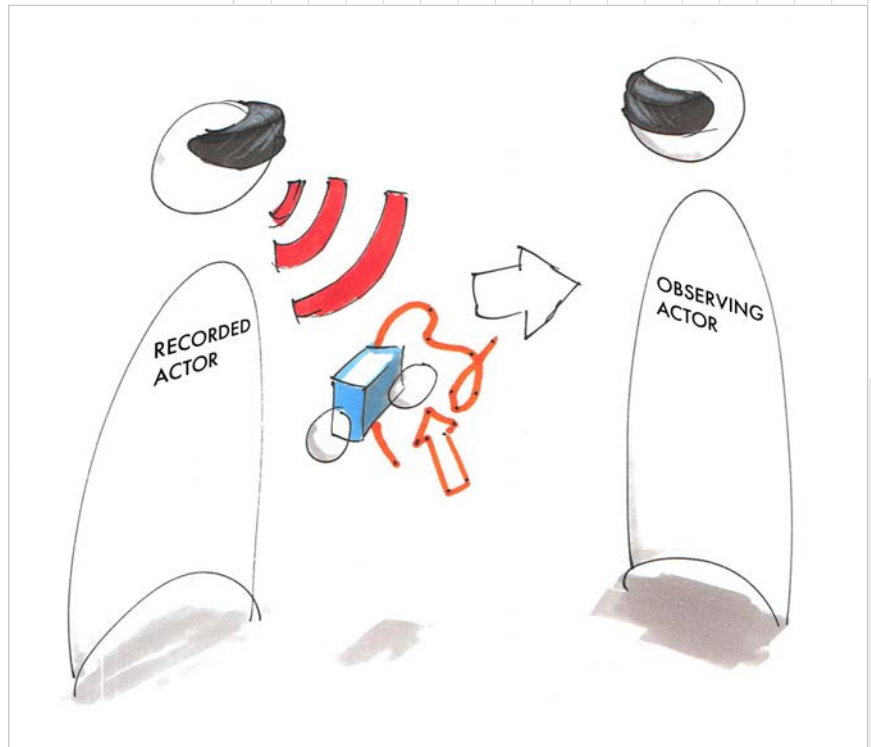
By creating HKJ's based on the requirements it helps to do the ideation quickly. The requirements already create the outline of the concept and these ideas fill in the blank for the concept to become tangible.

That being said, the ideation is not finished yet. During the RITE prototyping phase these ideas will be put to the test and will be changed. It serves therefore more as a starting point than a final concept. To put it in another way the three different concepts, that are standard IDE practice to finish ideation with, will instead be 3 different iterations that have been tested.

HOLISTIC CONCEPT

With RITE prototyping there is the opportunity to build a concept based on actual results. Therefore rather than presenting 3 final concepts a holistic concept based on the requirements and initial ideation was created. This concept has a set of goals that can be used to work towards in the prototyping phase. The prototyping phase will lead to a final concept.

Figure 39: Recording Mental Models for others to watch



“A Virtual reality tool that allows for the recording and playing back of narrated and annotated composite process steps”

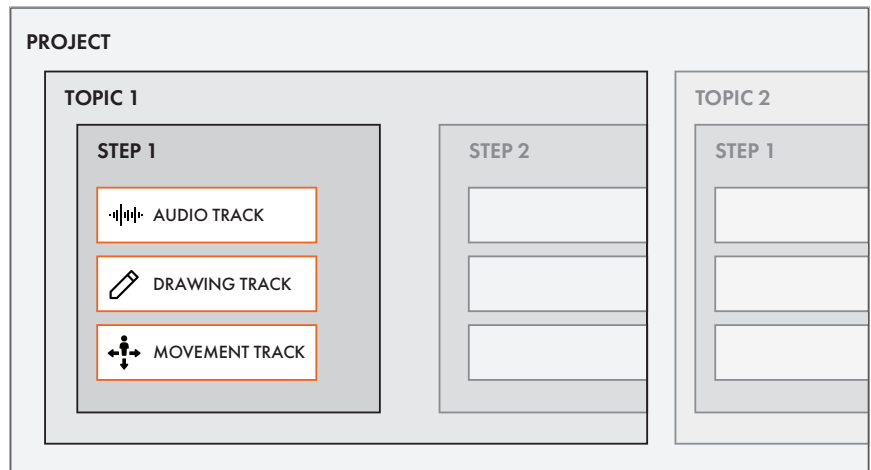


Figure 40: Illustration of project structure

CONCEPT IN SHORT

“A Virtual reality tool that allows for the recording and playing back of narrated and annotated composite process steps in order to transfer Mental Models in a traceable manner.”.

It does this by doing two main things. Firstly, by recording sketches, objects and the engineers position and voice in 3D over time to capture Mental Models Secondly, by organising those Mental Models in a clear project structure that makes the Mental Models traceable and findable in a persistent project.

FEATURES

This is comprised of several main features that will be summarised here. They will be explained in detail in the rest of this chapter.

Defined project structure

A clear layered project structure makes it easy to find Mental Models later on in the project. Information is also kept

in a persistent project for traceability. Users can be added and removed from a project in order to keep data safe.

Steps

The VR tool encourages you to record the composite production in steps. These make it easier to find the right bit of information or Mental Model during playback and makes revision during recording easier. Revised steps can be kept to show how processes have changed over time.

Recording multiple high bandwidth tracks

- Recording position
Record spatial information of object (i.e. how to align layers)
Allows to emphasize important information
- Recording sketches
Record a sketch or a composite being made for later playback
- Recording voice audio
Create voice recordings of explanation

INFORMATION TYPES:

In the previous chapter the alignment part of the composite production process was chosen. The alignment process required several types of information to be recorded. These are summarised here:

- Steps to be taken
The order of steps was found to be very important to convey clearly in this phase.
- Spatial information
For example, how do we keep air gaps between knots. Where should and should you not press.
- Importance of information
Where should an engineer especially watch out, it was found to be difficult to emphasise this in writing.
- Voice audio
It records an audio explanation together with the aforementioned visual information to capture a Mental Model.

PROJECT STRUCTURE

A key part of capturing information for later use is being able to find information later. There are multiple ways of doing this but the solution presented allows the user to organise information in clear categories during the capturing. An analogy of slack was used to develop this, which lead to four different information levels, the project, topics, steps, and tracks. In this section the goals of every level will be explained.

PROJECT

The first level of information in the concept is a project. ATG works on a project by project basis thus it makes sense to categorise information on a project basis. The best analogy for a project is a slack. It is a space that you can give team members access to that than contains channels or topics.

Making projects like this means there can be a single resource for all

knowledge. This has two main benefits. First, there is a consistent resource for later traceability. Every recording, step or topic made relevant for a project made can be found in a single place. No need to keep them in email or file folders. Second, this single resource can also be used to import 3d models and make them available project wide.

Not every composite engineer works on every composite project, thus team members should be given access to information on a project by project basis through a personal login. Rather than having access to all the projects all the time an invitation can simply be sent to the team member. This means access can also be taken away when no longer necessary.

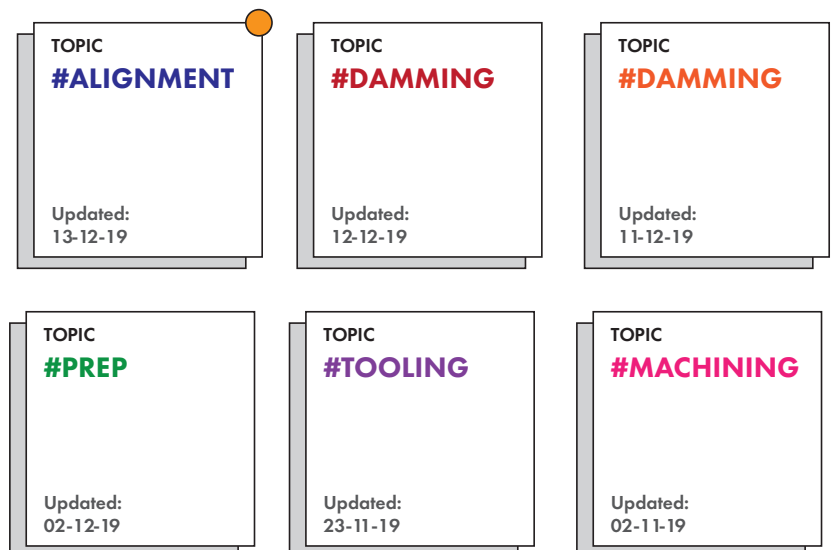
TOPIC

A topic contains all steps or information on a single topic within a project. For example, the composite layup has multiple phases which are considered to be different topics.

Figure 41: Project structure with multiple topics

PROJECT

COMPOSITE PRODUCTION



A project can contain multiple different topics. The best analogy for this is a slack channel. Where the project is a slack, a topic separates topics within a slack, a topic separates topics within a project like a slack channel separates discussion topics. Topics can be played back, playing every step after each other, like auto-play on YouTube.

Because steps can change over time a topic can change and evolve over time as knowledge changes. Old steps can be kept in branches as a way of visualizing changes in the project.

STEP

A step is simply put a single step in the composite production process. A topic should contain a single task or motion, for example, laying down or cutting a toe or properly aligning a composite ply. This ensures that knowledge is kept in short chunks which has 3 key benefits. First off, by ensuring content is broken up in small chunks it is easier to find the relevant piece of information, which makes for

better traceability. Second, by keeping the chunks short it becomes easier to revise a step as less effort is needed. Finally, by having shorter chunks of information it is perceived to be more like an encyclopaedia rather than a training film. Composite operators are very skilled and expensive craftsman thus wasting their time with long training films is not desired. Whereas an encyclopaedia respects their time a lot better by allowing them to find the right information themselves.

Keeping up with the analogy of slack, this is the message bubble. A step contains tracks which are the actual content, similar to how a message bubble contains different types of content such as text, images or URL's.

Steps can be added, deleted and revised in order to reflect changes in the information. Old steps are kept in order to see changes in information over time. How this is done is explained in the section on "topics".

TRACK

Tracks form the lowest level of information. They are the actual information recordings. Tracks show information in motion, similar to how you can have a track of video or audio in a video editing program, for example like in premier. However video does not allow for depth and the level of interactivity that tracks will allow. To give an example, at any point in time, a step can be paused and a new recording can be started adding on top of existing information. There are three types of tracks, object motion tracks, audio tracks, and drawing tracks, which each have their own features.

Object and user motion tracks

Objects and user motion tracks record the position over time of both objects and the position of the head and hands of the engineer. This allows engineers to record them manipulating objects and their own position. This forms the core of the concept. Objects that can

TOPIC

#ALIGNMENT

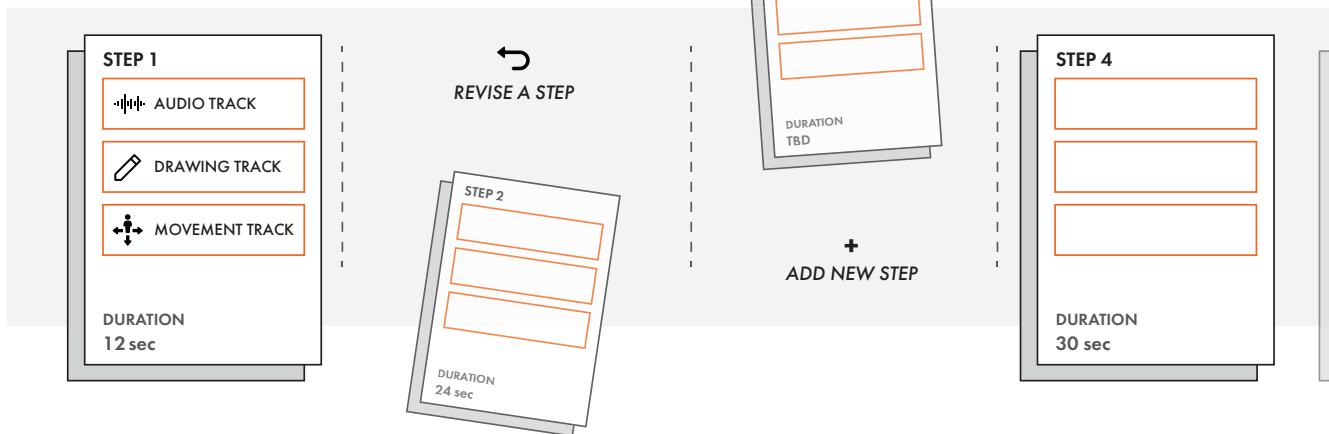


Figure 42: Topic showing multiple steps

be recorded can be anything from composite templates, to tools like knives and pieces of the mould like dams.

As mentioned earlier, the engineer is also visible in the form of an avatar when playing back. Existing of a head and 2 hands. These head and hand objects are similar to how normal objects are tracked however they can be extended upon by also recording finger positions and animate the mouth of the avatar according to loudness of the audio. The avatar is required to show what the recorder (or engineer) was doing. This makes it easy for an engineer to show importance because, for example, they can just point at stuff like they would face to face.

Audio Track

The audio track allows you to record your voice in the VR tool. This allows an engineer to explain what they are doing in Virtual Reality. Combining the visuals of VR and a voice recording enables more nuance and they work to support each other, according to Goldschmidt (2007). The audio is played back at the position of the engineer with realistic fall-off. This means an operator can hear the audio moving around with the engineer and infer the engineers position from that.

Drawing track

The drawing track allows a user to annotate and perform lay-up in the VR tool. Three different textures for drawings were thought of, each serving a different purpose. The first texture is a normal sketch texture. This is meant as a general solution, like a pencil or whiteboard marker, for annotating in 3D space. These sketches are curved, with a short distance between nodes,

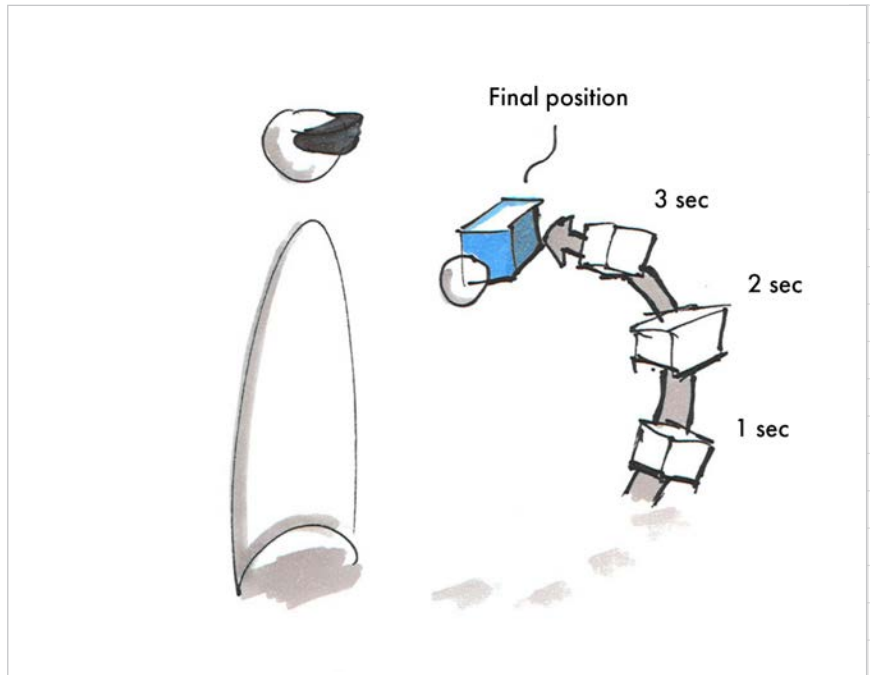


Figure 43: Project structure with multiple topics

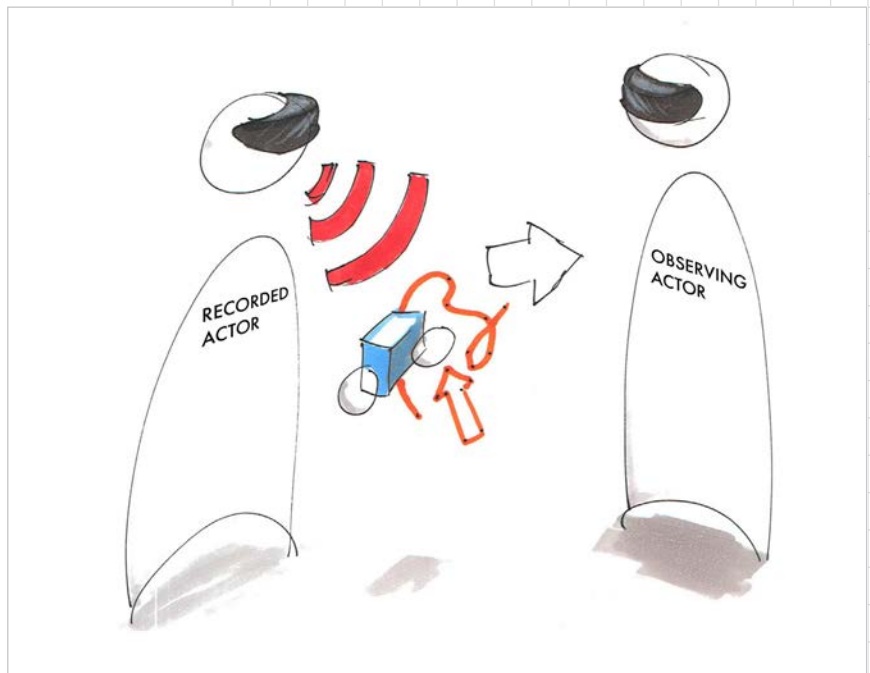


Figure 44: Project structure with multiple topics

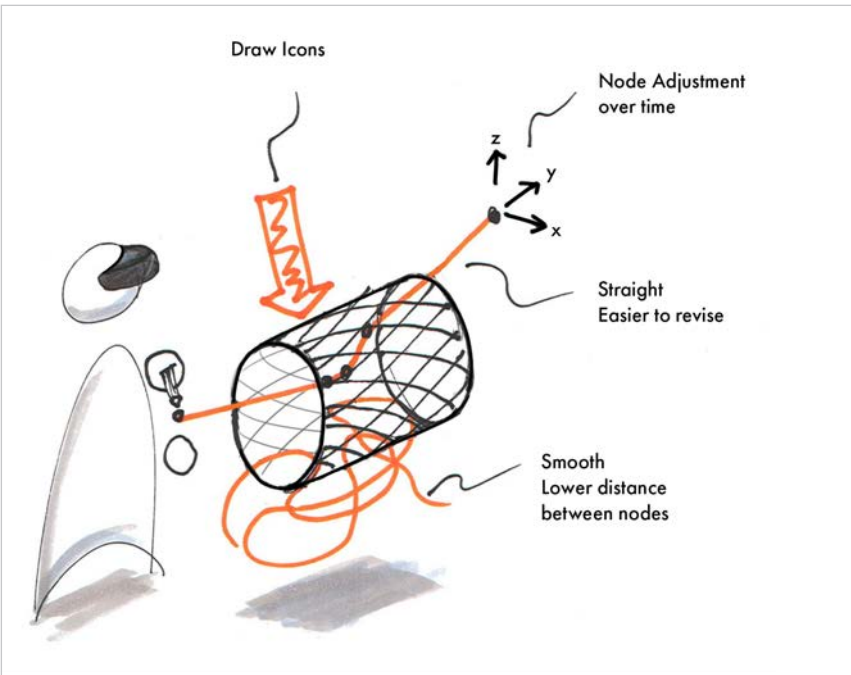


Figure 45: Project structure with multiple topics

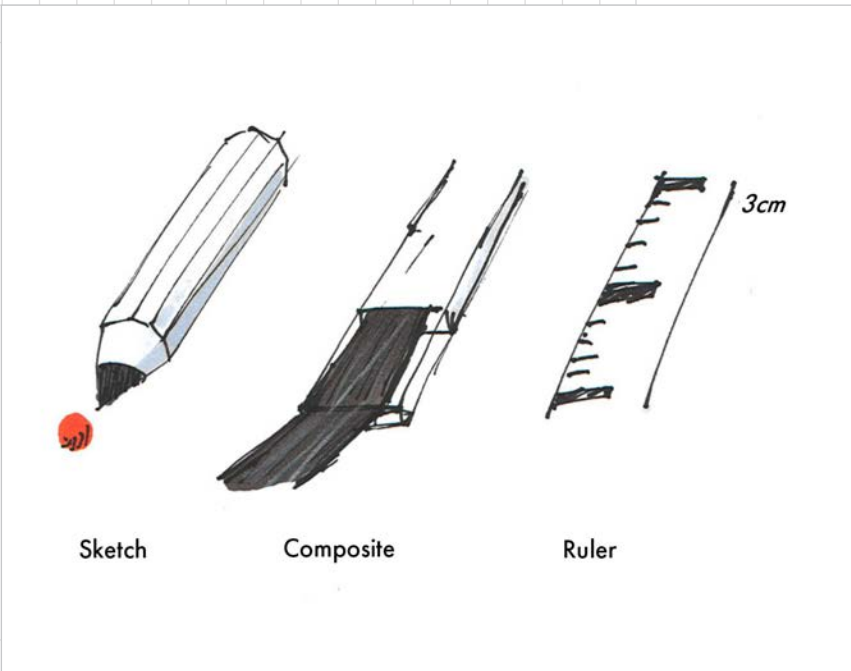


Figure 46: Project structure with multiple topics

in order to accommodate for small sketches. They can also change colour. Secondly, there is the composite texture. This will allow a user to do actual lay-up. They are flat and only curve at the nodes. Lastly, there is the ruler sketch. These are similar to composite textures but they have a ruler texture that will allow someone to indicate exact heights in a recording.

Sketches can be played back as well, fully showing how a sketch was created with all steps in between not just the end result. This was found to have a positive effect on Mental Model transfer according to Goldschmidt (2007). Adding to that, by making sketches 3D spatial positioning is inherently conveyed rather than inferred with 2D drawings. To that end the sketch lines should cast a shadow in order to improve understanding of where they exist in space and in relation to other objects.

Flexibility of tracks

The idea of explicitly naming and separating them is in order to breakdown information on a level smaller than a step. This would allow a user to for example to only delete an audio track but keep object motion data. Or first record audio then record position. Additionally, by separating everything into tracks it will be easier to add new types of tracks later to a tool. For example, particle flows or engineering data. This falls outside of the scope of the project but it is important to mention.

PROTOTYPING PLAN

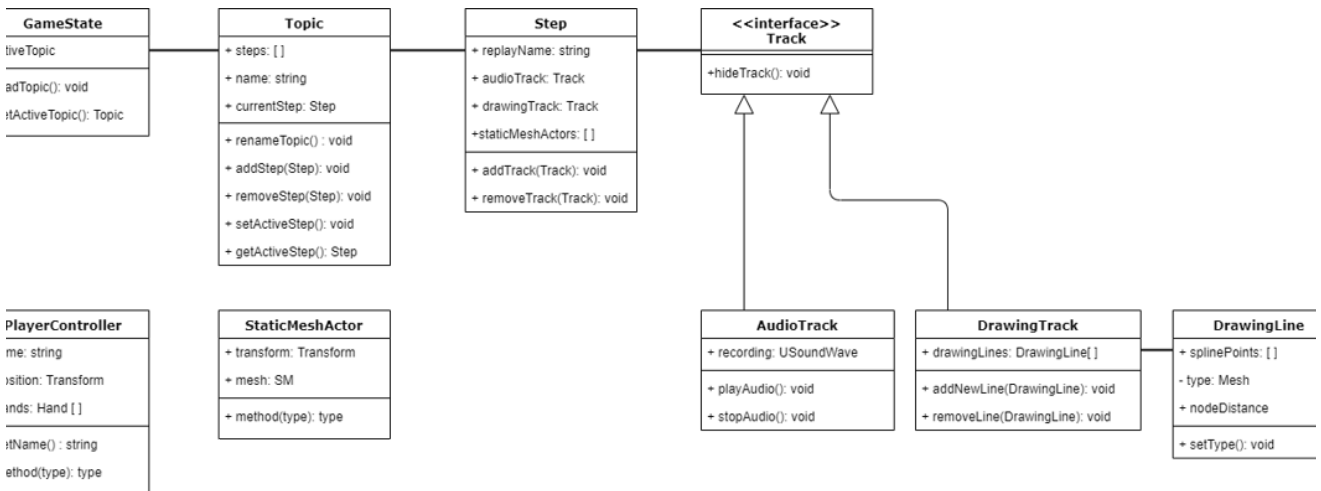


Figure 47: Initial Class flowchart

During the next steps, a prototype will be created. This prototype will be used to improve on the concept, by evaluating it using RITE, and finally to evaluate the concept as well.

The prototype will be continuously evaluated using RITE during the prototyping phase. This method will inform the changes being made to the prototype and concept during the prototyping phase. It will also give an evaluation of how usable the concept will be.

PLANNING

The planning is split up into two distinct phases. Because certain functions need to be there before they can be iterated on the first three weeks will be dedicated to creating a Minimal Viable Prototype. See Figure 47, for the class structure of those features. After those 3 weeks, a first evaluation will be done, kicking off four weeks of RITE. During which the concept is iterated based on insights from RITE.

MVP (3 WEEKS)

- Implement having multiple steps
 - Record steps
 - Delete steps (revise)
 - Playback of step
- Record voice audio
- Creating drawings
 - Start with sketching
 - Composites texture next
- Movement recording of objects
- Movement recording of user

RITE (4 WEEKS)

- Improve and expand on usability
 - For example, create a UI
- Iterate on features. More ideation is possible

RECORDING SYSTEM

For the recording system there are 2 main ways of building it in Unreal Engine 4 (UE4). There is a built-in replay system in UE4. This, in theory is the most complete option. It can in theory replicates every event call which makes for a system that can easily be expanded. However, it

does this by using network replication which requires the usage of C++. The researcher has limited knowledge of C++ and networking.

The second option is to write object location to a CSV or .TXT file. This is a simple, understandable, and achievable method of achieving recording functionality, requiring little C++. However, every object that you want to record requires extra code written thus it can be hard to expand. Considering it is a prototype it might be the quickest way to go.

HEADSET AND TOOLS

The prototype will be built using the most recent, as of time of writing, of Unreal Engine 4 (4.24). It will be built for one headset, namely the Oculus Quest using the Link cable. The Oculus Quest was chosen for its portability due to inside out tracking and versatility as it can both be used standalone as well as with a pc.

EVALUATION PLANS

Two types of evaluation will be done. One to evaluate the concept during prototyping, the other to evaluate the final concept and prototype. In this chapter, the methodology for both will be described in their respective chapters. RITE is chapter 5 and the final evaluation methodology is in chapter 7.

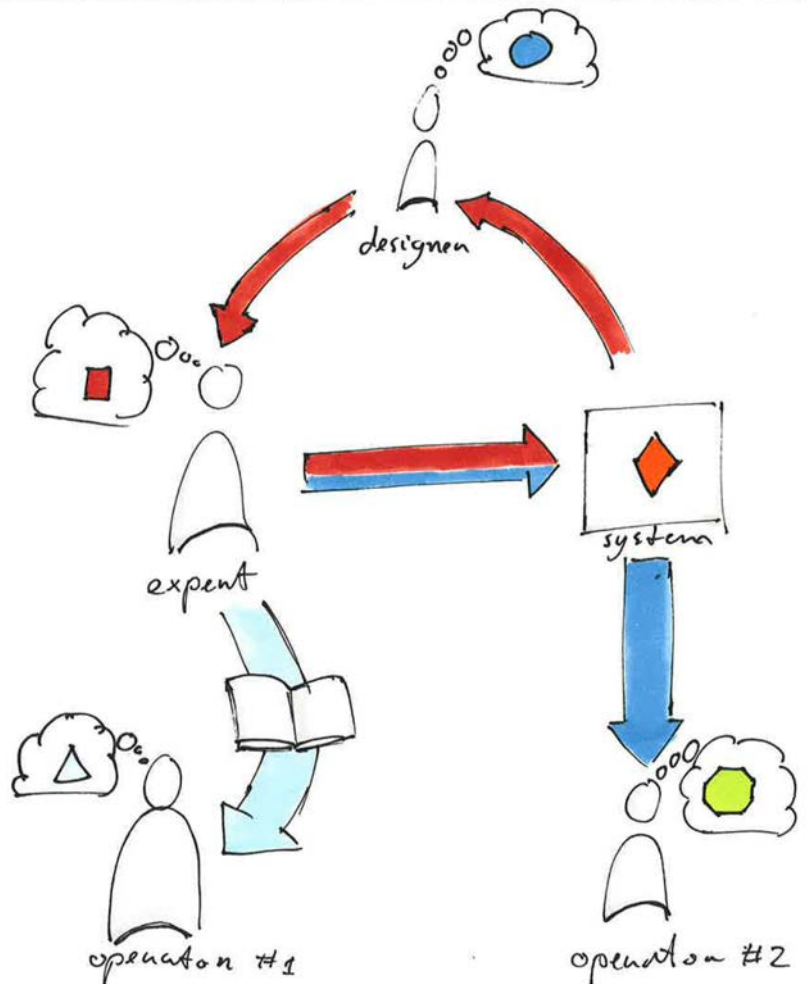
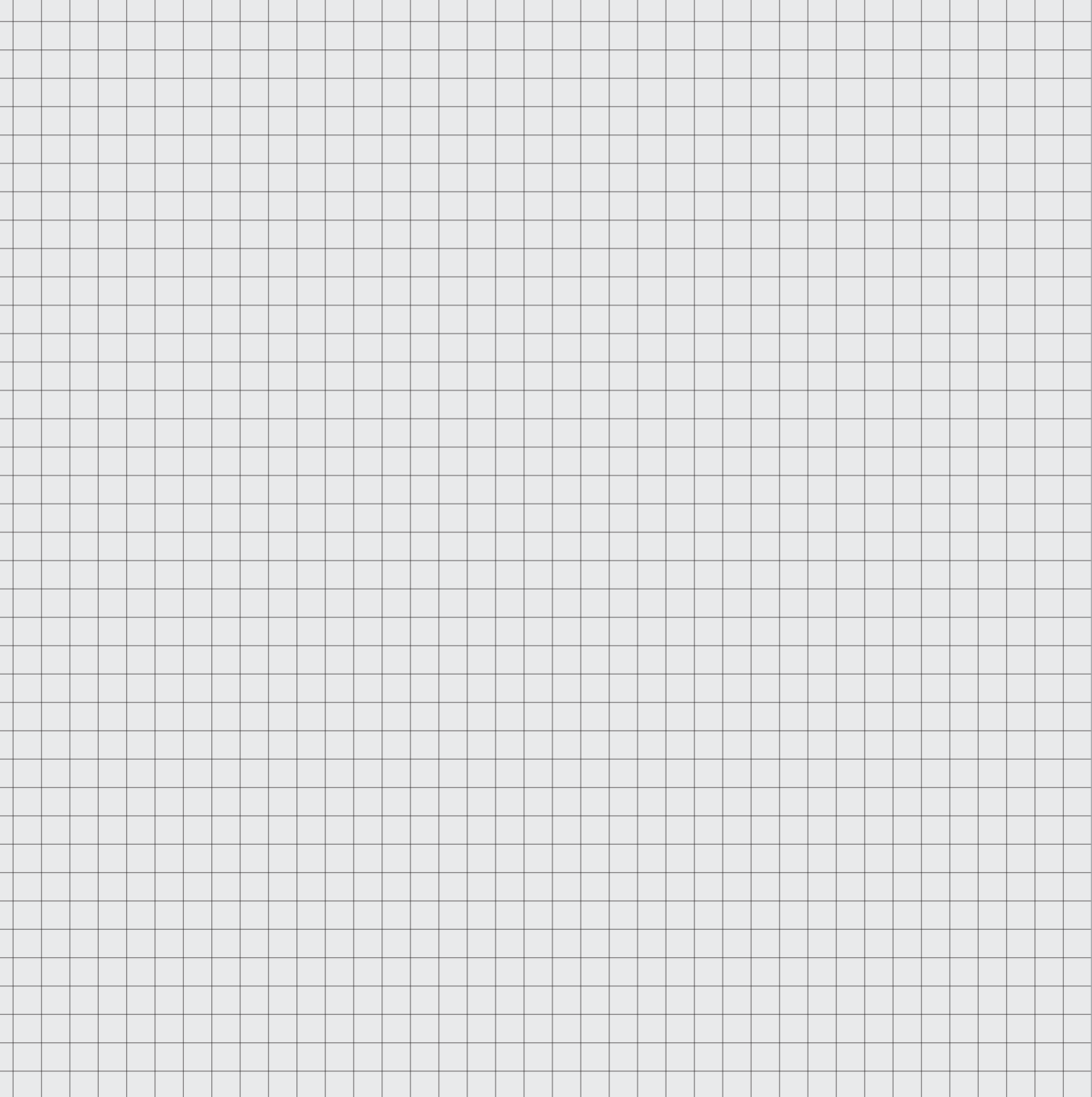
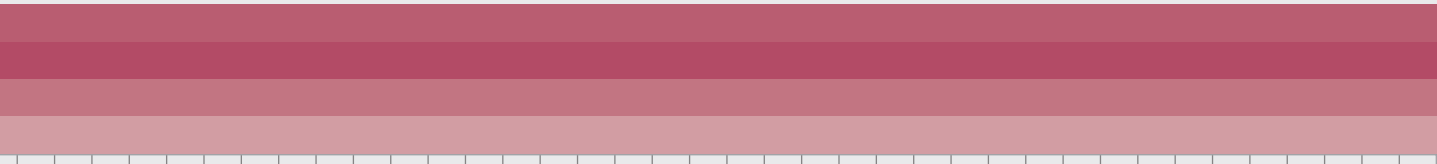
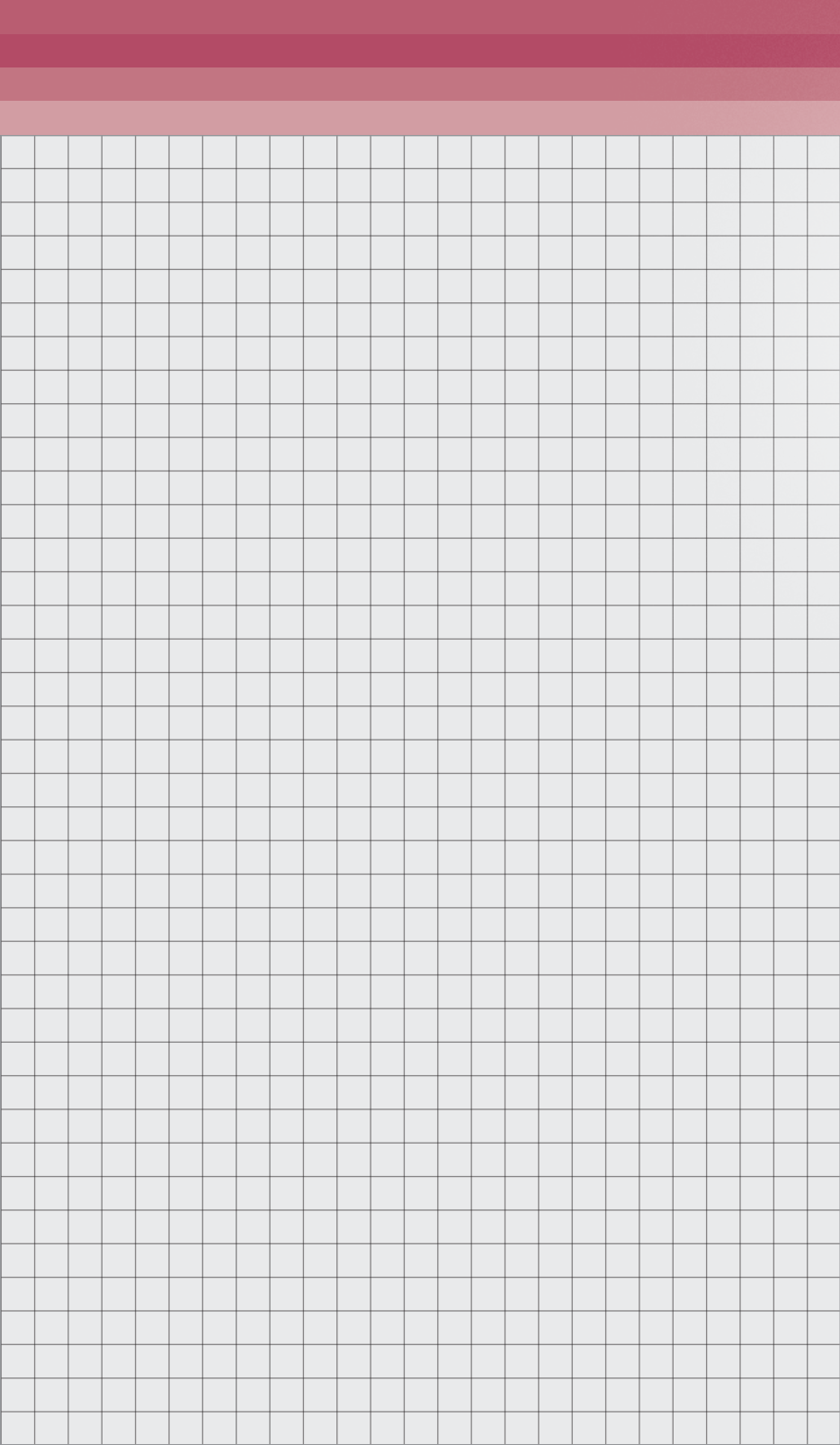


Figure 48: Evaluation diagram





This chapter will focus on the prototyping process using the Rapid Iterative Testing and Evaluation Method (RITE). First the RITE methodology is explained then the prototyping process is documented. Finally the prototyping process is evaluated and discussed using the results from RITE.

RITE METHODOLOGY

THE RITE METHOD

The Rapid Iterative Testing and Evaluation (RITE) method is a method created at Microsoft Game Studios by Medlock et al. in 2002. It is a method to iterate on a prototype while continuously evaluating the performance of the prototype.

RESEARCH GOALS

RITE has two main research goals. The first goal of RITE is to evaluate the usability of the current prototype and concept and improve on it in the next several weeks. By investigating the usability with users, it will provide insight into flaws into the concept that can then be iterated upon. That iteration can then be evaluated again to see if it is an improvement and why.

The second goal is to evaluate whether or not engineers can convey a Mental Model correctly to others using the VR tool. This is the red arrow loop in Figure 49. The engineer (or expert) will put their Mental Model in the system, the designer will watch it back and then try and explain it back to the engineer. By categorising what was understood correctly and what was not it can be understood where the system is performing well or not.

PARTICIPANTS

The participants will be the composite production expert group, or the target group. They exist of three different users so they will be asked to participate multiple times. This meant that there is a potential for the users to

improve performance through learning. This will be prevented by not requiring the users to test the same feature twice without significant changes.

ACTIVITIES

Every time an iteration is done the research will consist of several activities. Before starting the research the participant is asked to think of a process, related to composites, that they are working on to explain.

FAMILIARISATION

At the start of the research, the participant will be given sometime to familiarise themselves with the VR tool. The maximum learning curve as stated in the requirement should be no longer than 10 minutes, as such that is the maximum amount of time. During this familiarisation process they will not be given instructions. This is to simulate a real world scenario more closely.

USER EXPLANATION

After familiarising themselves with the prototype, they will be asked to explain their chosen process in VR. During this time the researcher will be observing their perspective on the screen.

OBSERVING

When they are done the researcher will observe their explanation in the VR tool and then try and explain it back to them. The participant will then be able to correct where someone went wrong and if important points were missed. These will be noted down for later categorisation.

These questions are followed up by a set of questions about the usability of the tool, see Appendix 06 on page 150, and finally a QUESI questionnaire to get objective data, see Appendix 07 on page 151.

DATA COLLECTION

In the case of Medlock et al (2002) the performance was defined as a the ability of users to successfully complete tasks. That requires writing down tasks to complete. During this RITE session the tasks might change. So, in order to evaluate every iteration equally the performance will be measured using the QUESI questionnaire. This will evaluate system performance while allowing for more creative use

In summary, data will be collected using 2 methods. A standardised QUESI questionnaire (Self-reported), see Appendix 07 on page 151, and a set of questions about usability and their experience was used. See Appendix 06 on page 150. These questions will be influenced based on observations.

DATA ANALYSIS

The data will be analysed using 2 methods. QUESI will show improvements being made to the prototype over time. The results will be interpreted using the method outlined by Naumann and Hurtienne (2010). The usability questions will be used in order to make improvements to the prototype. The changes and their reasoning, will be described in section "Prototyping Steps".

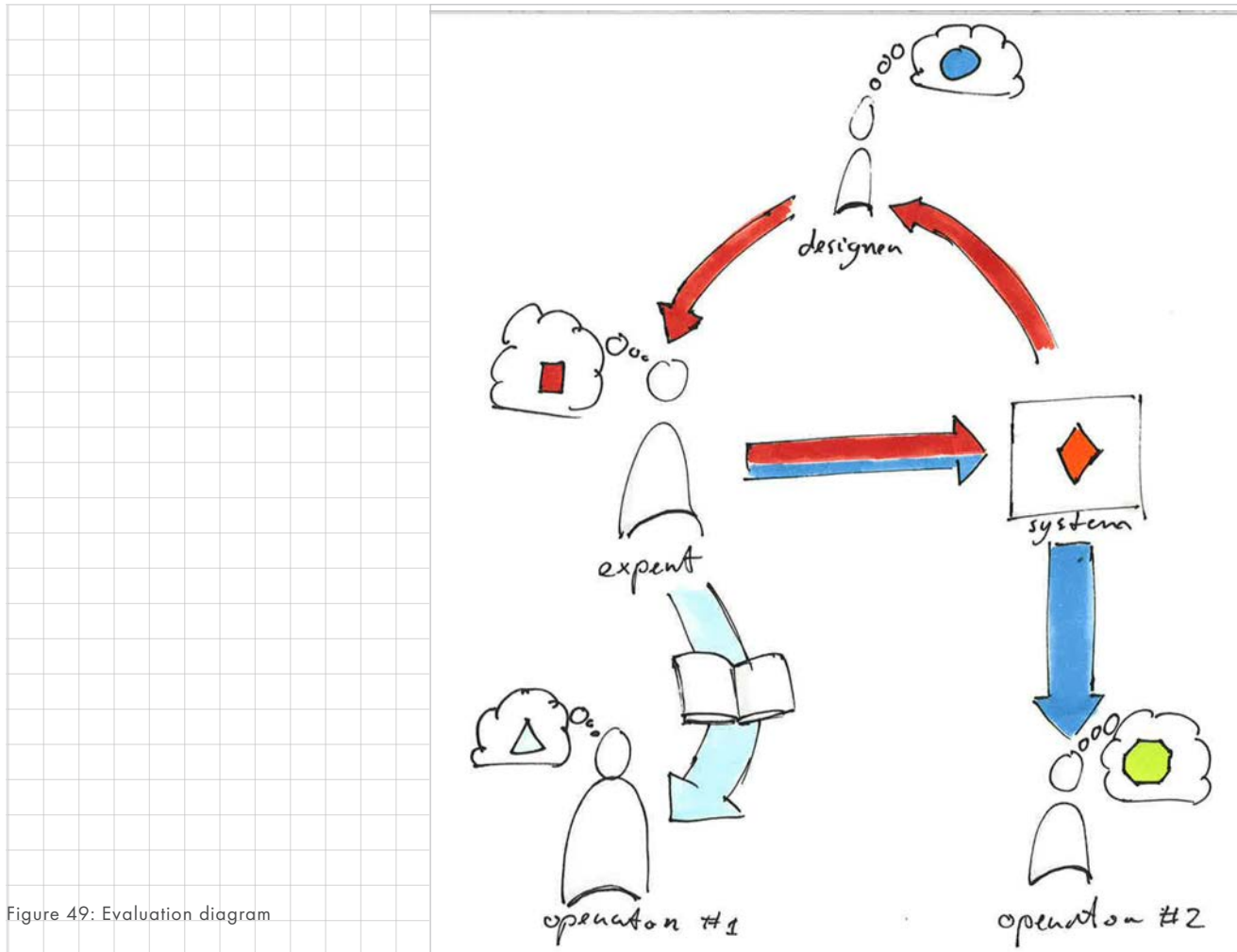


Figure 49: Evaluation diagram

PROTOTYPING STEPS

A list of changes during the RITE prototyping phase was kept. These changes are shown in this chapter. For a full explanation of every decision, see Appendix 09 on page 154.



Figure 50:
Drawing playback
functionality in first
MVP

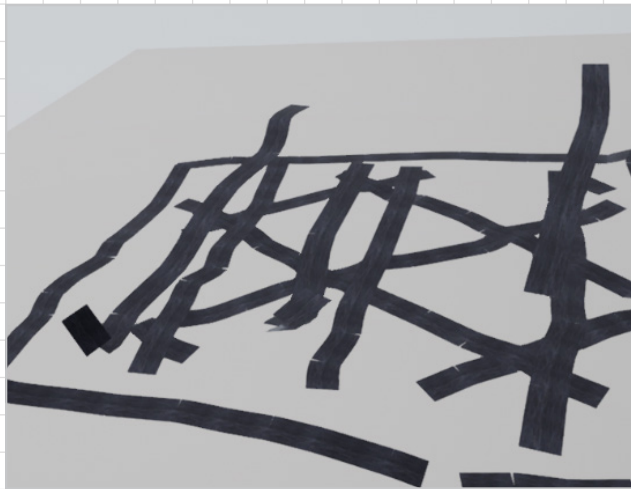


Figure 51:
Sketches made
of template by
participant during
evaluation of the
MVP

MINIMAL VIABLE PROTOTYPE

For the MVP the goal was to implement basic functionality to get to a testable state. This took roughly 3 weeks as planned.

FUNCTIONS IMPLEMENTED

- Object position recording and playback was added. Including user head and hand position recording
- Audio can be recorded and played but not paused.
- Drawing functionality was added. Users can use the controllers to draw 3d geometry. The position of this drawing can be recorded too, so that it can move.
- Step functionality like adding, skipping and play/pausing steps is also there but it is controlled with debug keys.
- Persistent save games are added keeping recordings between sessions.
- A skybox was made that responds to the state.

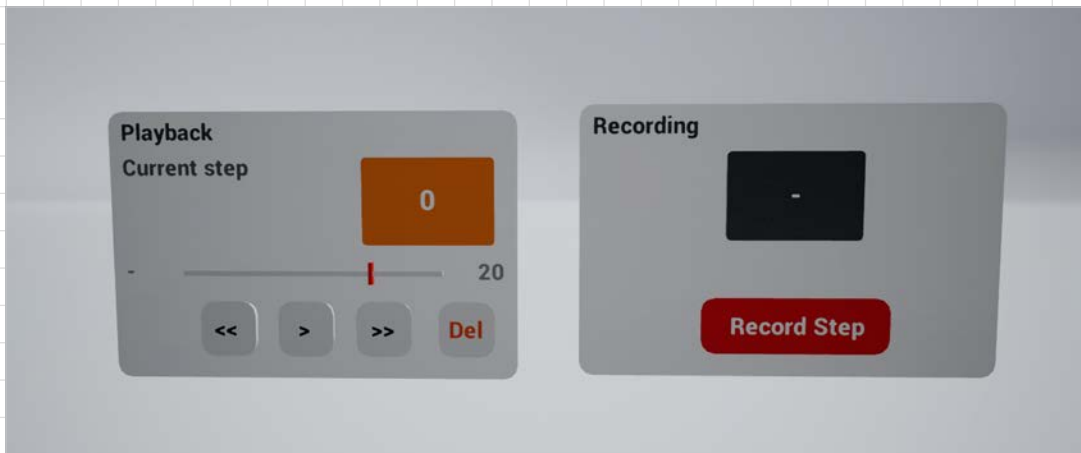


Figure 52:
Recording and
playback menus
implementation,
iteration 1



Figure 53: Drawing tool UI

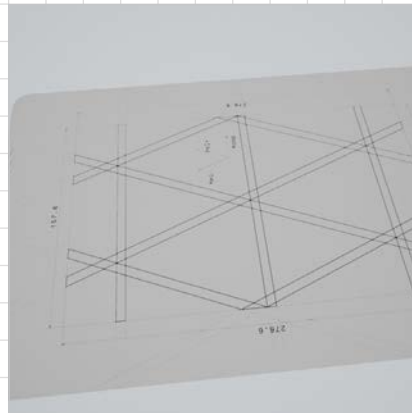


Figure 54: Working surface for lay-up

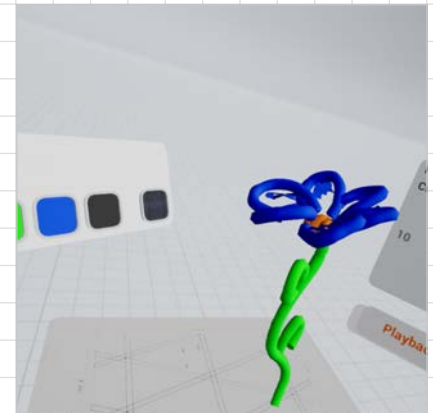


Figure 55: Drawing made by participant

ITERATION 1

For the first iteration the goal was to address the lack of UI in the prototype to improve usability. None of the functions were discoverable at this point. This iteration took about a week.

CHANGES MADE

- Recording and playback UI added. Consisting of a panel that would switch between modes (Figure 52)
- Reusable Template Buttons
- Drawing tools are no longer attached to the hands and a first draft of the UI is added (Figure 53)
- A first moveable working surface (Figure 54)
- Visual grid on the environment to help the user orientate

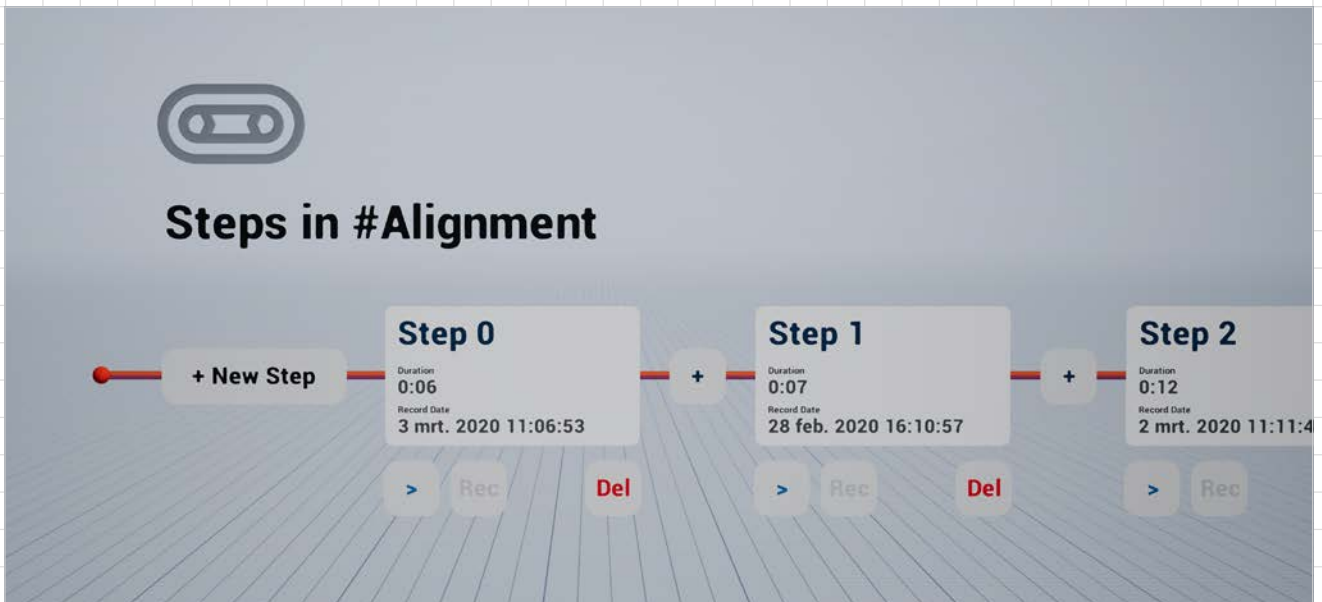


Figure 56:
Timeline interface

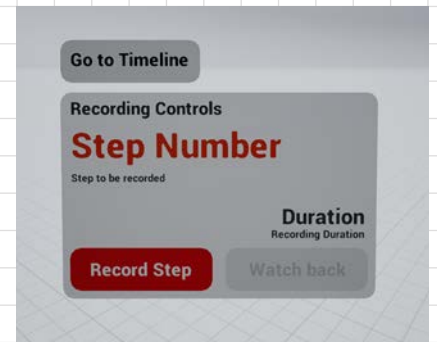


Figure 57: Updated
recording interface

ITERATION 2

From the previous iteration it was noticed that users often felt lost where they were in the system. This iteration focussed on the timeline idea to improve clarity. The timeline made the act of choosing a step much more intentional.

FUNCTIONS IMPLEMENTED

- Added the timeline
- Changed the recording UI to no longer easily switch between modes. Instead a back button was added.
- Large emphasis on the current step was added with labels for every item. Making it a lot clearer to users where they are in the step.
- Logo for the recording tool was made.
- Buttons will no longer press when a user moves using the joysticks. This prevents the user accidentally pressing buttons while moving backwards.

Figure 58: Model browser

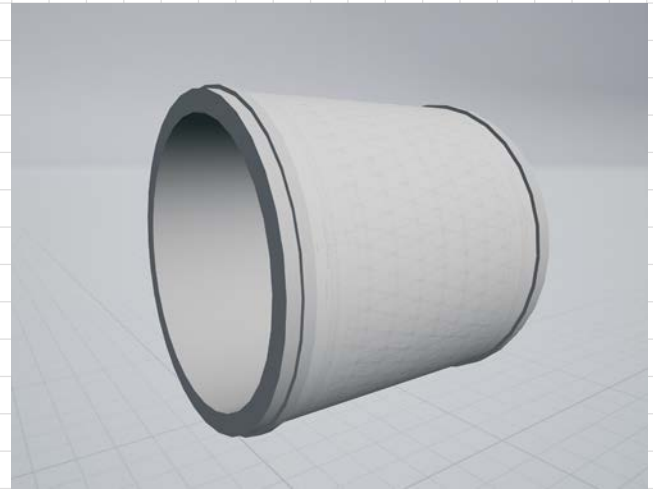
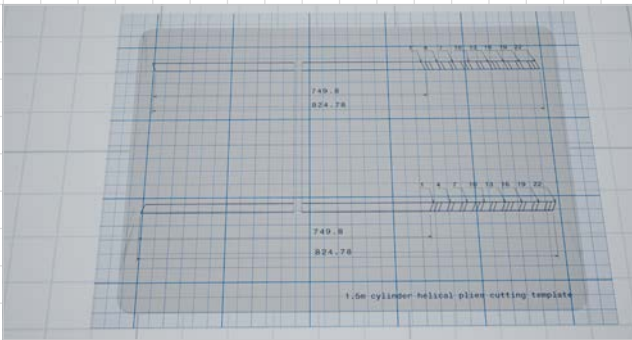
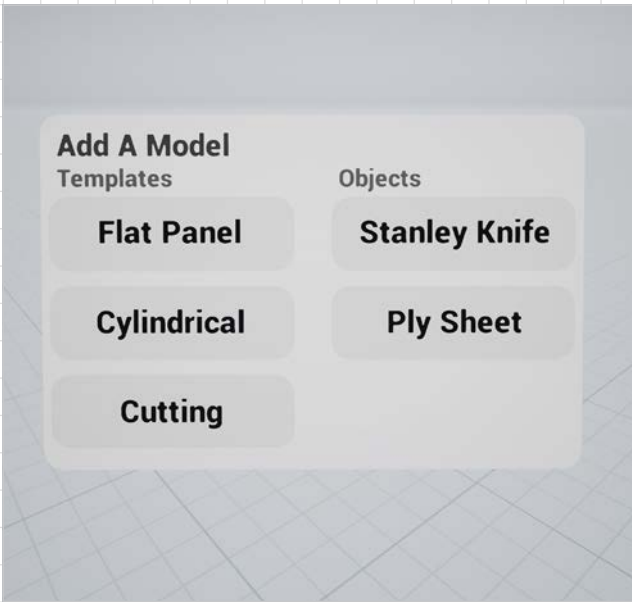


Figure 59: Alignment sheet on top of cutting template

Figure 60: Cylindrical Template

ITERATION 3

The timeline had tested well in the previous iterations therefore the focus came back on the lay-up tools. The goal was to provide the right tools needed for lay-up and also improve the drawing quality. This iteration was already smaller than the previous but it did have many small changes meaning it still took quite some time.

CHANGES MADE

- Alignment sheet
Participants often had trouble to draw a flat composite making it harder to proper lay-up. This tool helps them draw flat composites.
- Two Lay-up templates were added, a cylindrical template and a flat template.
- Cutting template. With an alignment sheet on top of it in order to draw flatter composites.
- A ply sheet, this is the sheet that is used during lay-up to keep track of layers done.
- A Stanley knife model added
- Hiding of irrelevant ui during playback to help users focus.
- Objects that are added later in a recording now only become visible during playback at the time they were added.
- Fixed locomotion orientation issue
- Removed the teleportation option as it lead to confusion
- Runs standalone on Quest

Figure 61: Model browser with models

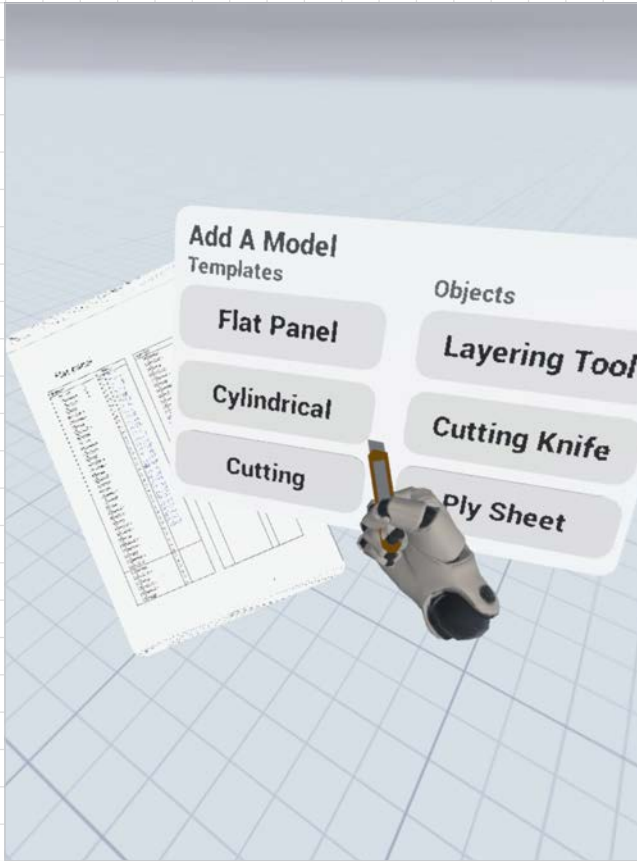
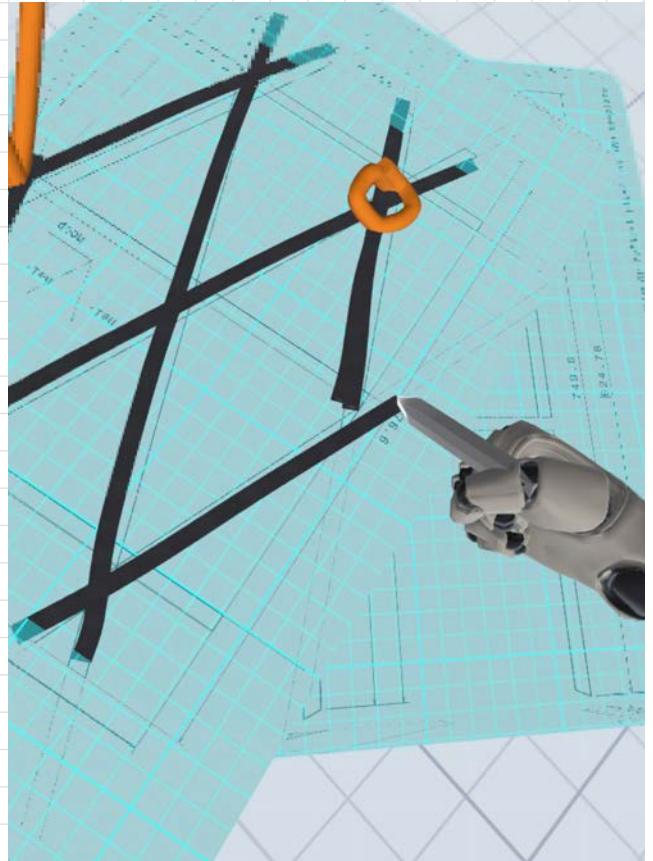


Figure 62: Drawing on alignment sheet



ITERATION 4

This was the last iteration during which mostly small changes were made.

CHANGES MADE

- The alignment sheet was separated from the drawing templates and already drawn composites can be snapped to it. This makes it easy to make a layer of composites.
- Composites highlight when they can be grabbed making it easier to see what you are picking up.
- Heads and hands are now automatically added to a scene which means they are recorded.

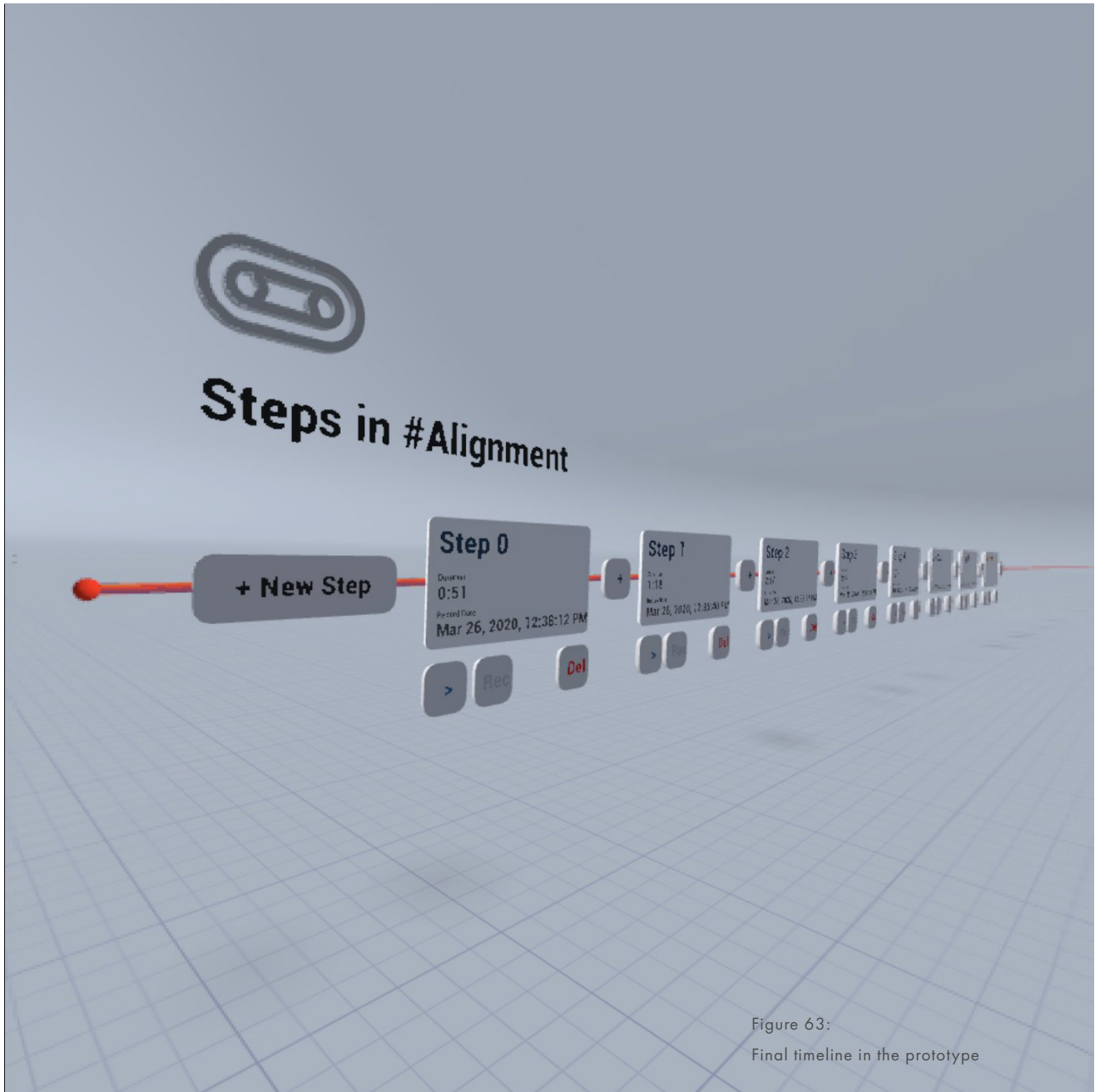


Figure 63:
Final timeline in the prototype

FINAL PROTOTYPE

Figure 63 on page 85 shows the timeline as it exists in the final prototype. All the steps are displayed in line and can be played, recorded and deleted. In addition, new empty steps can be added with the plus button. There exists both a sketch and a composite pen which can both be recoloured using the toolbox tablet.

As can be seen in Figure 64 on page 86. Multiple models can be added to help with the lay-up. Including 2 lay-up templates and a special layering tool, also known as alignment sheet. All models, tools and menus in Figure 65 on page 86 can be moved to help the user create their own workspace.

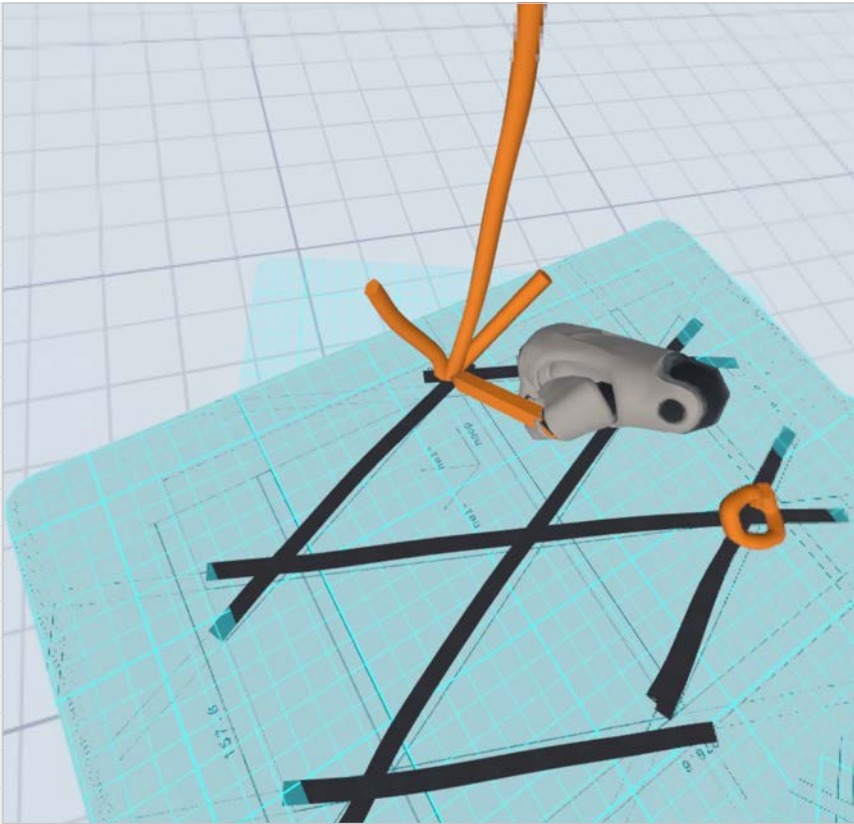


Figure 64: Sketching over composite lay-up

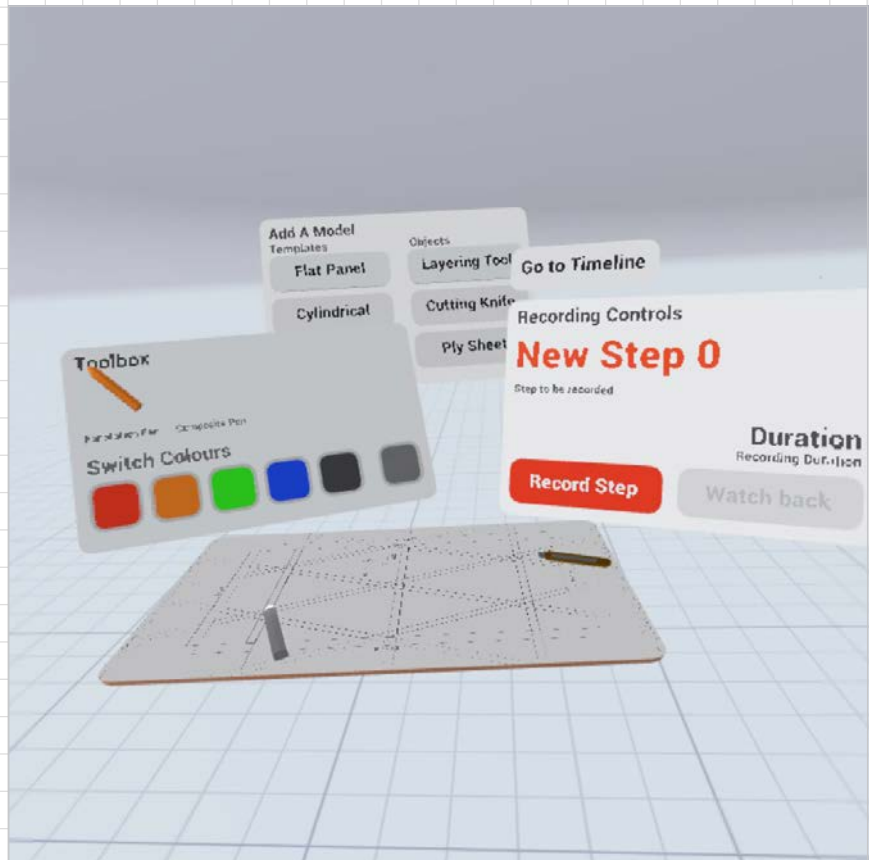
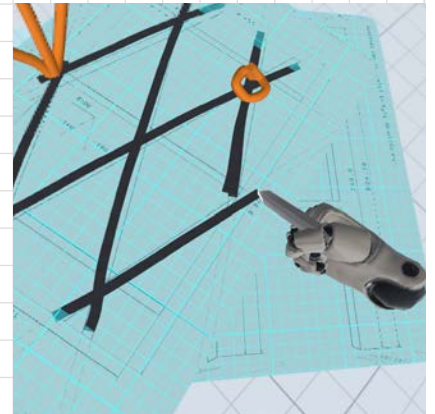


Figure 65: Movable Controls and models

PROTOTYPING IMPLEMENTATION

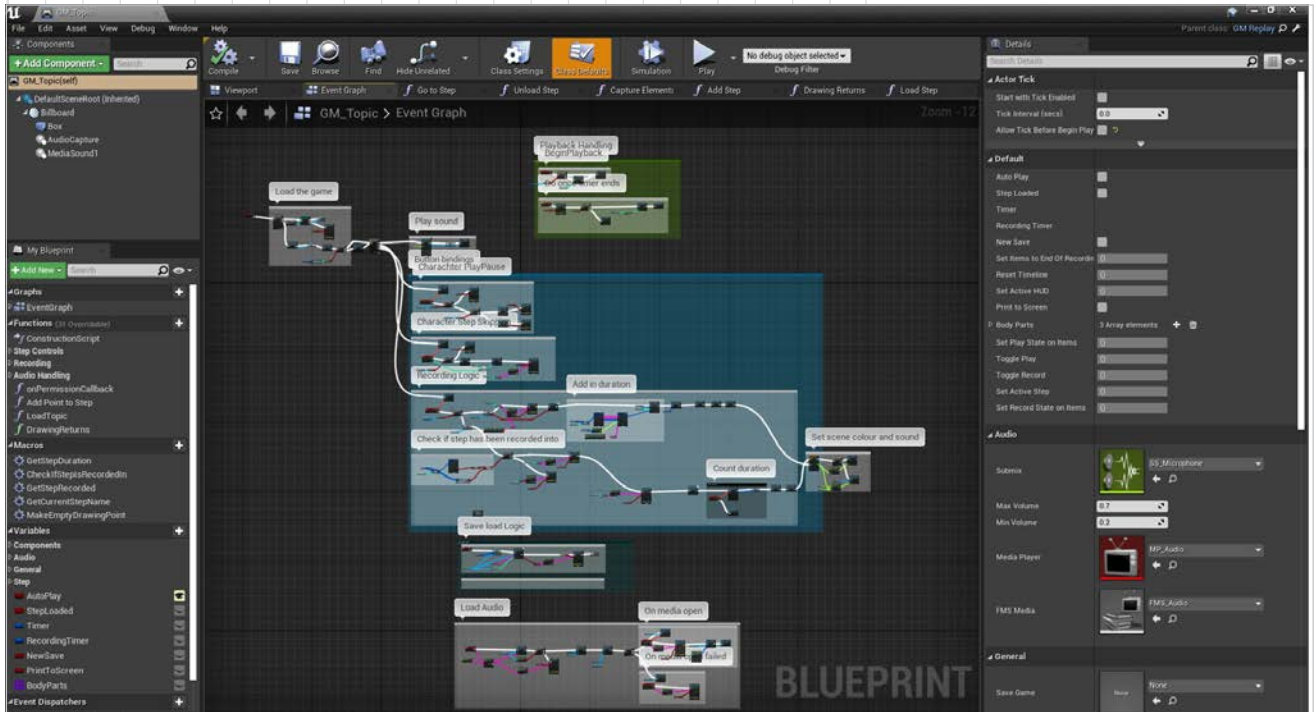


Figure 66: Sample of blueprint code from GameMode.Topic to add a step

The implementation of the prototype will be briefly discussed. As mentioned earlier in the report there were two main approaches to implementing a replay system.

1. Use the built-in Unreal Engine 4 (UE4) Replay system
2. Write a function that loads and saves text to .TXT files

The first 2 days of the prototyping exercise were used to explore these 2 methods. Unfortunately, the documentation on the Unreal Engine Replay System is fairly limited or outdated and it requires writing more complex C++ to expose the functionality to blueprints. Therefore it was decided to go with the second option.

The majority of programming was done in blueprints (BP) in UE4, which is a proprietary graphical programming language within UE4. It emulates and ultimately also compiles to blueprints. Two main classes were written in BP; the `ReplayObject` and the `GameMode.Topic` and four C++ functions which load and write to .TXT files were written.

LOADING AND WRITING .TXT FILES

Four functions were written in C++.. These functions make it possible to load and write a single string or an array of strings to .TXT files on the system. This is very useful to save for example transforms or other data that changes over time with a fixed interval.

These functions could be called on in blueprints. The loading function asked for a file path and outputted the transforms saved in the file to an array of strings. The writing function asks for a file path and a string to save and outputs this to a string.

One difficulty encountered is getting a useful file path on both the Quest and Windows. They use a different project root. UE4 has a function that outputs the project directory, by getting the root of the project directory the problem was resolved and the files were saved neatly on both Windows and Quest.

REPLAYOBJECT

A ReplayObject is the base class that contains all the recording and playback functionality. It calls the functions to both write and load TXT files from memory. Additionally, it has a mesh and material that are intended to be overwritten by child components.

When recording, a replayObject stores its current transform (location, rotation, scale) in an array at a fixed interval of .10 seconds. This array is then converted to a string where values are separated by a comma and each index is a new line. This can then be stored in a text file using the writing functions.

When playing back it first loads in this list of transforms from a file into a new array then it linearly interpolates (LERP) between the transforms to have the motion appear smoother.

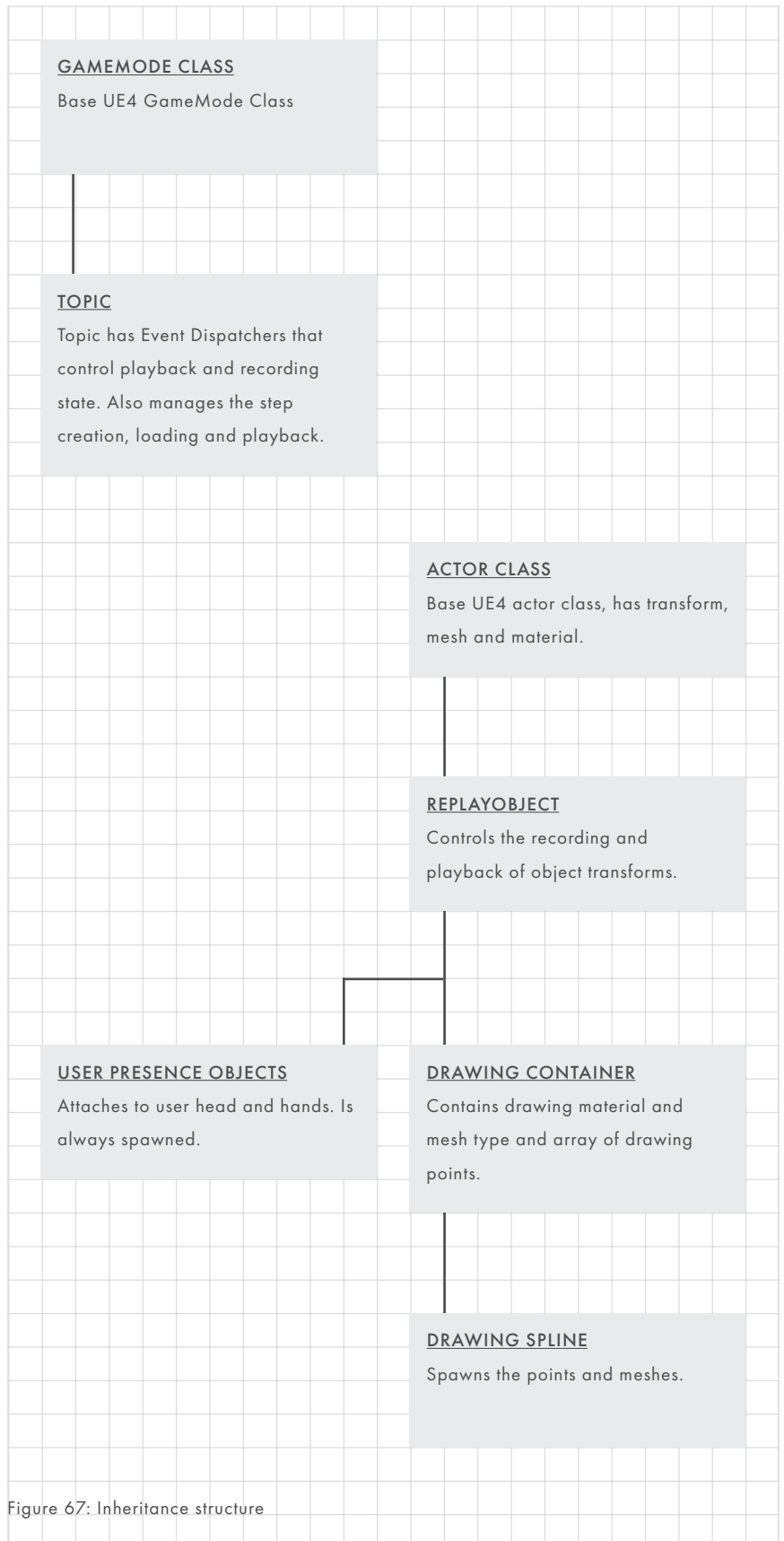


Figure 67: Inheritance structure

GAMEMODE TOPIC

The GameMode in Unreal Engine defines the rules of a game and handles most of the logic that is not for a specific actor.

Every actor has a convenient reference and is told to listen to events fired from this class. For example, an object with a reference to the GameMode, like the play button, can call the function SetPlayStateltems in the GameMode to which all ReplayObjects listen. This would start the playback on the replayObjects. This is the backbone of the project and it handles all step functionality. Including saving, loading, playing, skipping and deleting and the audio recording.

SAVING THE STEPS

When loading in a step we need a reference to the save location of the files. To keep this reference we keep information about the steps and ReplayObjects in Structs. The step struct keeps an array of ReplayObject Structs for each step, a reference to a wav file and the duration of the step. The ReplayObject struct keeps a reference to the folder, the mesh of an object, time of creation, and a reference to the material. The structs can be easily saved in a single array on the Topic GameMode. That single variable can then be saved to a UE4 SaveFile. Which keeps the array persistent between sessions.

The question remains, why do we not save the transforms in an array as well. By saving the transform in a TXT file it is easier for prototyping and export. With some additional work, a step could be zipped up and send to a different user.

LOADING THE STEPS

By opening up the aforementioned structs we can essentially recreate an object as it was. We have its mesh, material and position over time from the files. We only have to populate the steps variable in the GameMode topic from the SaveFile and then load in a step.

AUDIO RECORDING

AudioCapture component

The AudioCapture component is a relatively new component in UE4 that allows a user to record audio from the microphone to a wav file. This wav file is saved to the step folder.

Unfortunately, there are two issues with the AudioCapture component. On the Oculus Quest, it did not seem to work when outputting to bus-only and secondly using Oculus Link to run the app on Windows does not support using the microphone yet. This is a known issue and will be fixed.

Playback

Loading in the WAV file at runtime proved to be a difficult problem to solve. Fortunately, the MediaPlayer component allows you to stream in files from servers and thus also local files. This allows for playback, play, pause and skipping of the tracks. Additionally, the file is also played at the recorders head giving the sound the impression of spatiality and directionality.

DRAWING CONTAINER

The drawing container class is a child of the ReplayObject class which has a couple of unique elements. It contains a spline component, which draws a line of spline meshes between the drawing points. When a drawing tool is held and activated a drawing container is created with an initial drawing point at the local 0,0,0. If the distance between points is greater than the variable between points a new point is added. A spline mesh between the two points is then drawn. There are two types of spline meshes, flat mesh, the composite and a round mesh, the sketch. Different materials can be assigned on a drawing panel, which sets the material of a tool on collision.

The drawing points are saved in their .TXT file with the same name as the drawing container but with a postfix

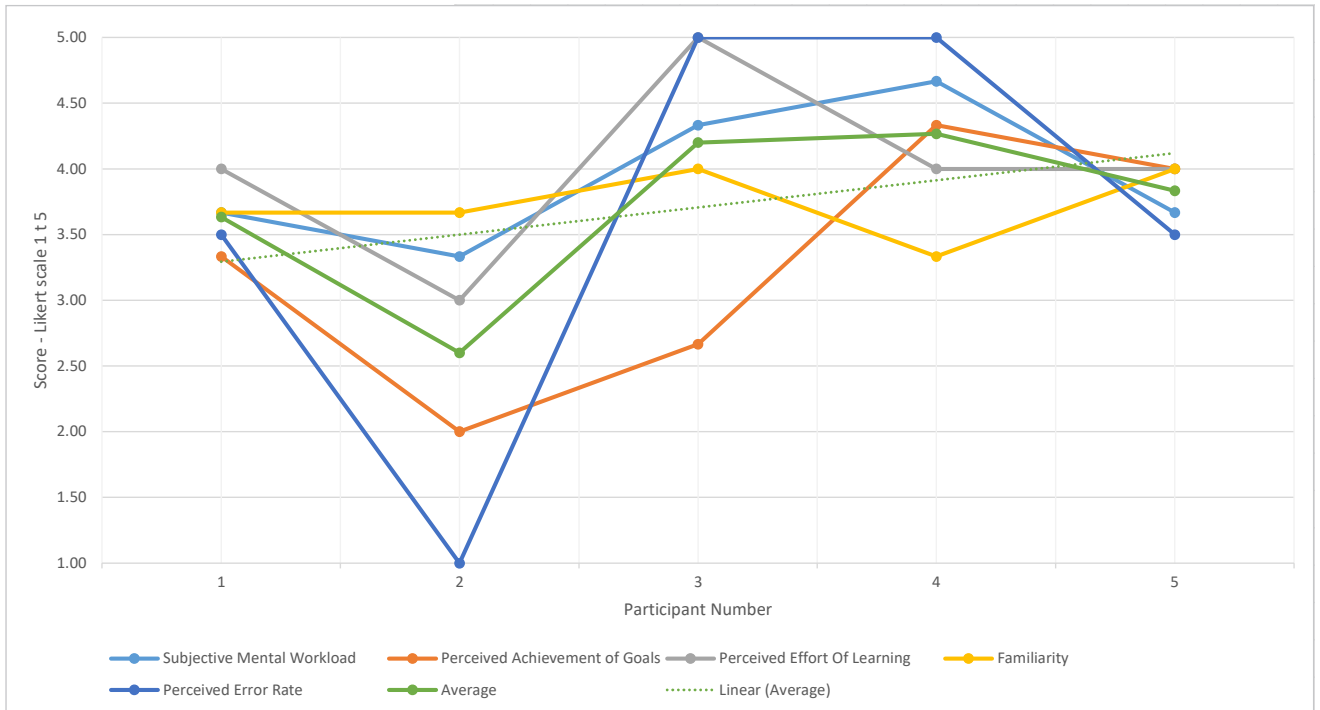
The drawing points listen to the activate tool function from the user's hands. This means the tool will not activate if it is not held and the hands can interface with multiple tools.

USER PRESENCE OBJECTS

User presence objects are children from the ReplayObject class. They have special functionality in that they must always be present and a check is built-in to the creating a new step function in the topic to ensure that they are.

They attach to the user's hand and head when recording. This is how they record the position of the user. Then they can also be used to playback that position.

QUANTITATIVE RESULTS



A positive trend line can be seen in the average results of the QUESI Questionnaire, see Figure 69. However, we cannot draw any conclusions from this dataset with this few iterations. The reason for this can be seen in Figure 68. The results are very distributed due to participants interpretation. This is even more visible in Figure 108 in Appendix 12 on page 168, where every question is plotted individually. Combining this with the qualitative feedback we do see the improvement mentioned by participants reflected in the average QUESI score. In addition, the amount of qualitative feedback became less over time as less breaking points or issues were found. This again is supported by the trend line in Figure 69 on page 90.

Figure 68: Results for each category of RITE for every iteration.

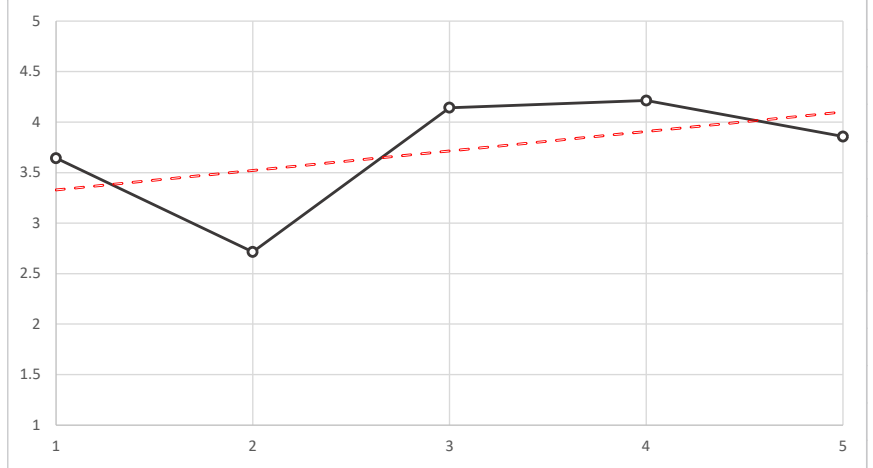


Figure 69: Average QUESI Score for each iteration (trend-line in red)

CONCLUSION OF RITE

QUESI INTERPRETATION

There is a rising trend-line for the usability of the prototype. However, the QUESI questionnaire was found to be interpreted differently by different participants. For example, the first and last participant rarely gave anything different than a 3 or 4. In contrast to participant 2 and 3 who used the entire range, as seen in Figure 68. In combination with a low amount of RITE iterations this makes the validity of the dataset questionable and therefore it's hard to draw conclusions from this dataset alone. Fortunately, there was a high amount of qualitative feedback that proved invaluable during RITE.

LONG ITERATIONS

The iterations were in general longer than planned, sometimes taking a week. It would have been possible to achieve more iterations was the recording functionality not built, due to its complexity. To give an example, the drawing functionality was by far the most complex thing to code. Not only did the code for spawning spline points need to be written they also needed to be added into a set of replay points dynamically, while the other replay points were already recording. There were many more challenges with the drawing. This reduced the ability to rapidly prototype so iterations became longer.

This did have a negative affect on the quality of the prototype. For example, the drawing of splines always lags

slightly behind the pencil tip because it was too costly to update the position of a spline point rapidly. Fortunately most of these issues, do not form, a usability issue and can be fixed in the future.

REQUIREMENTS MET

The RITE exercise is considered a success as the primary goal of improving the usability was met. Through lots of qualitative feedback lead to a greatly improved the design and actual changes in direction. For example, the emphasis on understanding where you are in the system which was achieved by the design of the timeline. In addition, users indicated that actual usability had improved more significantly then the numbers reflected. The quantitative results also show that any improvements are expected to continue if RITE would be continued.

PROTOTYPING RECOMMENDATIONS

There are a couple recommendations for future development based on the conclusions from RITE.

The colliders on the drawings are very rough currently and need to be dynamically generated to more accurately reflect the shape of the drawing.

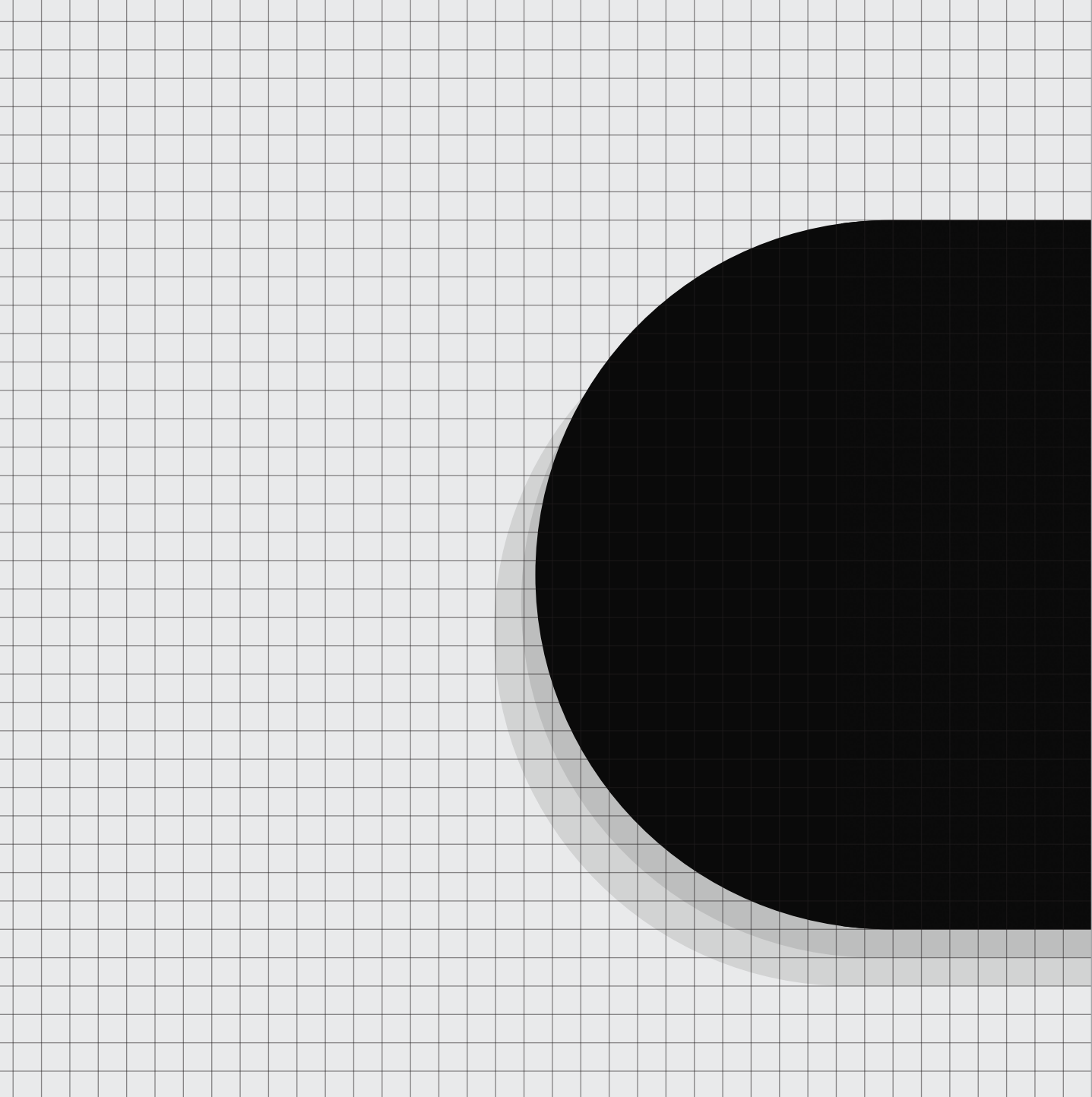
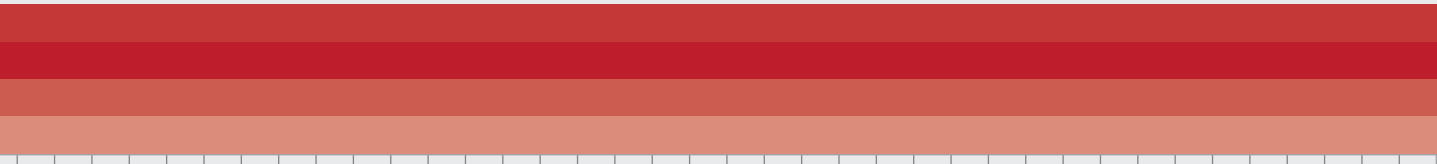
It could be beneficial to have a method that draws straight composites between points. This allows users to create accurate representations of composites.

However, it is argued that not having perfectly straight lines does not form a communication barrier. Users will be able to understand the more rough sketches just as well. It would mostly be a nice to have which makes the tool easier to use and more aesthetically pleasing.

Finally, the timeline is now linear. Ideally we would be able to branch out the timeline. There is also an issue of step numbers not communicating enough about the content of the step. Even though the recorder understands in which step they are it might still be hard to remember which step they should find exactly later on. This can be resolved by adding a title and a graphic of the last frame of the recording.

RECOMMENDATIONS

The recommendation for future research would be to use a different questionnaire when doing RITE and to ensure there is enough time to make many large iterations or that the iterations can be small.



In this chapter, the final prototype and concept will be described. The features will be listed and a customer journey is presented.





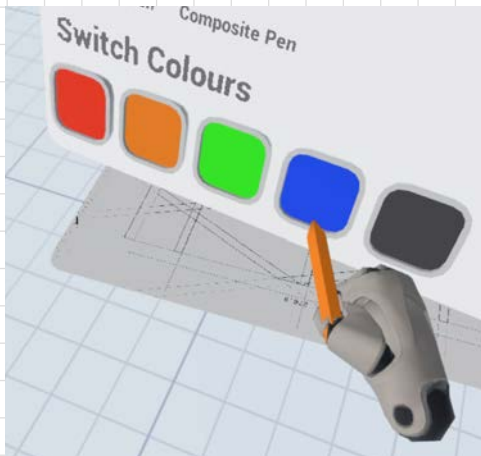
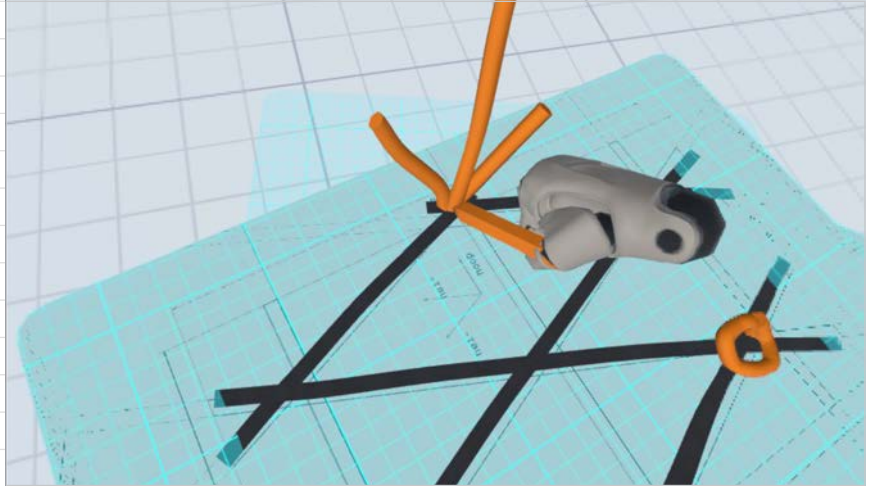
VR LAY-UP RECORDER

Record anything. Send it anywhere. Watch it anytime.

MADE FOR LAY-UP

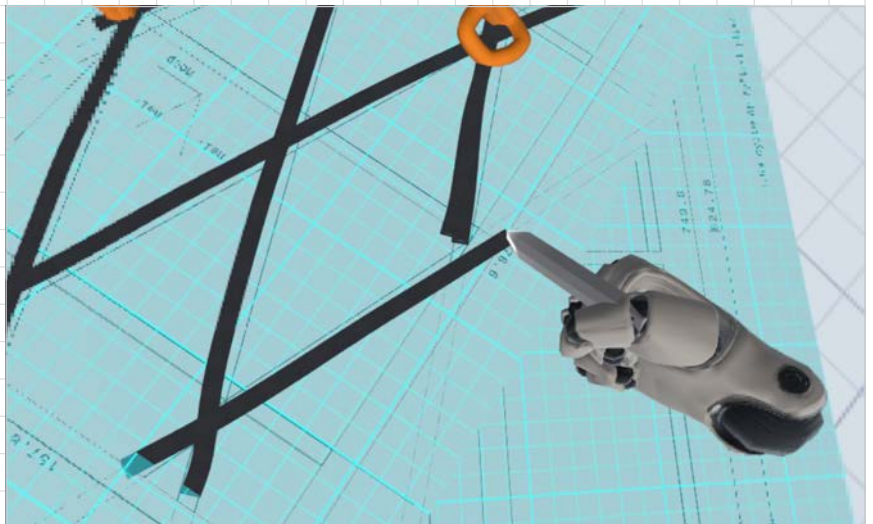
Show and tell

Get the efficiency and ease of explaining your thinking process using your voice and your physical presence. And support by illustrating the problem using a robust set of sketching tools and models.



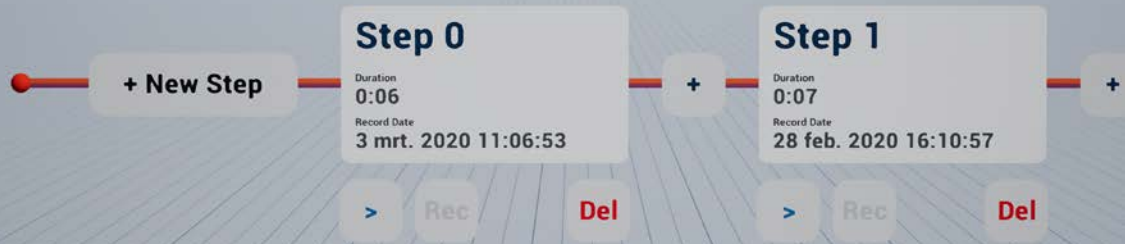
Explain Lay-up Anywhere

The VR tool is optimised to make an explanation of composite lay-up as easy as possible. Use the alignment sheet to do lay-up on your models and templates. Draw over the models, and show that in motion. Best of all you can do it from home!





Steps in #Alignment

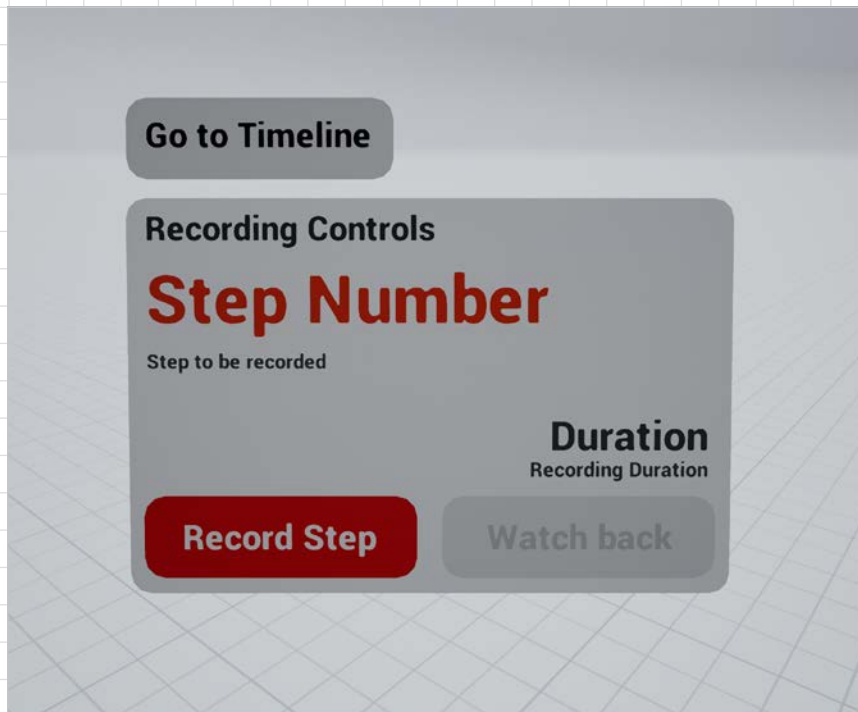


MADE TO MAKE KNOWLEDGE TRACEABLE

Keep it in traceable steps

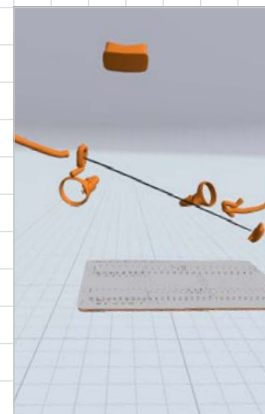
Capture your process inconvenient short steps that make finding the right information and revision easy. No more incredibly long documents about the process, a recording will suffice. Then watch it back anytime, no meetings required.





Record in motion

Capture and explain the details and motions of your process in a detail not before possible in a very efficient manner. Even record your own position.



Interactive Playback

Watch it whenever, no meetings required and traceable until forever. Pause an explanation at any time. Take apart any sketch and model to dig deeper.

CUSTOMER JOURNEY

RECORDING

THINK OF THE TOPIC

When you find a problem that is hard to explain through other mediums, think about how you can break it into steps.



GO INTO THE TOOL

Make sure you are in the right Topic, or create a new one.

CREATE A NEW STEP

Create a new step or add to an existing step.



OPEN THE STEP IN RECORD MODE

Press the small Record button to open the recording workspace



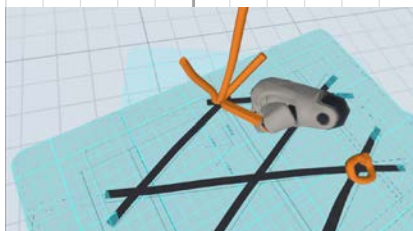
PREPARE YOUR WORKSPACE

Prepare your recording by adding models and making some initial drawings



START RECORDING

Press the big red recording button to start.



TALK AND SKETCH

Talk into the microphone to explain the steps that you are taking. This is heard by the receiving user.



DRAW AND ALIGN COMPOSITES

Draw composites as if you are laying them up. Then reposition them by grabbing them allowing you to move from the cutting to the lay-up template.



MANIPULATE MODELS

Add in any of the models required during lay-up from the model panel. Then record manipulating them.

FINISH RECORDING

Press the recording button again to keep the knowledge gained.

WATCHING

THINK OF THE TOPIC

Get a notification that more steps are available or remember a topic to look up again.



FIND THE RIGHT STEP

Open the step you want to learn or watch them all from the start

OPEN THE STEP INTO PLAY MODE

Press the small play button to open the step in the playback workspace

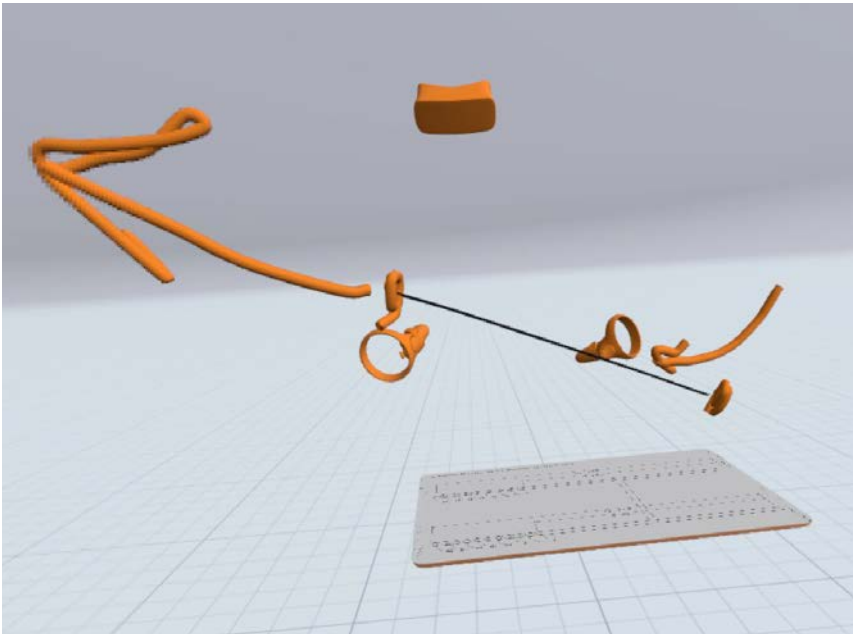
START PLAYING

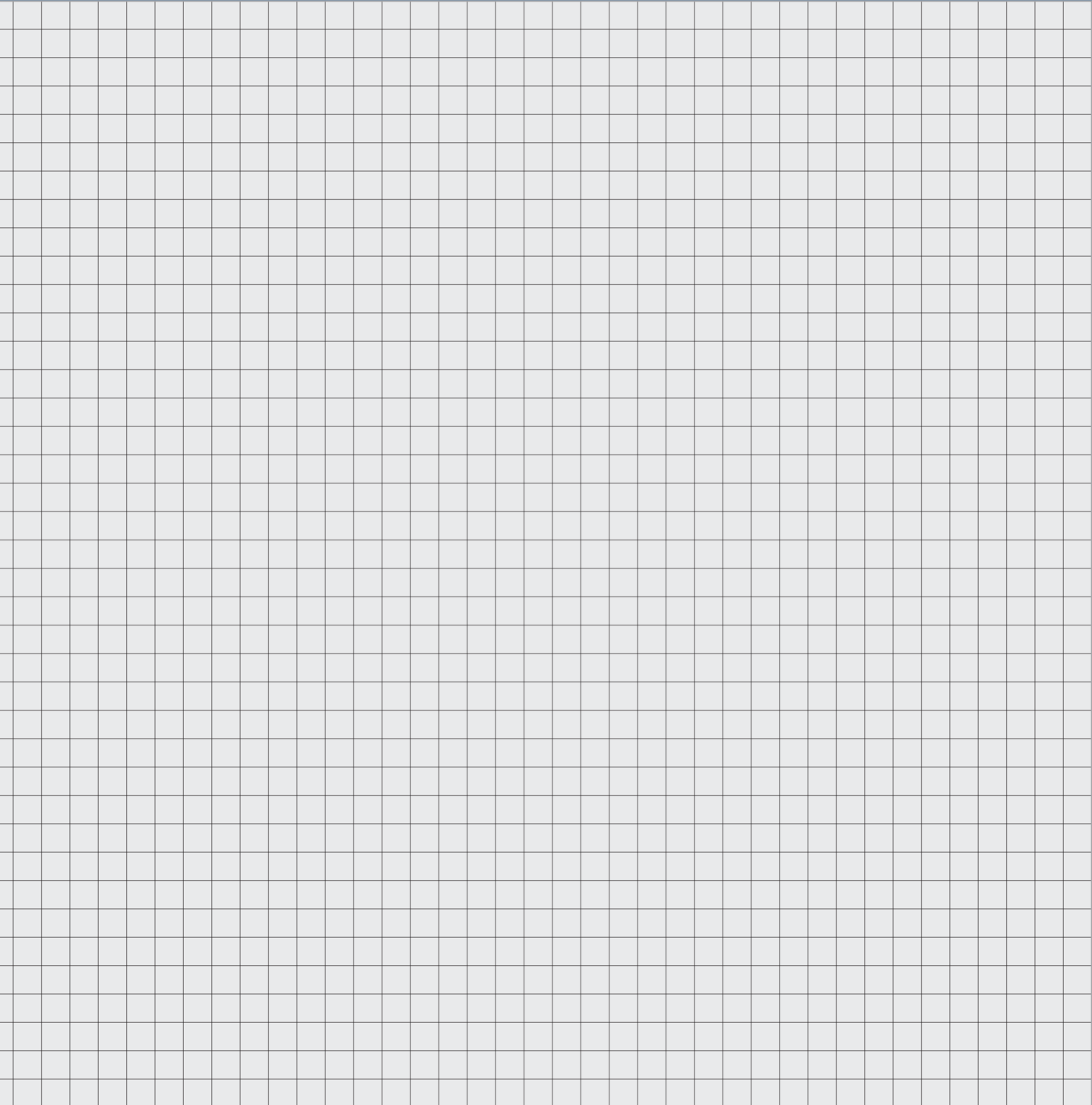
Press the play button on the console

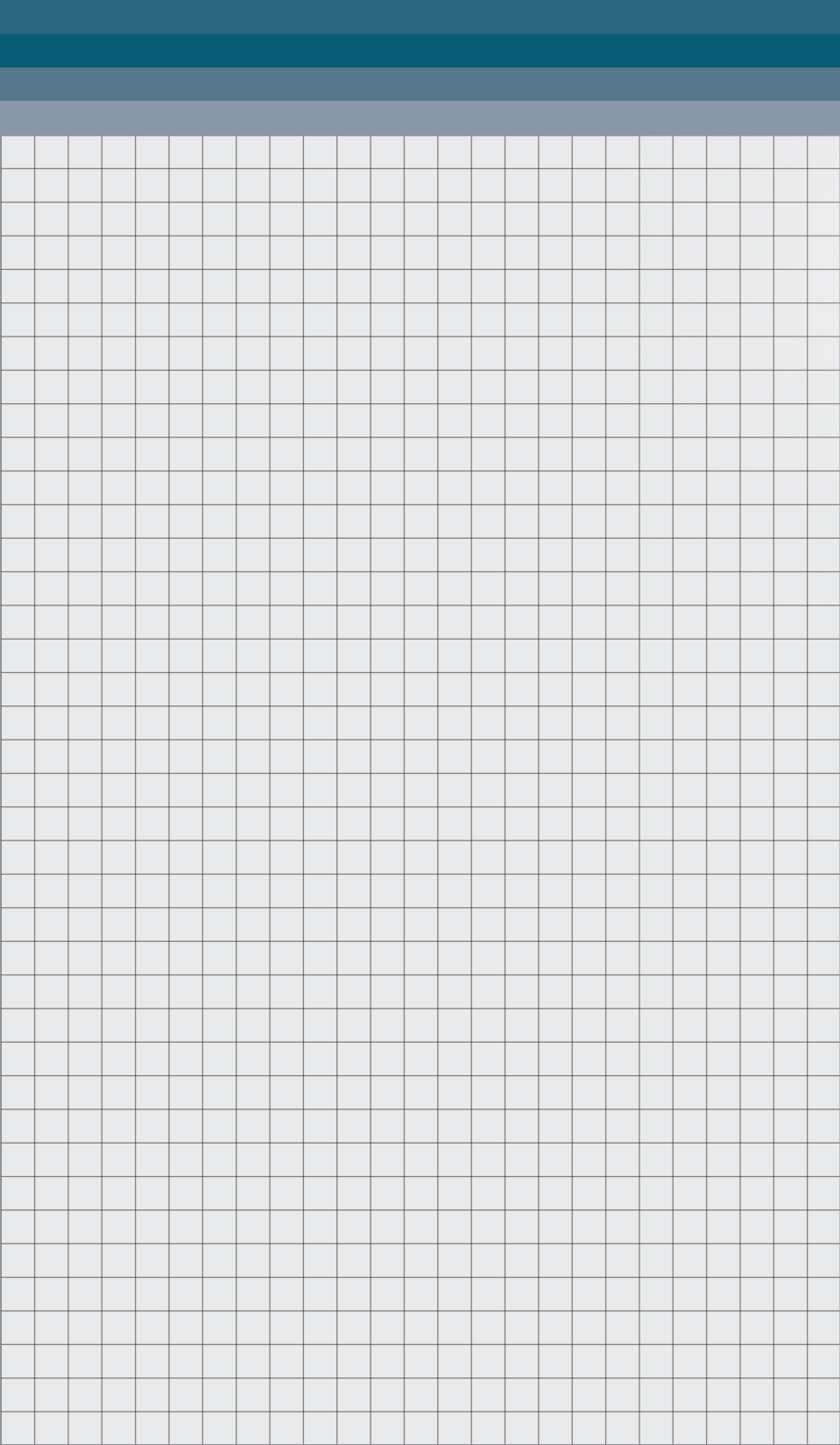


WATCH

Hear the recorder walking around, watch them manipulate composites and take apart and add to their sketches at any moment.





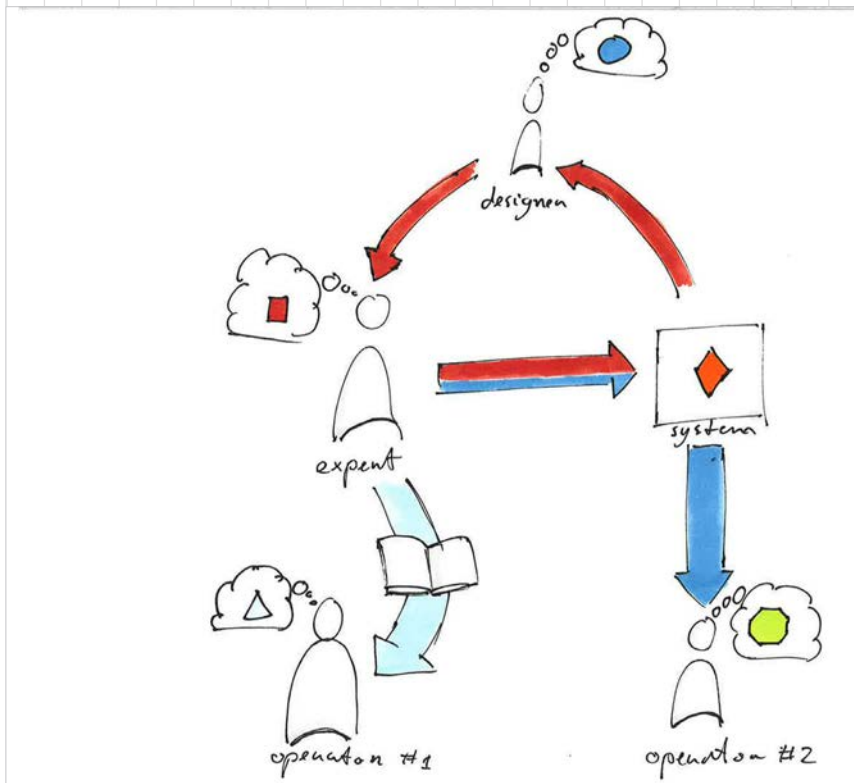


In this chapter, the final prototype will be evaluated on its ability to transfer Mental Model. This chapter contains the methodology, results and discussion of the study done.

RESEARCH GOAL

In this study, a between-group study will be done to determine the difference in knowledge transfer between a group watching a video of the VR tool and a written explanation. These are the blue arrows in the research design graph, see Figure 70. This will be determined by measuring the understanding of the domain by the participants. The amount of knowledge is correctly transferred is determined by measuring the understanding of the domain through a questionnaire. Kleinsmann (2008) stated that increased understanding of the domain is one of the benefits of establishing Common Ground. Thus if the tool creates a higher understanding of the domain in the participants then we can say that a higher Common Ground could be established.

Figure 70: Evaluation diagram



LIMITATIONS DUE TO COVID-19

The evaluation plan for this final evaluation has changed considerably over time due to the Coronavirus. These plans will be quickly outlined because they are referenced later.

PLAN 1 - TASK PERFORMANCE

In person between group testing. During this test users would have been asked to do lay-up themselves after watching a recording in the VR tool or reading a description. They would also have to fill in a questionnaire. This would have tested both the task performance as well as things learned.

PLAN 2 - FIELD TEST

A field test with the VR tool. The functionality of the tool would be expanded were two headsets could share recordings. The goal was to see how it would be used when working from home during the corona crisis. Unfortunately, the composite team was too busy to integrate a new tool in their process nor were they working on lay-up at the time. This will still be an interesting test for later

HYPOTHESES

Ha: Using the VR tool will lead to higher accuracy in the knowledge transfer of the process of composite hand lay-up steps compared to the knowledge transfer of a written description.

H0: Using the VR tool will not lead to higher accuracy in the knowledge transfer of the process of composite hand lay-up steps compared to the knowledge transfer of a written description.

METHODOLOGY

PARTICIPANTS

There was a sample size of 24 with an average age of 37 (11 female, 13 male). Participants had no understanding of composite lay-up. This meant prior experience would not be of influence on the results. This means giving users a score will be representative of the amount of information accurately transferred. For this reason, no people from ATG were used. Participants were recruited by the researcher based on personal connections.

EXPERIMENTAL DESIGN

Between-group study design was chosen to compare the performance of a written description (reading group) and a video of the VR tool (VR group) when explaining a set of steps in composite production. The controlled variable is the tool used. The criteria measured will be the number of correct answers, opinion on experience and perceived understanding.

A stand-in was required for the VR tool. Using the actual VR tool was not possible due to social distancing. Therefore it was decided to record a video of the VR tool. This still provides the same sound and visuals but the perspective is different and users cannot interact with a recording.

A written description was chosen as this is the closest competitor to the VR tool during use. The tool is not meant to replace synchronous collaboration tools but it is meant to have the same traceability as documents.

The steps that were chosen earlier during the process as the focus were used again. These steps were, placing composite on the cutting template and how to cut it, how to remove neatly from the cutting template, how to place it on the template, how to remove the protective film, and how to do the next layers.

MATERIAL CREATED

WRITTEN DESCRIPTION OF STEPS

A step-by-step explanation of steps was written in the style of an email with some attached images, this description can be found in Appendix 08 on page 152.

VIDEO OF VR

It was decided to use a video of VR to make this completely online and therefore possible. This could have an effect on the results as video is a different medium. This will have to be taken into account.

CONTEXT DESCRIPTION

From the pilot, it became clear that the lack of understanding about composites was an issue. To resolve this an explanation of composites, their material properties, and the process that the steps would be explaining were added to the questionnaire. This provides all participants with the same base level of understanding.

QUESTIONNAIRE ABOUT THE VIDEO AND DESCRIPTION

A questionnaire was created to evaluate how much participants have learned from the material and how much they understood the explanation provided. These questions form a mix of remembering details, but also

being able to infer information from the material provided. For example, it is never specifically mentioned how many toes make up a layer but users know that there are 3 toes in a ply and 3 plies in a layer. Therefore the answer is 9. Whilst most of these questions are multiple-choice some are open so the participant can explain their answer. These questions can be found in Appendix 13 on page 169.

EXPERIMENTAL PROCEDURE

During the questionnaire the participant will go through a couple activities.

PREPARATION AND CONTEXT

As mentioned before the participants are given some background understanding of composites. This explains the material and shows pictures of the strips and the result. Next they fill in their experience on composites

IMMERSION

Next the participants will immerse themselves in the chosen composite hand lay-up steps. They are randomly divided between the VR or Reading group. When participants are finished they are asked to record the time again. The learning material is then taken away by going to the next page.

QUESTIONNAIRE

Finally, the participants are asked to fill in a questionnaire meant to measure their understanding of the process. Next, they are, again, asked their perceived understanding of composites production and their opinion on the experience of the tool.

SYSTEMS USED

An oculus Quest running the VR tool was used for recording the video.

Google Forms was used for the questionnaire. This is rather limited at times but it has the advantage that no physical presence of the participants is required. Thus it can be done when everyone has to stay home.

DATA COLLECTION

Data will be collected through a questionnaire. The results of the questionnaire will be quantitative and self-reported.

QUESTIONS SCORE

Users will be given a score based on their performance in the questionnaire. This is ratio data as there is a true zero at no correct answers.

Weight was given to questions.

Multiple choice questions weighted 1, open questions weighted two but half points could be scored for a partially correct answer. There was a total of 29 points to be made.

PERCEIVED UNDERSTANDING

The perceived understanding of the domain was measured before and after the explanation and questions. This is a self-reported Likert scale from 1 to 7. 1 being no understanding and 7 being an expert on the subject.

OPINION ON EXPERIENCE

The final measurement was their self-reported opinion on the learning experience. Participants were asked to in how far they agreed or disagreed with a statement. For example, the

	Reading	VR
Mean	11.8	13.6
Variance	21.2	20.3
Observations	12	12

t Stat	P(T<=t) two-tail	t Critical two-tail
-0.96	0.34	2.07

Figure 71: t-Test Score comparison between reading and VR group: Two-Sample Assuming Equal Variances

	Before	After
Mean	1.96	3.21
Variance	2.74	0.78
Observations	24	24

t Stat	P(T<=t) one-tail	t Critical one-tail
-3.31	0.0015	1.71

Figure 72: t-Test increase in perceived understanding before and after the questionnaire for both groups: Paired Two Sample for Means

	Increase Reading	Increase VR
Mean	0.83	1.66
Variance	5.78	0.96
Observations	12	12

t Stat	P(T<=t) one-tail	t Critical one-tail
-1.11	0.14	1.75

Figure 73: t-Test increase in perceived understanding before and after the questionnaire comparing groups: Two-Sample Assuming Unequal Variances



Figure 74: Score comparison between both groups

explanation was clear. This was a Likert scale from -2 to 2. -2 being fully disagreed, -1 somewhat disagree, 0 neutral, 1 somewhat agree and 2 fully agree.

RESULTS

A t-test comparing the scores of the reading and VR group was done, see Figure 71 on page 104 and Figure 74. Mean score of the VR group was higher by 1.8 points, out of a total of 29 points. The median score of the VR group was higher with 2.25 points. The results of the T-test show that the difference between the mean scores of the two groups is insignificant. This is because the t critical two-tail value is 2.07 which is higher than the t stat of -0.96. The probability is also too high $p = 0.35 > 0.05$.

Another T-test was done for the perceived understanding before and after the questionnaire for both groups. A significant increase in perceived

understanding was found for the sample as a whole. The t stat = -3.3147 and the probability was 0.0015.

There was a higher increase for perceived understanding for the VR group 1.66 compared to the reading group 0.833. Unfortunately, the comparison in the perceived increase of understanding is not significant between the two groups because the t stat was -1.11. There was a noticeable difference in variance between groups. The variance of the reading group was 6 times higher, which was 5.8, compared to the variance of the VR group, which was 1.0.

Another t-test was done for the average opinion on experience. The t-test statistic for the variable clear was 0.015, significant at the 5% level. All results are in Figure 76 on page 107.

CONCLUSION

There are indications that the VR group performed better than the reading group. The experience was perceived consistently better than the written instructions and both the increase in perceived knowledge, as well as the test scores, were higher. This indicates a better Mental Model transfer. However, the results of this study were insignificant.

Even though the results are insignificant this is a promising result. The VR tool can be used to convey as much information as a detailed document whilst requiring significantly less time to prepare. However, more research is necessary to find statistically significant results.

DISCUSSION

How come the results were insignificant and how can we continue from here?

TOO SMALL SAMPLE SIZE

One factor was that the sample size was unfortunately too small. As mentioned before, the evaluation plans had to be changed multiple times because of the coronavirus. With the original plan incorporating measuring task performance for actual lay-up. Unfortunately, this original study could not be done as it required physical presence. The second plan, to use the tool in a field test was supposed to get around this problem by only requiring two participants and no physical contact. Unfortunately, no willing participants were found.

VIDEO OF VR

To make it possible to do a study, the originally planned study was redesigned to be possible without physical contact. This influenced the study in several key ways. Instead of using actual VR, a video was used. This meant that the interactivity that is possible in the tool was lost and the viewpoint became fixed. Especially the viewpoint will have made a difference as comments indicated it shifted quickly which was distracting. This was not due to the tool but due to the recording.

TASK PERFORMANCE NOT MEASURED

Second, it was not possible to measure task performance in this online study. No actual lay-up could be done. It is expected that the VR tool is to have a larger influence on the task performance rather than remembrance as it more closely demonstrates the task than a written description. It is

also important to note that higher task performance can indicate a better Common Ground according to Kleinsmann (2008). This limited research design could be another factor why the results are insignificant. In addition, it is why it is believed that getting a larger sample size will not necessarily yield better or usable results.

PARTICIPANT SELECTION

It was questioned why more experienced participants at ATG weren't used. After all they are the target group of this product. This was considered but it was decided not to do so for two reasons.

First of, there weren't enough experienced users to get a large enough sample size. That meant a more qualitative study would have to be done but this simply wasn't possible with an online questionnaire.

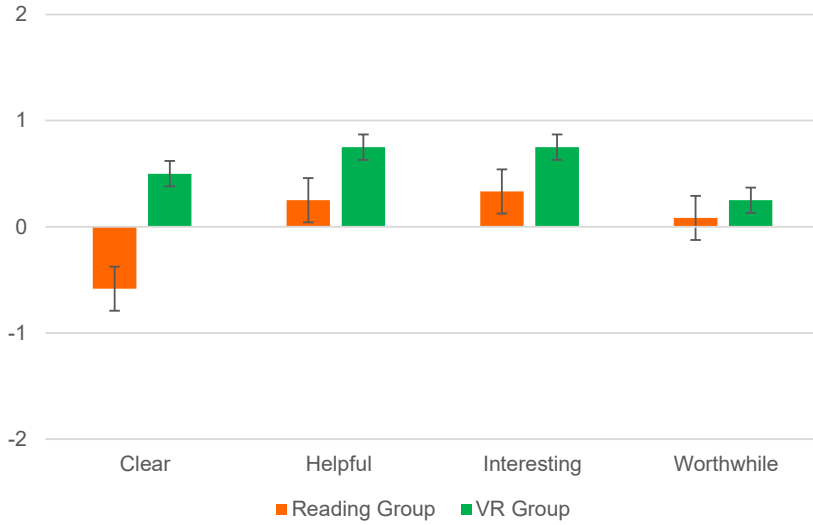
Secondly, they could have been mixed in with the participants without prior understanding but this would only have complicated things and potentially made the results less significant.

RECOMMENDATIONS

It would be recommended to do the first study with the evaluation of the task performance. It is expected that the task performance will then be significantly higher for the VR group which would indicate that closer Common Ground was established. Again, this was not possible due to the measures against the Coronavirus. This would also make it possible to do the study using actual VR instead of a video of the VR. Another option would

be to do the field study, this would provide valuable qualitative feedback on the tool itself but would not be a direct comparison to existing methods. If the measures take longer another option does exist where it can be evaluated how well the tool performs for certain types of information. For example, information about placement in space, colour or steps. This could indicate when the tool should be used and when other communication mediums would be more suitable.

Average opinion on Experience Higher is better



Average opinion on experience Lower is better

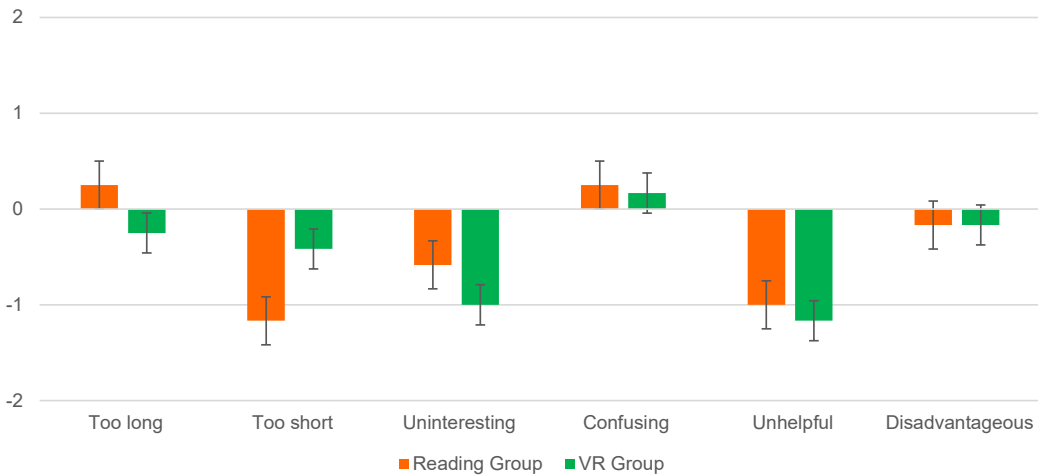


Figure 75: Results of experience questionnaire between both groups. -2 is fully disagree, -1 is somewhat disagree, 0 is neutral/no opinion, 1 is somewhat agree, 2 is fully agree. 1 standard error was used for error bars.

Clear	Helpful	Interesting	Worth-while	Too long	Too short	Uninter-esting	Confusing	Unhelpful	Disadvan-tageous
0.0153	0.1993	0.2306	0.6813	0.1968	0.0708	0.3663	0.8232	0.7200	1.0000

Figure 76: Probability of significance. Results of the t-test for each variable

REQUIREMENTS EVALUATION

A set of requirements was defined after the analysis, these were mostly achieved in the final prototype. In this section, an overview and discussion of the requirements is given.

INSTALLATION

This requirement is more hardware than software related and in hindsight may not have been as important as the others. That being said because the prototype runs on the Quest the criteria for an easy installation is met.

LEARNING CURVE

From the RITE it was clear that an engineer from ATG did not have trouble understanding the tool which means the learning curve was quite low. Most functionalities were discoverable through their design. For example, the drawing tools needed to be picked up and then activated. This was not always immediately clear but it was always discovered by the user. There was also a large focus during RITE to improve on this requirement.

ASYNCHRONOUS

The final concept did end up being asynchronous. The specific requirement of not taking more time to explain something than on a whiteboard explanation was not tested. However, in the final evaluation, the tool was compared to a written description or emailed for which it did test favourably.

Interestingly due to its asynchronous nature, it could potentially be used as a prototyping tool for multiplayer tool. It is possible to make a repeatable interaction in this tool that can then be tested with multiple participants.

CAPTURE PROCESS EXPLANATIONS

The focus of the prototype created was definitely on process explanations, e.g. the timeline and the multiple steps. During the final evaluation, it was proven that both the VR tool and a written description have a positive effect on the perceived knowledge on a subject. There was however no significant difference between the two groups for the same measure. This means that the tool did allow for Mental Model transfer on why a position was chosen.

The requirements about air gaps were not tested because the steps could not be used to protect intellectual property. A user should be able to better convey Mental Models within and about 3D space better than a still image with description. The ability to draw attention was only partially tested during the final evaluation because of the use of a video. Users were able to focus on the important subjects during a test conducted with RITE. In conclusion, the requirements were addressed and designed for but not all were evaluated during the final evaluation which means evidence is incidental.

REVISION

Users were able to revise a recording in some form in the prototype. They would be able to both expand on a recording or delete them entirely. The recommendation to expand on this is to build out the recording tools more giving access to the tracks. Allowing a user to only rerecord audio. Relaxing music was added to the tool and the environment dims giving you a feeling of focus.

CREATE TRACEABLE INFORMATION

Information can be kept indefinitely in a structured manner which makes it easy for an engineer to find the information later. In the final prototype, it can be a bit obtuse where a piece of information is kept as there are no images nor very descriptive information available but this is not an issue in the final concept. The information recorded in VR can be referenced in other media as well by taking screenshots and recording a video.

LOW PREPARATION TIME

The preparation time between steps is lowered as users can easily take drawings and composites from one step to the other. Copying the final drawing and position of models to the beginning of the new step. It does not take long to put on the headset and to get into the tool. On average it takes 3 clicks within the tool to start recording. The nature of the medium also allows for a more impromptu explanation that does not require as much preparation as an email or an official manual. This condition was met in the prototype.

ALLOW FOR MEDIUM REACTION TIME

No real response functionality was built-in within VR. During this project, the focus shifted more towards building a timeline of steps and the recording tools. Of course, users can continue working on each other steps by taking the drawings and model to a new step. This can be seen as a form of response functionality.

FINDABILITY

In the prototype, this was not necessarily met. Although the focus on the timeline during RITE did mean the

recorder was aware where knowledge was being stored and how to build on it this did not necessarily transfer well to others. There is an argument to be made that by having the recording be short, on average a couple of minutes, this already increases the findability. However to ensure this criterion was met the final concept takes the conclusions from RITE and builds on the functionality of the timeline to increase findability. It does this in two important ways. It gives a title to each step and makes the final drawing and model visible on the step. Providing feed-forward what knowledge is contained within.

CONTEXT REQUIREMENTS

This requirement was mostly about being able to use it in the context of an office. Although no functionality to import models was added in the prototype a model browser does exist. This can easily be extended to include an import function on the desktop. How this should work is detailed in the concept. As explained before it does not take long to get into the tool and because it is running on an Oculus Quest it can be used anywhere which makes transport easy as well.

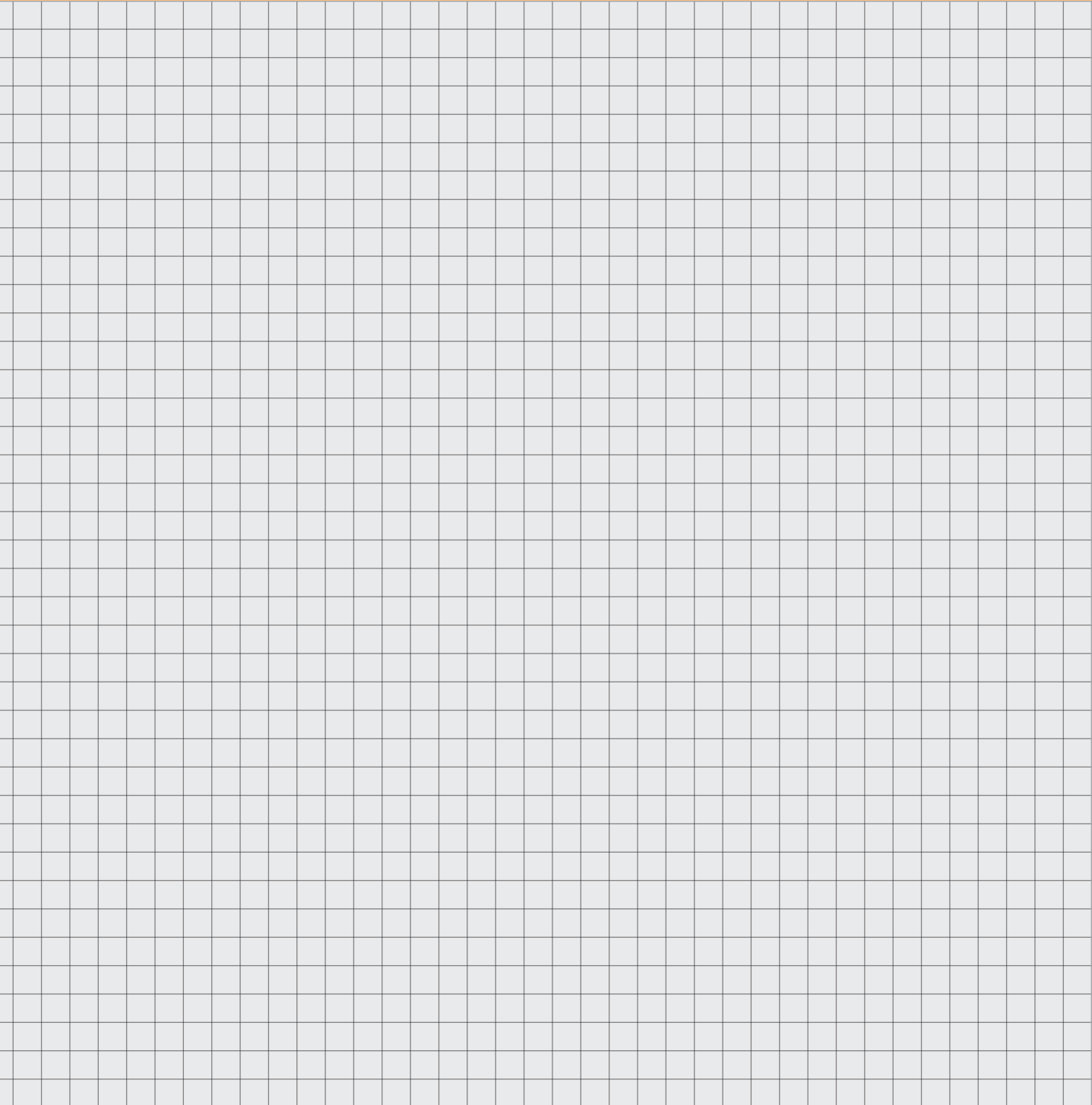
WATCHING BACK

The steps that were implemented makes it easy for a user to skip uninteresting steps. They are essentially a way for the recorder to create bookmarks during an explanation. The explanations recorded during RITE were often no longer than 5 minutes. However, it did depend on the context. For future developments, the emphasis on the shorter duration can be made stronger.

Requirement category	Evaluation per Requirement							
Installation	1	2	3					
Learning Curve	4							
Asynchronous	5	6						
Capture Process Explanations	7	8	9	10	11	12	13	14
Revision	15	16						
Create Traceable Information	17	18	19	20	21			
Low Preparation Time	22	23	24	25				
Allow for medium reaction time	26							
Findability	27	28	29					
Context Requirements	30	31	32	33				
Watching back	34	35	36	37				

Legend	
Fulfilled	
Fulfilled but not prototyped explicitly	
Probably but insufficient evidence	
Future Work	
Not fulfilled	

Figure 77: Overview of requirements. Every block is a requirement. Requirements can be found in Appendix 11 on page 166 and in chapter "Requirements" on page 62.



A large grid area for writing, with a decorative orange gradient bar at the top. The grid consists of 20 columns and 30 rows of small squares.

In this chapter, the results of the project will be discussed and an evaluation of the requirements will be done. In addition, future work is presented and explained and a personal reflection on the project was done. This can be found in Appendix 16 on page 200.

PROJECT SUMMARY

478 Words

LITERATURE REVIEW

In the literature review, four main things were explored. The concept of Mental Models and Common Ground, the concept of bandwidth, the current state of VR and VR collaboration and the composites of ATG. This formed the theoretical basis for the project.

CONTEXTUAL ANALYSIS

It became clear that there were two knowledge gaps. The first one being the composite production process was still unknown. Secondly, it was unclear what the current communication tools were and why they were used.

To gain insight into the production process, an immersion exercise was done in which the designer did the actual production process. This was then made it into a timeline and discussed with the composite team to ensure it was accurate for the process in Ireland. The main conclusion was to focus on the alignment process.

The timeline can be found in section "Composite Production Timeline" on page 36 and a version with confidential information is found in Appendix 14 on page 184.

Ten interviews were done to determine the use of each communication tool. The results of these interviews were then clustered and made it into charts and a write-up. This indicated that a traceable and high bandwidth tool does not exist yet which presents an opportunity for VR.

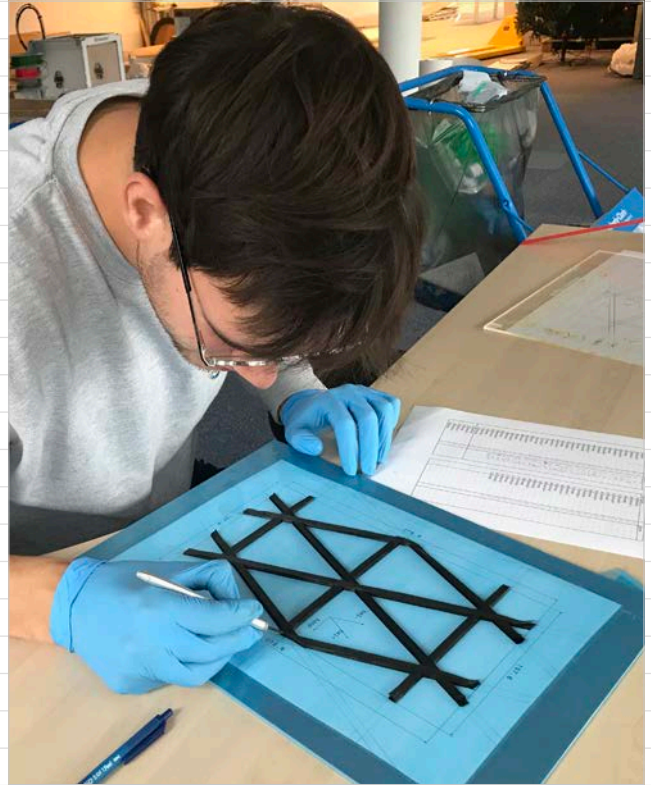
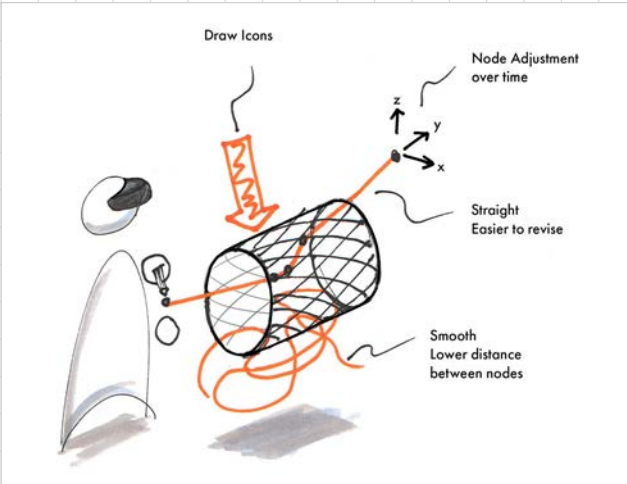
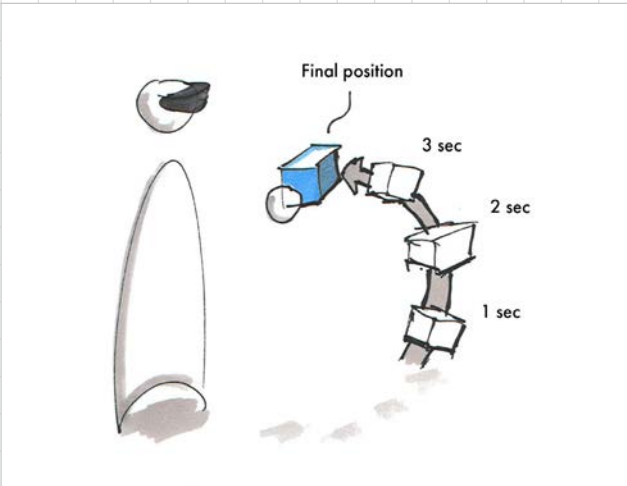
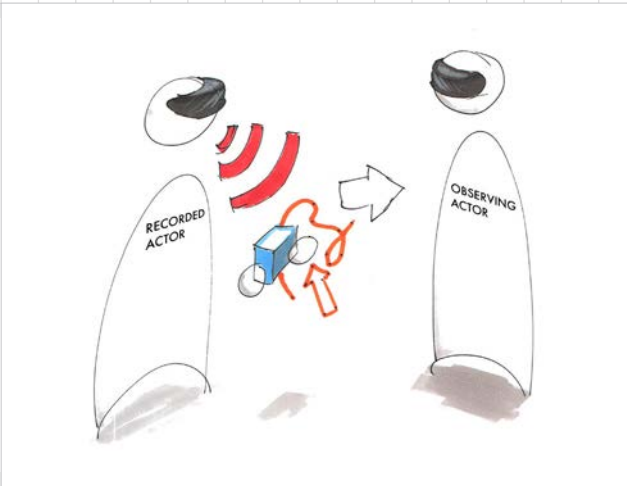


Figure 78: Contextual Analysis

Figure 79: Three pillars of concept direction



CONCEPTUALISATION

For the conceptualisation, a set of requirements were created based on previous research. These requirements then helped to create a concept direction.

CONCEPT DIRECTION

The concept direction is a Virtual reality tool that does two main things. First, it records sketches, objects and the engineers' position and voice in 3D overtime to capture Mental Models. Secondly, by organising those Mental Models in a clear project structure that makes the Mental Models traceable and findable in a persistent project.

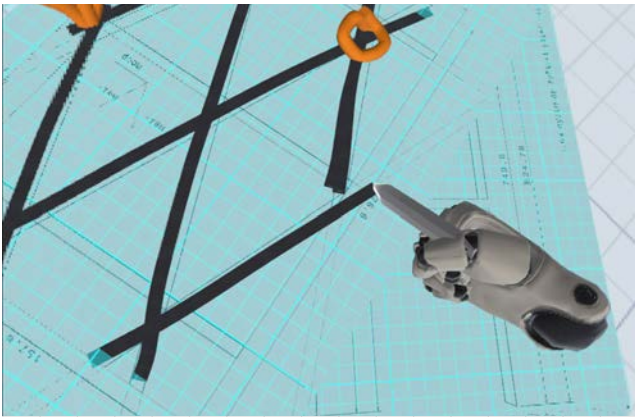


Figure 80: Lay-up in final prototype

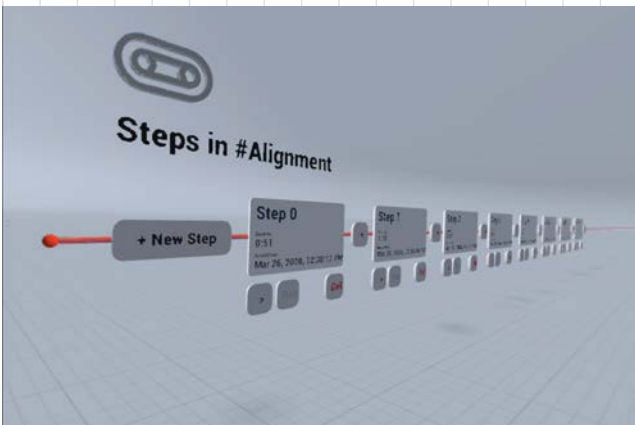


Figure 81: Timeline in Prototype



Figure 82: Score comparison between both groups

RITE PROTOTYPING

An almost fully featured prototype of the concept was build using a method called RITE (Rapid Iterative Testing and Evaluation). This meant multiple iterations of the prototype were made and evaluated.

The QUESI questionnaire was used to evaluate the performance of each iteration. For future work, it is recommended to either do more iterations or to use a different questionnaire as QUESI needs more iterations.

EVALUATION STUDY

A between-group study was done to evaluate the prototype on its ability to transfer Mental Models. Participants were shown either a video or a written description of a process, which they were asked to answer questions about. The more questions right the higher their score. Furthermore, they were asked about their perceived understanding of the domain before and after the questionnaire. As well as their opinion on the experience. A video of the prototype was used so the study could be done online. This was necessary to recruit participants.

With 24 participants the results came back mostly insignificant but the video of VR did perform better on clarity and experience. It performed slightly higher but not significantly so on the score and the perceived understanding. That is still a promising result as preparation time was lower and the VR tool is traceable, as according to the requirements.

PROJECT CONCLUSION

The most successful part of the project has been the RITE prototyping exercise. Even though the QUESI questionnaire did not deliver the best results, the qualitative feedback from the exercise proved invaluable. Being able to build such a detailed prototype proved to be very valuable for the final evaluation as well. Making it a lot easier to create visuals that could potentially have proven the usefulness of VR.

Even though the results of the final evaluation were insignificant, and more research is necessary, it does show that VR can be used to transfer knowledge and by extension Mental Models as well as, if not better than, a detailed document. In addition, most of the defined requirements were met with some exceptions due to a changing scope of the project. Although, exactly how well it can transfer Mental Models at this moment is still unclear. These are possibilities for future research and they are outlined in the next section of this chapter.

This project has laid a solid foundation for future research on using VR for long distance collaboration. The prototype itself was quite complete and it was tested thoroughly with RITE. From those results it is clear that this is a promising prototype for what is going to be a very interesting field. Especially given the current, as of time of writing, social distancing measures.

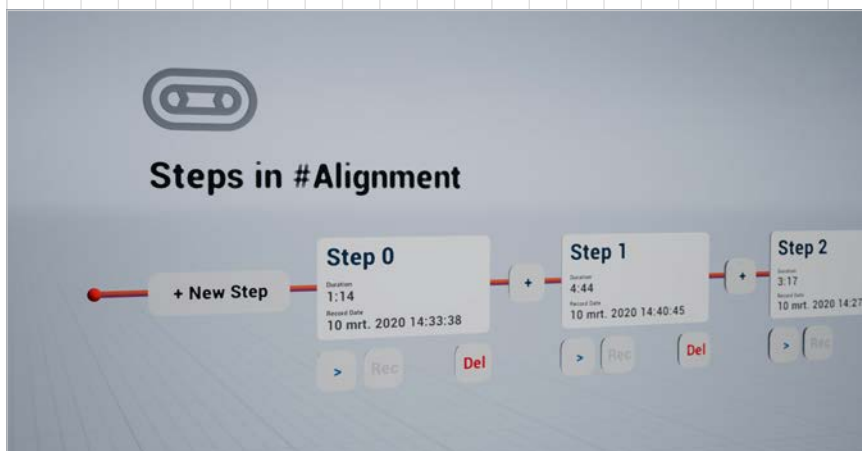
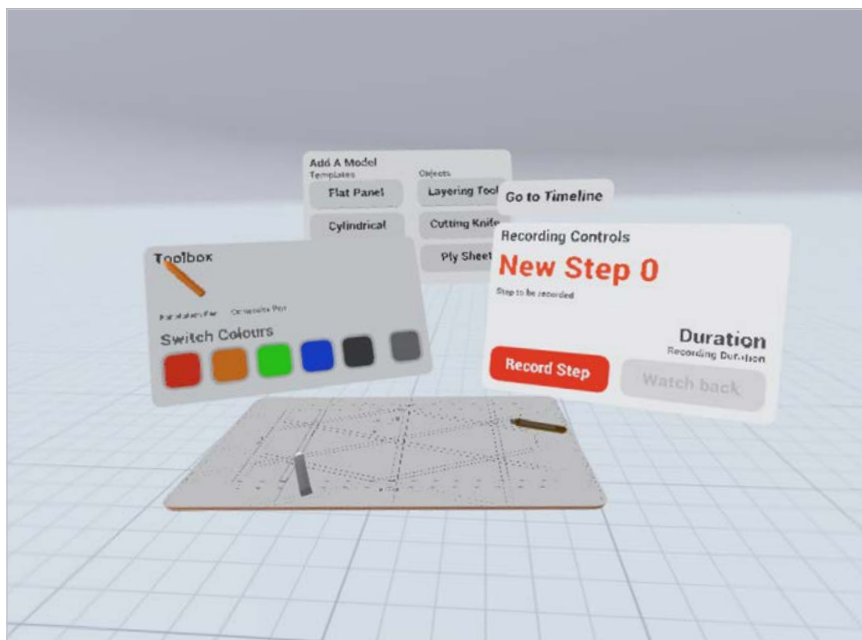


Figure 83: Collage of features final Prototype

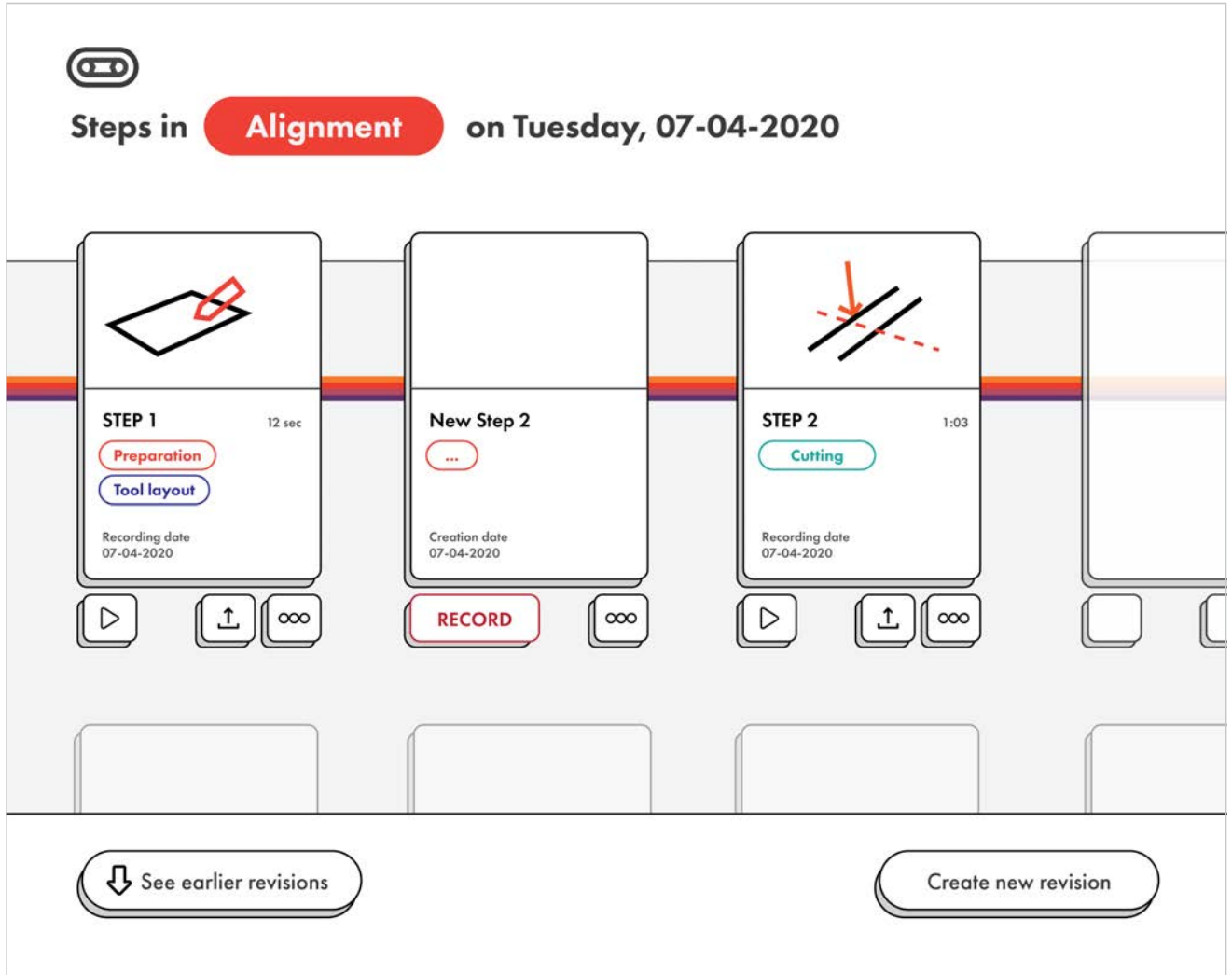


Figure 84: Revisionist Timeline

More research was deemed necessary. So how can we extend on the knowledge gained from this project. There are two main recommendations for future studies. In addition to those, it is recommended to keep iterating on the prototype. These are explained in the prototype/concept section.

FURTHER STUDIES WITHIN THIS PROJECT

There are two studies that are recommended to do. They will be explained briefly and the reasoning behind them

STUDY ON TASK PERFORMANCE

It would be recommended to do the first study with the evaluation of the task performance. Using the actual VR instead of a recording of VR. This is recommended because it would better evaluate the performance of the VR tool. By doing actual lay-up with participants, it can be measured how well the participants are able to perform a task after learning about it in VR. This would indicate that Common Ground on a problem was established instead of how much information was transferred.

FIELD STUDY

The proposed field study could be done. This would provide valuable qualitative feedback on the tool itself but would not be a direct comparison to existing methods. It would also allow to evaluate how well the tool performs for different types of information. This would also extend on the knowledge of Virtual Reality use in office and might provide interesting concept directions for future projects.

PROTOTYPE/CONCEPT

CONTINUING RITE

It would be recommended to continue prototyping work with RITE. However, a different questionnaire than QUESI would be a good idea to help evaluate the progress. QUESI does not allow for enough refinement to see improvements on the long term and it is interpreted differently by different participants. This necessitates many smaller iterations to get clear results.

Alternatives to QUESI

A recommendation would be to use the defined tasks and errors from RITE. This can only be done if the steps are fixed but do give a clear indication of performance.

Another recommendation would be using UEQ. This gives a more detailed look into the experience but because it poses alternatives against each other it allows for less confusion on the users part and it is quicker. It also gives more detailed results as the Likert scale is from 1 to 7.

REVISION TIMELINE

In the final prototype it was possible to revise information. However, keeping the older information was not something that was prototyped.

For future development, it is recommended to add these revisions. This can be done in the following manner.

At first, the idea was to use branching paths. However, that is a paradigm that clashes with the idea of watching back VR in a linear fashion. Therefore, it is believed that these will get confusing

over time and it would be better to have multiple versions, or revisions of the same timeline. This would mean users will be able to watch back a revision of an entire timeline all at once.

How this would look can be seen in Figure 84 on page 116. This shows a mock up a revision timeline. If the user would want to create a new revision, the old revision would be entirely copied into the new one. From this point steps can be added and deleted without revising the old timeline.

This makes for a more intentional revision, meaning the revisions on the timeline also reflect revisions in the real-world context. It also eliminates a problem with steps that contain wrong information. These can now be deleted without preventing confusion.

In addition, the mock-up in Figure 84 shows how a timeline step should look. In order to increase traceability a header image of the recording should be added and a couple quick keywords about its content should be displayed. This helps the user find the right information.

DRAWING TOOLS

From the RITE method it became clear that people still had trouble making the drawings flat. The recommendation for this would be twofold.

Collision pencil

First off, by adding collision to the composite pencil it would be easier to draw flat or on surfaces. With the alignment sheet you can draw flat but the pen will go through the alignment causing you to overshoot. If the pen

can no longer clip to the alignment sheet this would help the user draw on a 2d plane.

Node based drawing tools

Secondly, a recommendation would be to go for a more node style based composite lay-up. Similar to how this works in gravity sketch. By placing nodes the segments between knots in the composite lay-up would be entirely straight. This would also make it easier to make segments of a precise length on the lay-up templates.

The disadvantage would have been that this would have been harder to understand for the user. The quick draw and sketch method that is used now is definitely expected to be easier to understand. This method could still be used for sketches. There is also the argument of whether it is necessary. The final tool is a communication and collaboration tool instead of a lay-up tool. While the communication may be about lay-up, exact lay-up does not need to be done. Instead a rough representation of lay-up seems to work fine.

REMOVING MODELS

There was not time to implement a way to delete a model or drawings from a recording. This is recommended to be added in the next prototype. The proposed implementation would be a bin where users can drop unwanted sketches and models in. In addition, to a spawn time a deletion time will also need to be kept per object if this implemented. And this deletion function needs to be replicated for playback.

EXPORT OF INFORMATION

Another type of use that was seen quite a lot during RITE testing was to use the tool more like email. Where a small recording was made that worked almost as a message. Enabling users to send a recording, existing of multiple steps, like or over email instead of keeping it in a shared project to another person would be a useful way to expand this project to different markets and uses.

ADDITIONAL TARGET MARKETS

The corona crisis has forced many people to work from home. This means that many more people are suddenly working long-distance or in virtual teams. This project can potentially fulfil some of the needs those people now have to successfully work together. Practically this means many more target markets than just composite lay-up. Potential target markets that can be looked at are:

- Teaching classrooms
- Physical training or dance recitals
- Model review in many more fields
- Assembly training

And as mentioned before, this tool could also be potentially used for research where physical instruction is required. This could be a stand in as it can be easily pre-recorded and than shown from a safe distance in a very repeatable manner. Or it could be used to help evaluate multiplayer interactions without needing a second person present. If it can be recorded then it can be evaluated from a third person perspective using this tool.

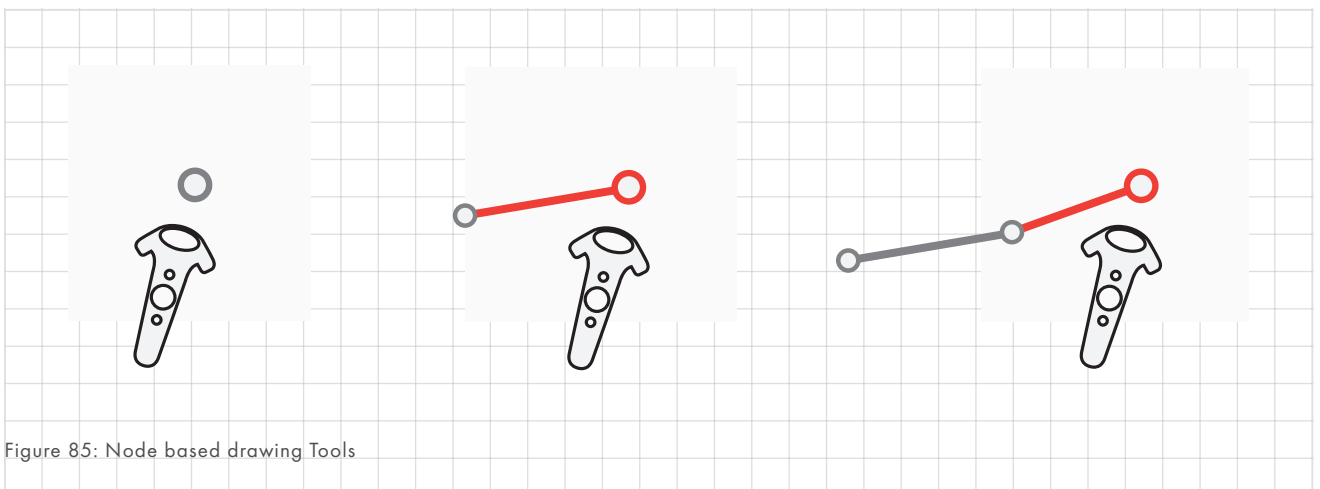


Figure 85: Node based drawing Tools

FUTURE PROJECTS

PROJECT ON TRAINING TO GIVE VR TRAINING

One thing that came up during RITE iteration is that the tool worked better with a more informal style of communication. For example, if the users used the tool to more loosely represent composites and models it was just as accurate but faster to explain the same problem. This however, was not always immediately clear to users.

An interesting project would be to see how users can be guided to use a certain type of language. Or to say it more broadly, there is a need for training users how to communicate more efficiently within Virtual Reality. In other words, a communication training within VR.

This project can use the theoretical basis on communication and the prototype created in this project as a technical base on which to extend the knowledge.

TECHNICAL PROJECT

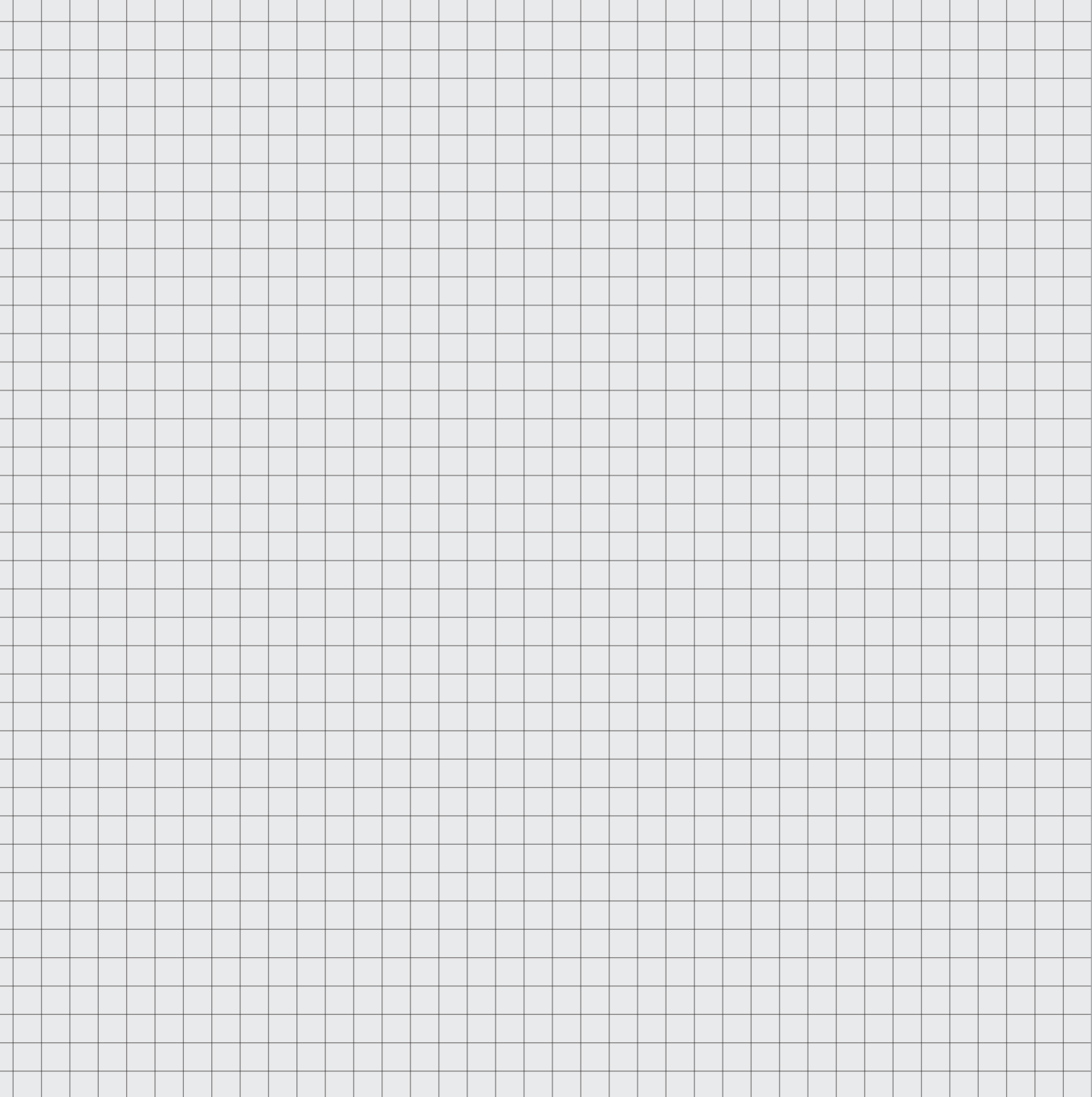
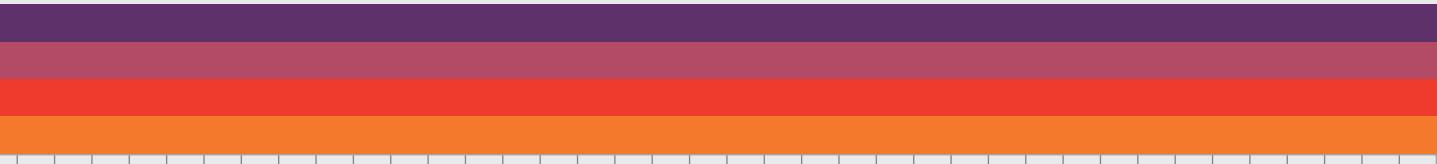
The current technical solution is useable but if it is deployed in a field setting a more robust solution would need to be found. There already exists a replay system within Unreal Engine however it is not possible to take that information into other systems. A future graduation project could focus on building a more reliable and expandable system that can still be exported to other media.



- Abramovich, H. (2017). 1 - Introduction to composite materials. In H. Abramovich (Ed.), *Stability and Vibrations of Thin Walled Composite Structures* (pp. 1-47). Woodhead Publishing. doi:<https://doi.org/10.1016/B978-0-08-100410-4.00001-6>
- Aschenbrenner, D., Leutert, F., Çençen, A., Verlinden, J., Schilling, K., Latoschik, M., & Lukosch, S. (2019, 5). Comparing Human Factors for Augmented Reality Supported Single-User and Collaborative Repair Operations of Industrial Robots. *Frontiers in Robotics and AI*, 6. doi:10.3389/frobt.2019.00037
- Asschenbrenner, D. (2017). *Human Robot Interaction Concepts for Human Supervisory Control and Telemaintenance Applications in an Industry 4.0 Environment*. Ph.D. dissertation, Julius-Maximilians-Universität Würzburg.
- Badke-Schaub, P., Lauche, K., & Neumann, A. (2007, 3). Team mental models in design. *CoDesign*, 3, 1–3. doi:10.1080/15710880601170743
- Badke-Schaub, P., Neumann, A., Lauche, K., & Mohammed, S. (2007, 3). Mental models in design teams: a valid approach to performance in design collaboration? *CoDesign*, 3, 5–20. doi:10.1080/15710880601170768
- Bekebrede, G., Lo, J., & Lukosch, H. (2015). Understanding Complex Systems Through Mental Models and Shared Experiences: A Case Study. *Simulation & Gaming*, 46, 536–562. doi:10.1177/1046878115621463
- Bordia. (1997, 1). Face-to-Face Versus Computer-Mediated Communication: A Synthesis of the Experimental Literature. *The Journal of Business Communication*, 34, 99-120.
- Caggiano, A. (2018, 3). Machining of Fibre Reinforced Plastic Composite Materials. *Materials*, 11, 442. doi:10.3390/ma11030442
- Casakin, H., & Badke-Schaub, P. (2013, 1). The Psychology of Creativity: Mental Models in Design Teams.
- Chiu. (2000). An Organizational View of Design Communication in Design Collaboration. *Design Studies*, 23, 187-210.
- Churchill, E. F., & Snowdon, D. (1998, 3 01). Collaborative virtual environments: An introductory review of issues and systems. *Virtual Reality*, 3, 3–15. doi:10.1007/BF01409793
- Cidota, M., Lukosch, S., Dacu, D., & Lukosch, H. (2016, 10 10). Comparing the Effect of Audio and Visual Notifications on Workspace Awareness Using Head-Mounted Displays for Remote Collaboration in Augmented Reality. *Augmented Human Research*, 1, 1. doi:10.1007/s41133-016-0003-x
- D. Hull, T. W. (1996, 8 1). *An Introduction to Composite Materials*. CAMBRIDGE. Retrieved from https://www.ebook.de/de/product/6559379/d_hull_t_w_clyne_an_introduction_to_composite_materials.html
- Dalgarno, B., & Lee, M. J. (2009, 12). What are the learning affordances of 3-D virtual environments? *British Journal of Educational Technology*, 41, 10–32. doi:10.1111/j.1467-8535.2009.01038.x
- Dey, A., Billingham, M., Lindeman, R. W., & Swan, J. E. (2018, 4). A Systematic Review of 10 Years of Augmented Reality Usability Studies: 2005 to 2014. *Frontiers in Robotics and AI*, 5. doi:10.3389/frobt.2018.00037
- Du, J. M. (2013, 1). Shared Mental Models for Collaborative Mechanical Design in Mechanical Engineering. *Advanced Materials Research*, 644, 378–381. doi:10.4028/www.scientific.net/amr.644.378
- Elkington, M., Bloom, D., Ward, C., Chatzimichali, A., & Potter, K. (2015, 7). Hand layup: understanding the manual process. *Advanced Manufacturing: Polymer & Composites Science*, 1, 138–151. doi:10.1080/20550340.2015.1114801
- Gascons, M., Blanco, N., & Matthys, K. (2011, 1). Evolution of manufacturing processes for fiber reinforced thermoset tanks, vessels and silos: A review. *lie Transactions*, 44. doi:10.1080/0740817X.2011.590177
- Goldschmidt, G. (2007, 3). To see eye to eye: the role of visual representations in building shared mental models in design teams. *CoDesign*, 3, 43–50. doi:10.1080/15710880601170826
- Hammond, H. (2001). Distributed Collaboration for Engineering Design: A Review and Reappraisal. *Human Factors and Ergonomics*, 11, 35-52.

- Jarvenpaa, S. L., & Staples, D. S. (2000, 9). The use of collaborative electronic media for information sharing: an exploratory study of determinants. *The Journal of Strategic Information Systems*, 9, 129–154. doi:10.1016/s0963-8687(00)00042-1
- Johnson-Glenberg, M. C. (2018, 7). Immersive VR and Education: Embodied Design Principles That Include Gesture and Hand Controls. *Frontiers in Robotics and AI*, 5. doi:10.3389/frobt.2018.00081
- Johnson-Laird, P. N. (1986). *Mental Models: Towards a Cognitive Science of Language, Inference, and Consciousness* (Cognitive Science Series). Harvard University Press. Retrieved from <https://www.amazon.com/Mental-Models-Cognitive-Inference-Consciousness/dp/0674568826?SubscriptionId=AKIAIOBINVZYXZQZ2U3A&tag=chimbori05-20&linkCode=sm2&camp=2025&creative=165953&creativeASIN=0674568826>
- Kim, K., Billinghamurst, M., Bruder, G., Duh, H. B.-L., & Welch, G. F. (2018, 11). Revisiting Trends in Augmented Reality Research: A Review of the 2nd Decade of ISMAR (2008–2017). *IEEE Transactions on Visualization and Computer Graphics*, 24, 2947–2962. doi:10.1109/tvcg.2018.2868591
- Kleinsmann, M. S. (2006, 9). *Understanding collaborative design*. phdthesis, Delft University of Technology, Industrial Design Engineering.
- Kleinsmann, M., & Valkenburg, R. (2008, 7). Barriers and enablers for creating shared understanding in co-design projects. *Design Studies*, 29, 369–386. doi:10.1016/j.destud.2008.03.003
- Kleinsmann, M., Buijs, J., & Valkenburg, R. (2010, 3). Understanding the complexity of knowledge integration in collaborative new product development teams: A case study. *Journal of Engineering and Technology Management*, 27, 20–32. doi:10.1016/j.jengtecman.2010.03.003
- Landman, R. B., van den Broek, E., & Gieskes, J. F. (2009, 9). Creating shared mental models: The support of visual language. In Y. Luo (Ed.), *Proceedings of the 6th International Conference on Cooperative Design, Visualization, and Engineering (CDVE 2009)* (pp. 161–168). Springer. doi:10.1007/978-3-642-04265-2_23
- MacAllister, A., Hoover, I. S., Gilbert, I. S., Oliver, I. S., Radkowski, I. S., Garrett, I. S., . . . Company, T. B. (2017). Comparing Visual Assembly Aids for Augmented Reality Work Instructions. *Proceedings of the 2017 Interservice/Industry Training, Simulation, and Education Conference (I/ITSEC)*, 2017, p. 17208. Orlando.
- Medlock, M. C., Wixon, D., Terrano, M., Romero, R., & Fulton, B. (2002). Using the RITE method to improve products: A definition and a case study. *Usability Professionals Association*, 51.
- Miller, J., Eneyew, E., & Ramulu, M. (2013, 3). Machining and Drilling of Carbon Fiber Reinforced Plastic (CFRP) Composites. *SAMPE Journal*, 49, 36-46.
- Miller, N., Willemsen, P., & Feyen, R. (2018, 3). Comparing Interface Affordances for Controlling a Push Broom in VR. 2018 IEEE Conference on Virtual Reality and 3D User Interfaces (VR). IEEE. doi:10.1109/vr.2018.8446510
- Miura, T., Yoshii, A., & Nakajima, T. (2016). Designing affordances for virtual reality-based services with natural user interaction. *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, 9748, 266-277. doi:10.1007/978-3-319-40406-6_25
- MrBurgerAt. (2019). *Replay System Tutorial*. Retrieved from https://webcache.googleusercontent.com/search?q=cache:6l6MO7olru8J:https://wiki.unrealengine.com/Replay_System_Tutorial+&cd=1&hl=nl&ct=clnk&gl=nl
- Naumann, A., & Hurtienne, J. (2010). Benchmarks for Intuitive Interaction with Mobile Devices. *MobileHCI '10: Proceedings of the 12th international conference on Human computer interaction with mobile devices and services* (pp. 401-402). New York, NY, USA: Association for Computing Machinery.
- Norman. (1983). Some observations on Mental Models. D. GENTNER, and A.L. STEVENS, eds. *Mental Models*, pp7-14.
- Oculus. (2012, 8). *Oculus Rift: Step Into the Game*. *Oculus Rift: Step Into the Game*. Retrieved from <https://www.kickstarter.com/projects/1523379957/oculus-rift-step-into-the-game>
- Ostergaard, K., Wetmore, W., & Summers, J. (2003, 9). A Methodology for the Study of the Effects of Communication Method on Design Review Effectiveness.
- Potter, K. (2009, 1). Understanding the origins of defects and variability in composites manufacture. *ICCM International Conferences on Composite Materials*.
- Radkowski, R. (2015). Investigation of Visual Features for Augmented Reality Assembly Assistance. In *Lecture Notes in Computer Science* (pp. 488–498). Springer International Publishing. doi:10.1007/978-3-319-21067-4_50
- Radkowski, R., Herrema, J., & Oliver, J. (2015, 1). Augmented Reality-Based Manual Assembly Support With Visual Features for Different Degrees of Difficulty. *International Journal of Human-Computer Interaction*, 31, 337–349. doi:10.1080/10447318.2014.994194

- Sanders, E., Stappers, P. J., & Sanders, E. (2016, 10 21). Convivial Toolbox. BIS Publishers bv. Retrieved from https://www.ebook.de/de/product/18377952/elizabeth_sanders_pieter_jan_stappers_elisabeth_sanders_convivial_toolbox.html
- Taylor, & MacDonald. (2002). The Effects of Asynchronous Computer-Mediated Group Interaction on Group Processes. *Social Science Computer Review*, 20, 260-274.
- Wadstein, M. (2019, 11). Unreal Concepts - Updating Data From a Text File at Runtime (UE4). Unreal Concepts - Updating Data From a Text File at Runtime (UE4). Retrieved from <https://www.youtube.com/watch?v=zuJ2tjZW770>
- Walton, M. (2019, 5). Start recording output and stop recording output? Start recording output and stop recording output? Retrieved from <https://forums.unrealengine.com/development-discussion/audio/1649864-start-recording-output-and-stop-recording-output>
- Wang, X., & Love, P. E. (2012, 5). BIM + AR: Onsite information sharing and communication via advanced visualization. *Proceedings of the 2012 IEEE 16th International Conference on Computer Supported Cooperative Work in Design (CSCWD)*, (pp. 850-855). doi:10.1109/CSCWD.2012.6221920





CURRENT STATE OF VR

Virtual reality was first thought of in the '90s. However, due to insufficient processing power to render complex 3D environments and the lack of any affordable lightweight screens the technology was too limited and cost-prohibitive to reach mainstream success. In 2012, Oculus held a successful Kickstarter for the Oculus Rift, a new VR headset. Consequently, this led to a renewed interest in the area. Since then a lot of players have entered the VR market, of which the major players will be introduced in this chapter.

HTC/ VIVE

The high-end HTC Vive Headset, co-developed with Valve, is regarded by many as the default for high-end Virtual Reality. The headset supports full motion tracking, using outside-in tracking. They currently offer a wide range of headsets, targeted to the very high end of the consumer market and also offering high-performance solutions for the enterprise.

VALVE

Originally a game developer, known for popular video games such as Team Fortress 2, Portal and Half-Life 1 and 2. Currently, they are best known for their pc-games store and network, Steam, and never developing Half-Life 3. After creating the successful Vive headset together with HTC, and developing the SteamVR platform, they've struck out on their own and created the Valve Index. This headset sets itself apart with a high refresh screen and unique pressure-sensitive controllers that can also measure finger curl. These controllers allow for new interactions in VR.

MICROSOFT

Microsoft is active not just in VR but also in Augmented Reality (AR). They are best known for the Microsoft HoloLens, a device not released to consumers yet which can overlay information on the real world. Rather than replacing your reality like in VR, it augments it.

They have also seen some success with their Windows Mixed Reality platform, which allows third-parties to develop VR headset with inside out tracking. This is comparable to Windows, where Microsoft develops the software that

runs on the hardware of others. They, however, insist on using the term Mixed Reality, a confusing term that does not distinguish between AR and VR. Microsoft is inherently involved with VR as most VR applications run on Microsoft Windows. They are also the owner of Xbox, a popular gaming console that does not support VR.

SONY

The PlayStation VR (PS VR) is the best selling VR headset right now. This headset works together with the PlayStation 4 to deliver entry-level Virtual Reality with 180 degrees outside in motion tracking. The PS VR is mostly meant for entertainment and is not a great fit for enterprise solutions because it cannot run off a pc.

FACEBOOK / OCULUS

After being bought by Facebook, Oculus has continued to be a large driving force behind the industry. They are best known for their Oculus Rift Headset, this was the kickstarted headset that brought VR back into the public eye. Initially, Oculus offered more limited 180 degrees outside-in motion tracking compared to the HTC Vive, they have since caught up. In 2019 they released the latest generation of their headsets. Most notable of all is the Oculus Quest, a 400 dollar headset that does not require any additional hardware and offers full-motion tracking, using inside out tracking. Facebook is now also actively developing applications for the Quest, the most recent example being Facebook Horizons. Horizons is supposed to become a social network, where people can hangout and play games. They also developed a headset together with Samsung, the Gear VR.

GOOGLE

They are best known for Google Cardboard, a cheap cardboard VR headset that works together with a phone, but offers very little interactivity. This is the form of VR most people will be familiar with. The Oculus Quest runs on a fork of Android, an OS developed by Google. Their latest VR effort, the Daydream platform, was however recently discontinued.

THE FUTURE OF VR

In 2019, the two most notable new headsets that were released were the Valve Index and the Oculus Quest. Both representing different directions for VR. The index has the index controllers, which are touch and pressure-sensitive controllers that can measure finger curl and stay in your head even if you do not grip them. This makes actions such as grabbing and throwing much easier and more natural compared to the older Vive controllers. The Index's high refresh screen of 144hz indicates that Valve seems to be striving for the highest quality VR possible. However, their solution still requires a powerful, and expensive, PC, and it requires mounting "lighthouses" on tripods or walls.

Oculus, on the other hand, seems to be focussing on lowering the barrier of entry for VR. Their Oculus Quest headset does not require a PC at all. It has a built-in mobile CPU and GPU thus it renders everything on the headset. This has the added advantage of not requiring a wire to the PC but it does lead to lower graphics quality compared to PC VR. The Quest also only has half of the refresh rate of the Index, 72 Hz. This leads to less fluent

Figure 86: Oculus Quest



Figure 87: HTC Vive



Figure 88: Windows Mixed Reality Headsets



Figure 89: Playstation VR





Figure 90:
The Oculus Quest in use

motion. Additionally, the Quest does not require any lighthouses like the Index but rather it relies on Inside-Out Tracking. A type of tracking that uses built-in cameras in the headset to determine its location in 3d space. This means the installation of the headset is incredibly fast as a user only needs to draw his play space on the floor. Thus lowering the barrier of entry for VR. Finally, the headset with controllers is, as of the time of writing, only 400 dollars, compared to the 1000 dollars it costs to buy the full Valve Index headset with controllers

and lighthouses. It could very well be argued that this makes the two headsets cater to different markets.

It seems reasonable that these two headsets present what is next for VR. At the one end, you have expensive headsets pushing what is capable in VR. Their main customers being VR enthusiasts and enterprise customers who can afford the higher price tag. On the other end, you have cheaper headsets, such as the Quest, making VR easier and cheaper to get in to for average consumers.

SUMMARY

To summarise, there are currently many different visions of what VR should be and how it should be. Nevertheless, VR seems to be moving in two directions. First, you have companies creating more capable and cheaper headsets. Thus lowering the barrier of entry. Secondly, high-end headsets are becoming ever more capable while still maintaining a relatively high barrier of entry.

COLLABORATION STUDY QUESTIONNAIRE

Collaboration Methods

Thank you for participating in my research on collaboration methods.

There are a couple things you should know beforehand. I have spoken with you last week about which method you would like to talk about. There is a reminder in the email which method you are doing the questionnaire about.

***Required**

General Questions

1. What is your name? *

In order to do a follow up I need to know which answers belong to who.

2. What is your chosen method? *

Mark only one oval.

- Face-to-face
 Video calling
 Voice calling
 Report writing
 Email exchange

3. Roughly, how many years have you used this collaboration method in a professional capacity? *

4. Do you most often use this method in a group setting or one-on-one? *

Mark only one oval per row.

	Solely one-on-one	Mostly one-on-one	Roughly equal	Mostly in group setting	Solely in group setting
Use	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Open questions

The following questions are open questions. I do not expect long answers from you, a short sentence or a couple of keywords should suffice, but what I would like you to do is think about it a bit longer. For example, you can write them down and think about it on the way home. In general, I prefer you to leave the questionnaire for a while and come back later rather than filling it in immediately. You can take a couple of days to fill this in if you like. There are also no wrong answers if you are unsure about something just fill it in and we'll discuss it later.

5. What are the first three terms that come to mind when you think of this method? *

Don't think too long about this one. Just write down the first three terms that come to mind when you think about this method. There are no wrong answers and if you need more words go ahead.

6. When do you use this method? *

What leads to you to use this method to tell, explain, or make clear information to others?

7. What kind of information do you feel this method allows you to express most easily? *

What type of information do you find to be easy to communicate using this method. For example, you can think about: engineering parameters, meeting times or your opinion on a subject.

8. Describe a moment when you used this method to collaborate or communicate with someone with different expertise in a professional capacity. *

9. Were there things that you found difficult to tell, explain or make clear in this situation? *

If so please describe them..

10. Were there things that you found you could tell, explain, or make clear really well or easily in this situation? *

If so please describe them..

11. Why would you use this method over the other methods, in this situation? *

What makes this method especially more suited for what you wanted to communicate, compared to the other methods?

Open
questions

You can be brief in your answering of the following questions. It is however important to give it thought. If you don't immediately know the answer

12. What did you find this method allows you to communicate easily or well in this situation?

13. What did you like about using this method?

14. What did you find hard to communicate well in this situation?

15. What did you dislike about using method?

16. What were you trying to convey to the other person using this method? *

17. Did you need to explain yourself further? If so how did you do that?

Did you use the same method or a different one?

18. Why would you use this method over the other methods? *

As a reminder, the collaboration methods are: face-to-face meetings, video meetings, phone calls, report writing, and email exchanges.

19. Why would you NOT use this method over the other methods? *

As a reminder, the collaboration methods are: face-to-face meetings, video meetings, phone calls, report writing, and email exchanges.

Keywords

20. Keywords *

Please indicate which keyword applies more to this method if . 3 is equal to fully the former term, +3 is fully the latter term. 0 = neutral. To give an example -3 is completely cumbersome and +3 is completely straightforward.

Mark only one oval per row.

	-3	-2	-1	0	+1	+2	+3
Cumbersome - Straightforward	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Human - Technical	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Pleasant - Unpleasant	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Unimaginative - Creative	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Simple - Complicated	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Professional - Unprofessional	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Predictable - Unpredictable	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Rejecting - Inviting	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Brings me closer to people - Separates me from people	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Confusing - Clearly structured	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Undemanding - Challenging	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
motivating -Discouraging	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Unruly - Manageable	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

21. State your current opinion on this method in about 3 keywords *

What are the first three terms that come to mind when you think of this method?

This content is neither created nor endorsed by Google.



COLLABORATION STUDY FOLLOW UP QUESTION GUIDE

OPINION

1a. What are the first three terms that come to mind when you think of this method?

I expect to receive people's opinion. Briefly explain the 3 associations, where do they come from. Can you give an example of how it is traceable, reliable, messy etcetera? Remember these and use them later.

CONTEXT

2a. When do you use this method?

Why do you use them in these moments?

When given reasons rather than a moment, why do you want to do this? What value has this to you?

2b. Describe a moment when you used this method to collaborate or communicate with someone with different expertise in a professional capacity.

Can you go into more detail, for a specific example?

I expect to hear an example of a difficult situation. So what made the situation difficult would be a good follow up and then asking more about the difficulties.

2c. What were you trying to convey to the other person?

Were you trying to convince them, inform them, or motivate them?

Can you give a specific example?

INFORMATION

3a. In a more general sense, what kind of information do you typically share using this method?

List some things. Why do you decide to use this method for that?

3b. Of that, what kind of information do you feel this method allows you to express most easily?

What kind of information is it? What does it consist of, abstract, concrete, pictures, motions, etc.

Why is this easiest with this method? What is the reason? Did you find that you found you could tell, explain, or make clear really well or easily in this situation?

3c. Do you think you can share this in another medium, why or why not?

What would be lost if you were to do it through another medium.

3d. Were there things that you found difficult to tell, explain or make clear in this situation?

No? Okay but what would you hesitate telling something using this method in this situation?

Yes, how do you deal with that situation?

Do you ever feel limited in expressing yourself using this method?

3e. Do you use this in support of other collaboration methods or vice versa?

If yes how come?

Is anything lacking?

If no, why not? Do you find that it is immediately clear?

Ask about the scope that they use it in. If scope is more limited a follow up might not be needed. Do you receive follow up questions?

3f. Do you find often afterwards that people have interpreted what you said differently and does that lead to problems? For example did they take different steps then you would have taken.

Do you get questions back when working with this method?

3g. How do you deal with technical jargon that you don't know? Do you need to explain yourself further (later)?

Do you then use the same method? No, which method why that method.

3h. What is the main thing you use to convey information using this method?

Written words, Spoken words, Motions, Pictures, Colours, Complex math problems, screenshots.

Why that one?

3i. Can you explain which additional elements you use with this method?

Written words, Spoken words, Motions, Pictures, Colours, Complex math problems, screenshots.

Why do you use these? Do you use these to convey additional information? Can't you get that using the main method?

3j. Do you use any supporting tools with this method?

When they say they use one ask them what makes them use that one...

Why do you use that one? Why don't you use one?

OPINION AGAIN

4a. What do you like about using this method?

Directness, indirectness. Paper trail, non-paper trail

4b. What did you dislike about using method?

Anything that stands out

4c. Can you sum up for me, why would you use this method over the other methods?

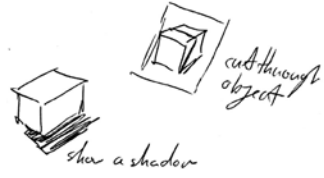
Do you like using this method? Just write down their answers. See if it rhymes later.

4d. And also, why would you NOT use this method over the other methods?

Just write down their answers. See if it rhymes later.

4f. Again, state your current opinion on this method in about 3 keywords

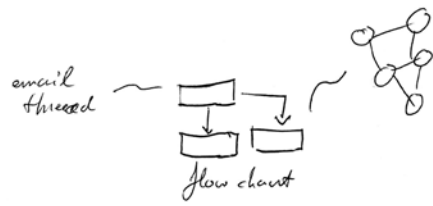
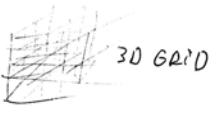
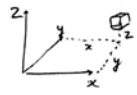
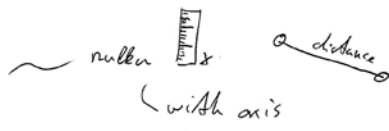
HKJ IDEATION RESULTS



HKJ show location in 3D space (absolute and relative)

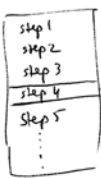
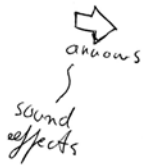
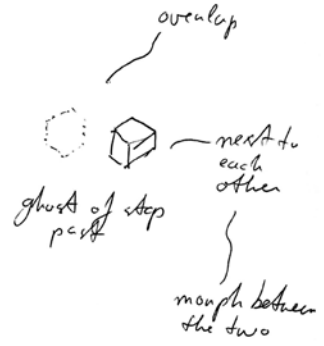
proximity map
light up objects

3 different coloured lines (vectors) from origin to object. clear indication of axes.



HKJ show connection between steps

Overview of all the steps, along with the current step highlighted, to give context and an indication of progress



top view
 export 3d model of drawings
 3d print

fixed video with depth
 render to google cardboard

export audiobook

qr code
 receive in email / report etcetera
 - render in browser
 - view interactive scene

HKJ export VR to other media

- spectator cameras when in VR - provides overview of the session in a non-nauseating way.
- Multiple spectator cameras for multiple camera angles?
- Camera automatically following the user or object of interest
- User can manually position the virtual camera

virtual camera
 take photos in vr
 {
 balance in desktop
 gifs

show a paper plane in a basket
 }
 skeuomorphism

via email
 type in
 program select a guy
 use email as modification

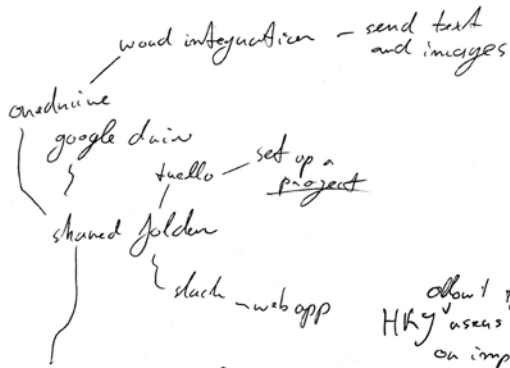
- send/receive info:
- Voice over IP: voice chat in VR
 - Emojis to express emotions

- send/receive objects/data
- Type text on computer, display text in VR
 - File readers in VR?
 Pdf, excel, csv readers

HKJ send and receive something in VR

program a guy
 }
 create a standard group of people
 }
 block like environment
 }
 channels

hello



to do list with models attached

about to HKJ users input/models on input anything

File browser in VR: search for compatible files in the computer from within VR.

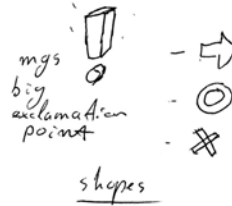
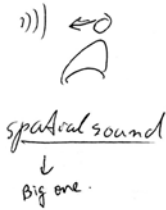
webtransfer - drop into bot

Voice commands to search / open / import models etc.

google assistant

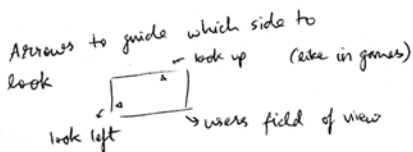
whatsapp

send via email to specific mail address



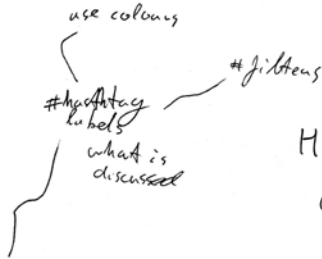
HKJ draw Attention on guide users eyes

Apart from drawing attention, wait for user to look at object before continuing progress



make voice into
transcript and make
the transcript searchable

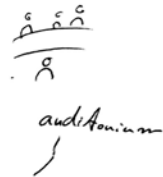
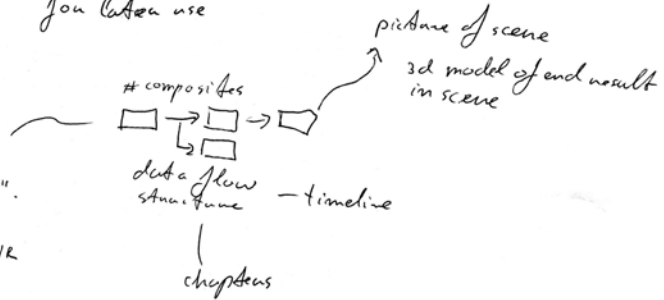

add the current
date



HKY make non-verbal information
findable / traceable
you later use

Assign an icon / 3d model
as labels for info - make
info visual.
Place those labelled info
pieces in a "knowledge-inventory".

Record short "video" clips in VR

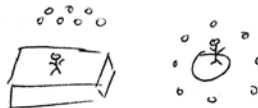


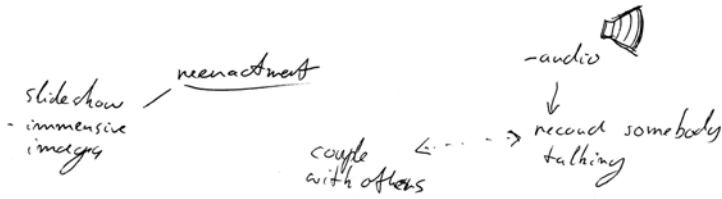
HKY create the feeling of
gathering round
without others present



ambient noise
with people
ban background
noise

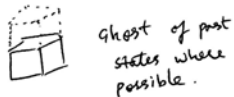
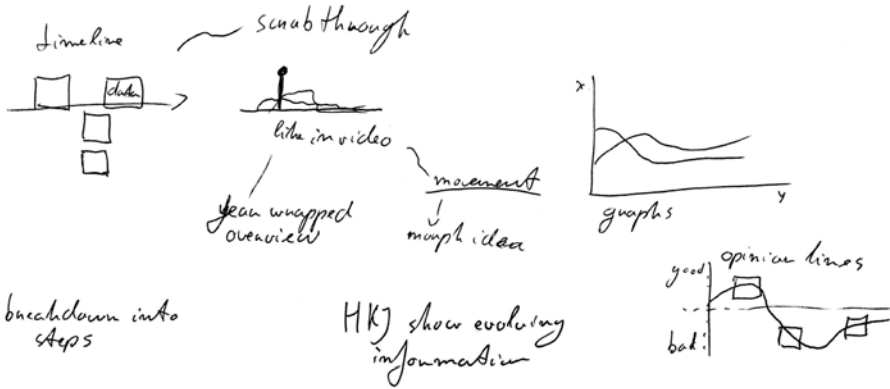
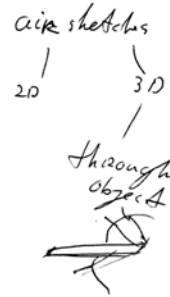
Dedicated "stage" area
and "audience" / observer
area.





WKJ info kind of information/data/expressions
 can you capture in VR and How?

- sequence of steps, specially when steps involve manipulating objects in 3D space - visual avatar / model based
- speed of object handling which could provide a sense of how delicate an object is. ~ hands position
or how heavy an object might be.
- ~ showing weight



send message when new stuff is recorded

emojis
☹ ☹

like in telescope
↳ spam hearts

watch on pc
attach text blocks

floating response blocks



HJK lot people respond in VR (afterwards)

screenshot + email

annotation will be visible in vr

- Record a voice msg reply
- Draw / annotate
- Link comments to other comments - create a thread or a graph

different colour

- Provide a way to review information
- option to modify / edit / delete
- to edit text info, link to computer



HJK lot people revise captures of information

redo or info track

break into steps

video editing timeline like premiere

smaller chunks easier to undo



fold up throw into trash

RITE QUALITATIVE QUESTIONS GUIDE

1. Did you feel like you were able to express yourself fully? (Could they communicate their Mental Model)
Why/why not?
What did you want to express that you were not able to?
2. Were there any tools you missed having?
If yes, what and why? What would you hope to achieve that you could not.
3. Were there any tools you did not use?
If yes, why? Do you think there would be a use for it
If you saw them not using it, make them aware of it.
4. Were you confused by something?
If yes, what and why?
Which function did they confusing? If modes are introduced are they confusing?
5. Were you able to understand the step process?
Did you create small steps? Why not?
Where you able to skip, play, pause and record?
6. Did you feel stress while recording?
If so, when and why?
If not, why not?

QUESI QUESTIONNAIRE

		Fully disagree	Mainly disagree	Neutral	Mainly agree	Fully agree
1	I could use the system without thinking about it.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
2	I achieved what I wanted to achieve with the system.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
3	The way the system worked was immediately clear to me.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
4	I could interact with the system in a way that seemed familiar to me.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
5	No problems occurred when I used the system.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
6	The system was not complicated to use.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
7	I was able to achieve my goals in the way I had imagined to.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
8	The system was easy to use from the start.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
9	It was always clear to me what I had to do to use the system.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
10	The process of using the system went smoothly.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
11	I barely had to concentrate on using the system.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
12	The system helped me to completely achieve my goals.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
13	How the system is used was clear to me straight away.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
14	I automatically did the right thing to achieve my goals.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

WRITTEN DESCRIPTION OF LAY-UP

PLACING COMPOSITE ON THE CUTTING TEMPLATE AND HOW TO CUT IT

Place the composite roll on the holder. Place the cutting template in line with the composite holder. Next up, unroll the composite, with the green side up, from the holder onto the template but overshoot slightly on the outer edge. The outer edge is the edge the furthest away from the roll.

Make sure the composite is kept straight when placing it down on the cutting template. It is not necessary to press it down hard as this would make it harder to remove. When the a strip of composite is placed on the cutting template first check if it is within the lines. Do this both from above from the sides. Once it is placed correctly, cut the outer edge along the cutting lines on the template.

Be sure to cut straight through the composite in a smooth motion to make a straight cut. If any fibres are torn along the length of the composite then lift the composite and place it down further on the template. Getting the first toes right is very important to get a good result later on.

If the cut is successfully done on the outer edge, cut the inner edge as well. At this point, you have created your first composite toe.

HOW TO REMOVE NEATLY FROM THE CUTTING TEMPLATE

The composite material is slightly sticky. If it is straight out of the freezer it is less sticky which makes it easier to place down and also pick up again. Once it warms up the binder will start flowing and the material will harden, binding the composite material together.

Now how to remove the composite toe from the
152 - Appendix

cutting template. Because of the stickiness, special care should be taken when removing it from the cutting sheet. Often you can just lift the toe upwards but if the material is warmer you will find it sticking to the surface more often.

If it sticks to the surface, you should first try to slightly lift the outer edge of the toe. If this comes loose grab the edge and pull away from the other end. Do not pull the toe straight up. The straighter you keep the toe the better. This prevents you from damaging fibres and pulling other toes with it.

If it still does not want to loosen you can use the face of the knife to push the toe upward while still pulling at one end. Be careful not to cut through the material while doing this, as this would weaken the final product. If all else fails, use the freeze spray on the sticking part of the toe.

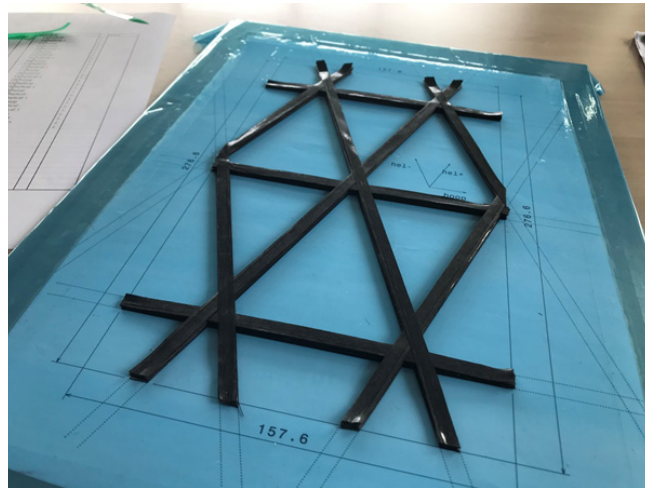
Once the toe is loose you can keep it around on the cutting template. It won't fasten if you don't press down on them. Repeat this until you have enough toes for the first layer.

HOW TO PLACE IT ON THE TEMPLATE

Now that the toes are cut it is time to place them down. That is done on the lay-up template. The lay-up template has lines indicating the grid made of triangle shapes. This grid makes the material able to resist very high loads while being as light as possible. There are several key features we will pay close attention to. These are the outer edges of the template and the place where the composite toes cross each other. The latter are called knots.

It is advisable to start with a hoop toe but in general follow the instructions on the sheet (not provided here). Align the outer edge of a hoop toe first to the outer edge of the lay-up template.

Keep in mind to place the green protective film side on top. Then while using one hand to keep tension on the other end of the composite, use the other thumb of the other hand to guide the material down into place. Again keep the material as straight as possible. While you're keeping tension on the material you will notice that there is no stretch to the composite. Exercise enough tension so that the material keeps straight, this is to reduce waviness, but don't pull hard enough that the material starts moving. Try to only press the toe down on the lay-up template where the toes are supposed to cross. Once the toe is placed properly within the lines of the template and press down repeatedly with multiple fingers on the toe to stick it to the surface. Do not slide your finger over the toe anymore to prevent it from shifting.



HOW TO REMOVE THE PROTECTIVE FILM

Now we need to remove the protective film. Take the knife and carefully stick the tip, facing down, into the protective film but be careful not to press it through the composite. You then twist the tip of the knife 90 degrees. Then you can pull up. This should create a small air bubble. Now you can easily pull the film off with that start. When pulling be careful not to rip off the side of the composite toe. If the side of the composite toe goes with the film, cut it off with the knife to prevent pulling it further.

NEXT LAYERS

Repeat this process with the other 2 toes in the hoop ply. And then for the other 2 plies (helical + and -) to complete the first layer. Repeat this process for the full twenty layers but do not press down with multiple fingers when it is placed. Placing them down, using your thumb as guidance is sufficient.

QUALITATIVE RESULTS RITE



Figure 91: Drawing functionality in first MVP

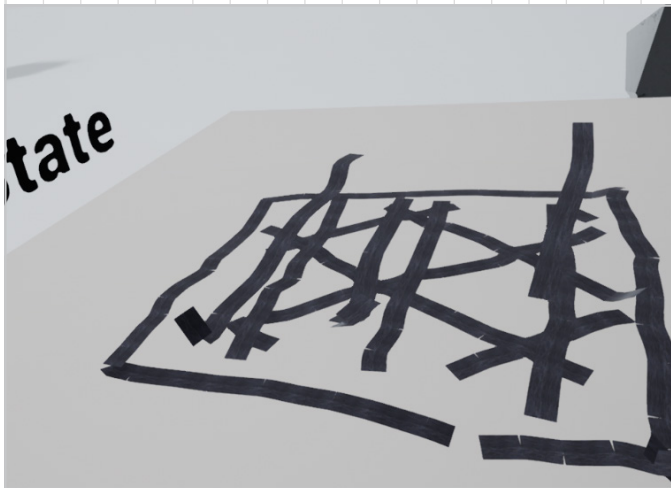


Figure 92: Sketch made of template by participant during evaluation of the MVP

A list of changes during the RITE prototyping phase was kept. The changes and the reasoning behind them will be explained in detail in this chapter:

MINIMAL VIABLE PROTOTYPE

For the minimal viable prototype, a bunch of functions needed to be implemented first, to get to a testable state. This took 2 weeks to complete. The functions implemented were:

FUNCTIONS IMPLEMENTED

Audio functionality

Audio can be recorded as well as played back. However, pause is not implemented yet.

Persistent save games

Steps are saved between sessions

Object position recording and playback

These objects can be extended to fit any mesh. The implementation chosen is one where it writes a TXT file to disk. By keeping the path to this file in an array we can replicate the object position later.

User head and hand position recording and playback

This was done by extending the object position class.

Drawings

- Users can use the controllers to draw 3d geometry
- The position of this drawing can be recorded too, like a normal object would move.
- Drawings cannot be removed yet, nor can you move individual points
- There is a known bug when taking

them to the next step

Step functionality

- Add step
- Skip step
- Play/pause step
- Functions are created for delete steps but there is no way of calling them yet

Debug keys

Currently there is no UI in VR

Audio-visual environment

A skybox was made that responds to the state that the user is in. This was a fun thing to do in an hour.

RITE CONCLUSIONS

Objects

The participant tried looking for a working surface but was unable to find one. It would be nice to be able to adjust the height of it. They mentioned snapping drawing to the surface to be able to draw flat on it. This table will be implemented. It might be good to find a solution for making flat drawings rather than 3d drawings. A lay-up template was drawn by the user, however this should come with the VR tool.

Drawing tool

The drawing tool was used to draw not only composites but also objects, it is good that it has a multiple purpose way.

The length of the segments were made smaller during the test, which made drawing a lot easier. Implementing the last segment updating while drawing would also be beneficial so that the participant can more easily make a dot. Width adjustment was requested but did not seem necessary yet.

The eraser tool was missed. The participant wanted to erase nodes rather than entire drawings. There is potentially no time for that but the goal is to have at least a drawing eraser tool. There are a couple of in between steps:

1. Implement Swappable drawing tools
2. Add a deletion point to the objects
3. Hide objects on deletion
4. If objects are deleted then do not copy them to the next step

The participant mentioned wanting to indicate exact distance. The ruler from the concept was not implemented yet, this would be good to add.

Locomotion

The smooth locomotion is too sensitive and too fast. Would be better to use for small adjustments.

Critical

The participant forgot to press record. They just started drawing and explaining. For now, the solution seems like a clearer distinction in what state they are. A UI for this would work well and needs to be designed.

Next steps

1. Reduce locomotion speed and sensitivity
2. Model working surface/templates
3. Model a roll and a knife
4. UI for play or record mode and clearer step indication
5. Implement swappable tools
6. Implement colour switching of drawing tool
7. Erasure tool, both for steps and individual composites.

ITERATION 1

CHANGES MADE

Recording and playback UI

A big focus for this iteration was to tackle the issue with people not triggering the recording tool. In my observation this was not done because there were no clear instructions on what state or step users were in. Therefore this iteration main focus was to introduce a clear set of UI that allowed users to more easily understand and make use of the functions of the tool.

Too that end, two main panels were created that could be switched between (not pictured here). The switching was made as a way to distinguish between a playback and recording state. Coincidentally this also allowed me to reduce the amount of buttons visible at one time.

The playback panel, contained several layers of information. The first layer would show you the current step, in the picture this is step 0. It is still called step 0 because arrays start at 0 and it helps me understand the code better that way. The next layer of information is where you are within the step. On the left is the current playtime and on the right is the total duration of the step. The bar in between should move based on the playtime. Underneath that is the controls, these allow you to play/pause, go to the next or previous step and delete a step.

Then there is the recording panel. It shows the duration of the recording in the black panel (in the picture it is not recording) and also between which two steps you would be recording.

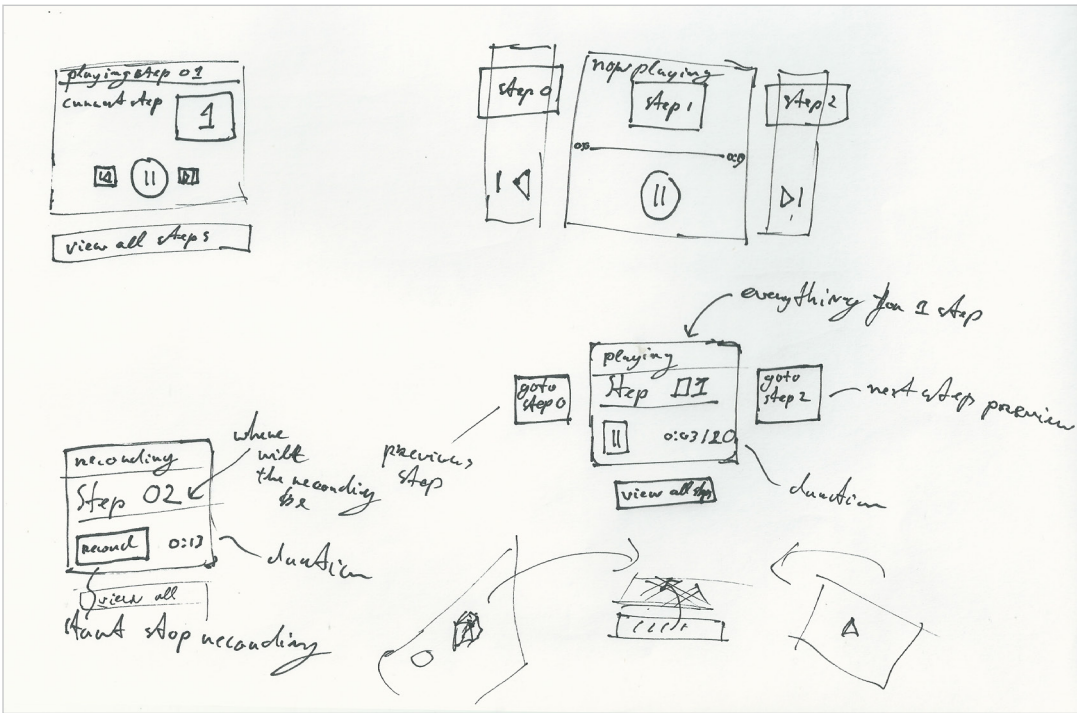


Figure 93:
Recording and
playback menus
ideation, iteration 1



Figure 94: Drawing tool UI, iteration 1

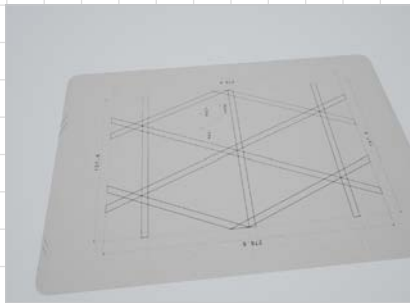


Figure 95: Working surface lay-up template,
iteration 1

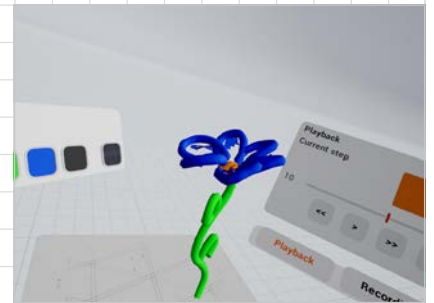


Figure 96: Drawing made by participant
iteration 1

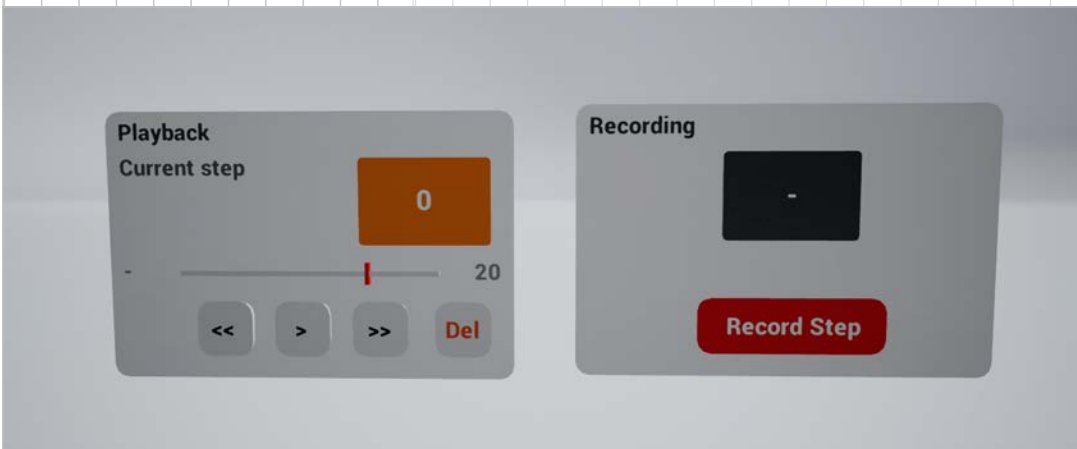


Figure 97:
Recording and
playback menus
implementation,
iteration 1

The rest of the panel is taken up by a large recording button. When people record a smaller button shows up that allows them to create a new step while keeping the recording rolling. If you press the record button the environment dims and the text on the button record button changes to indicate the recording state.

Buttons

In order to make these panels function, some simple buttons were created that would press in when you touched them and give you a bit of tactile feedback.

Drawing tools

Drawing tools can now be let go and swapped. Two different tools were implemented, a composite tool that draws flat meshes and a sketch tool that has volumetric round meshes. Colours can be switched on both tools. This could have been restricted for the flat tool but there was no reason to do so. Instead there are 5 colours and a composite texture.

Working surface

Additionally a table with a layup template was added. It can be moved around freely but when a user let's go of it, the template will automatically place itself flat in the world.

Small changes

Furthermore, there were many small changes and bug fixes in the recording code. A grid on the bottom of the environment to give more distinction between the menus and the background was also added. This helps users to position themselves in the space. The Locomotion speed was reduced to 1/3 of original speed.

RITE CONCLUSIONS

The drawing tool was perceived very well. Not only were they able to show composite lay-up, people found using it quite fun. However it could be improved by adding the removal function, and being able to move the drawings.

Moving around works well and does not make people nauseous anymore.

The simple buttons were too easy to unintentionally trigger, for example you could trigger them walking backwards. A simple fix seems to be to deactivate buttons when moving around. A better fix would be to have to actually press them in rather than just touching, this would give an opportunity to cancel the action. This will be a recommendation for the next steps.

The users was still confused by their position in the steps and what state they were in. In my observation this was because of 2 issues the first one being not providing enough insight into all the steps. It would display the step number but not how many steps there are and how they follow each other. Second, it would allow for too many accidental state changes, partially due to accidental button presses, therefore state and step changes should be more intentional.

The design that I'm going for is displaying all the steps at once in a timeline kind of interface with the active one being visible. Users can then select a step to play or a plus button in between steps to add a new step (record).

The lay-up template worked well,

but a cutting template would also be desirable.

Finally it is of note that this iteration received worse scores than the previous iteration. This is most likely not due to it actually being worse but because the participant interpreted the score sheet differently.

ITERATION 2

CHANGES MADE

Timeline and playback/record UI

During this iteration the main focus was on the step UI. This was largely overhauled to be clearer and more intentional. The main goal of making the UI more intentional is to prevent accidental actions that confuse the user and creating more chances for the user to receive feedback from the system. In this iteration a timeline for the steps was introduced. By creating a timeline, as in Figure 97 on page 156, the step order is visualised making it easier for the user to understand where they are in the process.

The playback and record mode were separated into two separate modes or environments. Users can no longer quickly switch between record and playback. Users now need to specifically select to record or play a step on the timeline and once they are done bounce back to the timeline. The UI of the playback and recording panel was also changed to clearly state the step the users are acting on, providing clear feedback on user actions. Additionally labels were added to most items on the menu. This makes the process of recording and playing very intentional, which leads to a better understanding of the system and the

Figure 98: Timeline interface



Figure 99: Update recording interface

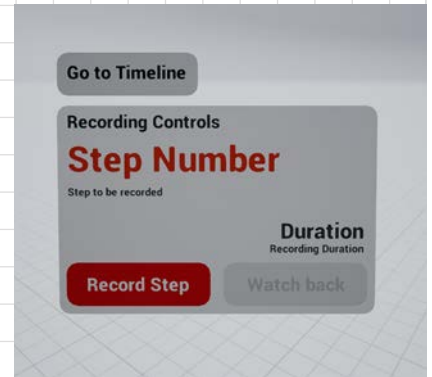
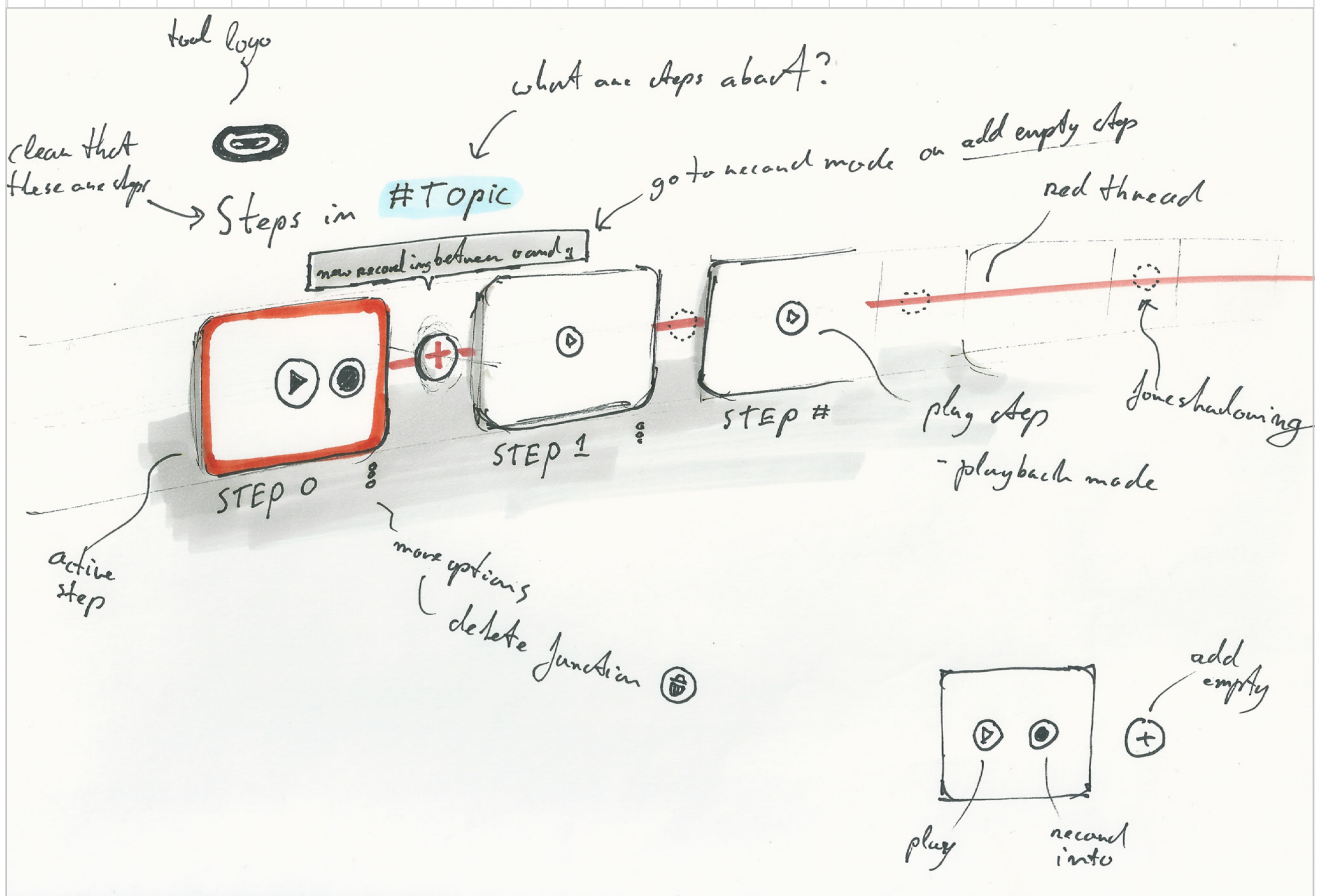


Figure 100: Timeline ideation



users position in the system.

Adding new steps is also improved, a new step can now be added directly to a position in the timeline. The new step is first displayed in the timeline and clearly indicated as empty by giving it a different colour and displaying it as a "New step". In order to record into the new step, the users presses the record button on the step to take them into the step and then record on the panel to actually start recording. This affords the users to check if the step placement is correct, two times, and reorient themselves when going into the record environment. Providing plenty of feedback and making the action very intentional.

Furthermore to reduce accidental actions, buttons will no longer press when a user moves using the joysticks. This prevents the user accidentally pressing buttons while moving backwards.

In short, the added timeline, separation of play and record mode and changes to UI should improve understanding of the current step and mode users are on and reduce confusion due to accidental actions.

Small changes

During this iteration a bunch of buttons were added as a placeholder. These buttons are disabled but do take up space in the UI. This is to indicate where the prototype could be extended upon after this project. It gives a more complete view of the concept without requiring much time.

Finally, the format of duration was changed to be more like it's archetype,

e.g. digital clocks. Before the duration was displayed like this "3" or "63", this was changed to "0:03" and "1:03".

Large parts of the recording code was rewritten to be more stable and work with the timeline.

RESULTS RITE EVALUATION

This iteration tested very well, which can also be seen in the questionnaire results. The current step, the step that a user can act on, was clear to the user and if not they could easily find this information. Playing back a specific step was easy and recording a new step at specific position was achieved without much effort as well. The new recording and playback panels more clearly communicated their main action. One main thing is that users sometimes got disoriented when switching between recording/playback and the timeline if they did not see an object after switching. This could be solved by spawning them at a fixed position.

While adding a new step, it was added slightly to the right of the user. Therefore a user did not always see the new step being created. Possible solutions could be to animate the new step in or shift the timeline to have the step open in front of the user.

The duration display was clear to the user. They could for how long they were recording or playing.

The iconography of the play button was slightly unclear. This is fair as the icon is currently the ">" symbol. A filled in play button would work better.

Apart from the already mentioned suggested changes, the next steps should be to improve the drawing/composite tools.

ITERATION 3

CHANGES MADE

Models and model browser

The models were created based on features within the composite lay-up process. This should help users to more easily explain the composite production process.

- Two Lay-up templates were added, a cylindrical template and a flat template.
- Cutting template. With an alignment sheet on top of it in order to draw flatter composites.
- A ply sheet, this is the sheet that is used during lay-up to keep track of layers done.
- A Stanley knife, used for cutting and removing double composites.

A way for the user to add these models during the recording was necessary. A placeholder panel was added that has buttons for every model, that when pressed spawns one in front of them.

Cutting template

In order to allow users to more closely represent the composite production process, during which composites are cut to size on a cutting template and then moved to the lay-up sheet, drawings can now be picked up and moved. A hover effect was added to indicate which drawing would be picked up if they are in close proximity.

Alignment sheet

When drawing a layer of composites

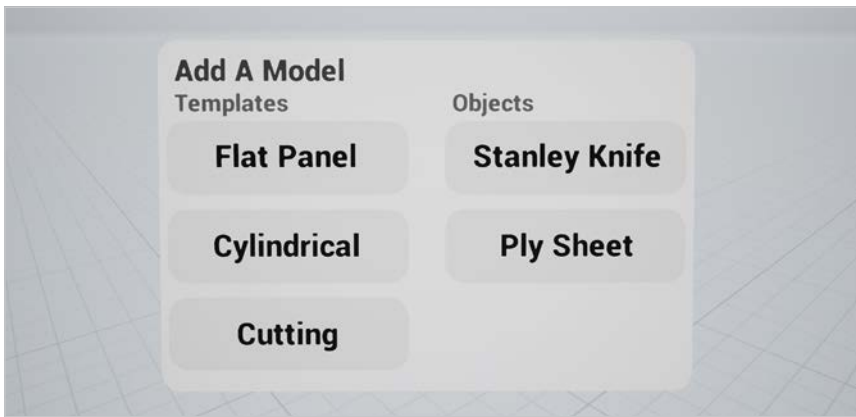


Figure 101: Model browser

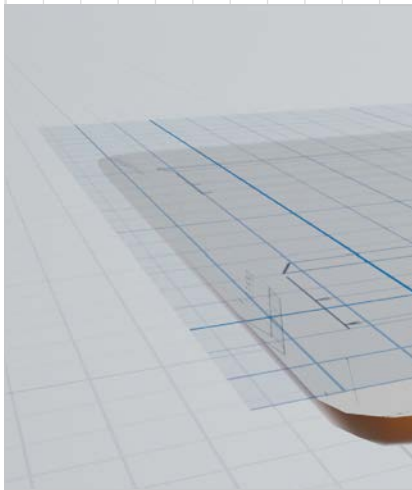


Figure 102: Alignment sheet on top of cutting template

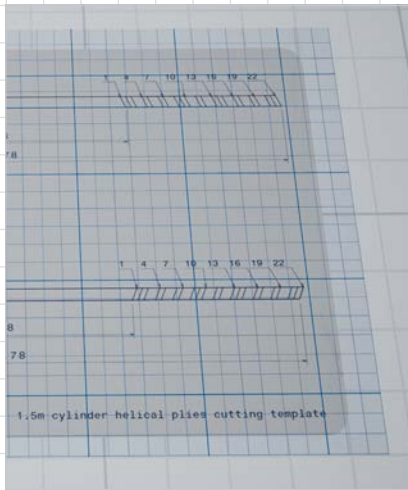


Figure 104: Cutting template with alignment sheet from above

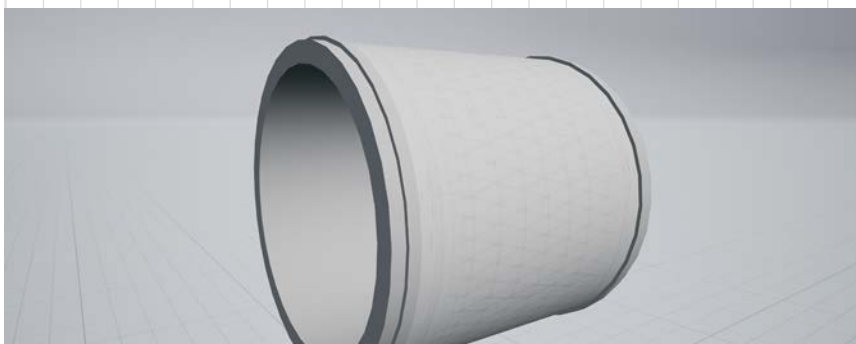


Figure 103: Cylindrical Template

users had trouble keeping the composite flat. This makes it hard to do lay-up as the toes would often clip through each other. In order to help this an alignment sheet was added to the cutting template. By drawing within a boundary box, a drawing is automatically snapped to a fixed z-height in world space. This means a user can still draw freely but get a perfectly flat composite.

Finally, better contextual UI during playback. The drawing tools and model browser are auto hidden while playing back a recording. This more clearly communicates what a user should do during recording and during playback.

Small changes

Slimmer sketch and composite meshes for finer drawing. This was preferable to allow for finer grain movement.

Objects that are added later in a recording now only become visible during playback at the time they were added.

Heads and hands are now automatically added to a scene and are thus recorded again.

Changes to movement

Teleportation option Removed it was not discoverable and only led to unexpected behaviour.

Fixed smooth locomotion to take user orientation into account.

Changes to get the prototype to run standalone on the Oculus Quest. This would be beneficial for testing as it simplifies set-up.

Overridden the GameMode in the map as it had trouble finding it otherwise,

only on the Quest. Added a larger tolerance to the movement check for the buttons as it would never allow you to press buttons before.

RESULTS RITE EVALUATION

Models

The selection of models is good for now. The user found the models helpful and understood their purpose. Unfortunately the participant had limited knowledge of composite lay-up process and thus had difficulty explaining the composite process without instructions from the researcher. He did not miss a model. It is hypothesised that was largely due to the instructions not requiring more models. This participant should not be used for further tests that require knowledge of the process. During the next test the selection might still change. Another improvement that can be made is a better spawn location for larger models. Large objects spawn around the user leading to confusion.

Drawing flat

Users still had difficulty drawing straight composites. The reason this happens is two-fold. First, it is hard to keep the drawing tool at a single height. Second, users draw composite very slowly whereas they would get a better result with quick strokes. For this there can be two solutions, maybe a more node based approach which allows for precision placement or the encouragement of quick and dirty usage of the tools.

The alignment sheet had the intended effect, users were able to draw flat composites which improved the lay-up experience. However, there were 2

main issues with it. 1. It wasn't clear that it would draw flat in the z-space and second it would be more useful to separate it from the cutting template. By separating it can have a broader set of uses, it allows the user to use it in ways not imagined yet. It would be good to also implement being able to use it an angle for the cylinder. Additionally, drawing flat composites worked now but there should be a solution to be able to place composite toes flat in the world too.

Tool usage

Users try to create literal representations of the composite lay-up. However this is not always necessary or even the best way to explain something. The tool lends itself to exaggerate situations or create more abstract representations in order to more clearly explain a process. It would be beneficial to see how this can be encouraged during usage.

Technical issues

The colliders on the drawings are still a bit unclear. Users would often try and grab a drawing in the middle but they could only grab it at the start of the drawing. This might not be changed in the prototype but will be useful to take into account for a final project.

Change the name the Stanley knife to cutting knife. Users did not understand what a Stanley knife could be used for. Cutting knife clearly communicates function.

ITERATION 4

CHANGES MADE

This was the first small iteration but unfortunately also the last. The

focus was to improve the layering experience. The alignment sheet was separated from the drawing templates and already drawn composites can be snapped to it. This makes it easy to make a layer of composites. Finally, the composites highlight when they can be grabbed making it easier to see what you are picking up.

RESULTS RITE EVALUATION

The snapping of composites to the alignment sheet is useful and discoverable through use. However, there is a technical issue where the composites would end up aligning to low. This needs to be fixed. Until then the recommendation is to only snap to alignment tool and not the templates.

Users weren't missing any functions anymore. They were able to explain everything that was asked of them. In addition, they preferred this tool over making a written description. In conclusion, the usability of the current functionality is fleshed out enough and it would thus be recommended to expand functionality.

BLUEPRINT CODE

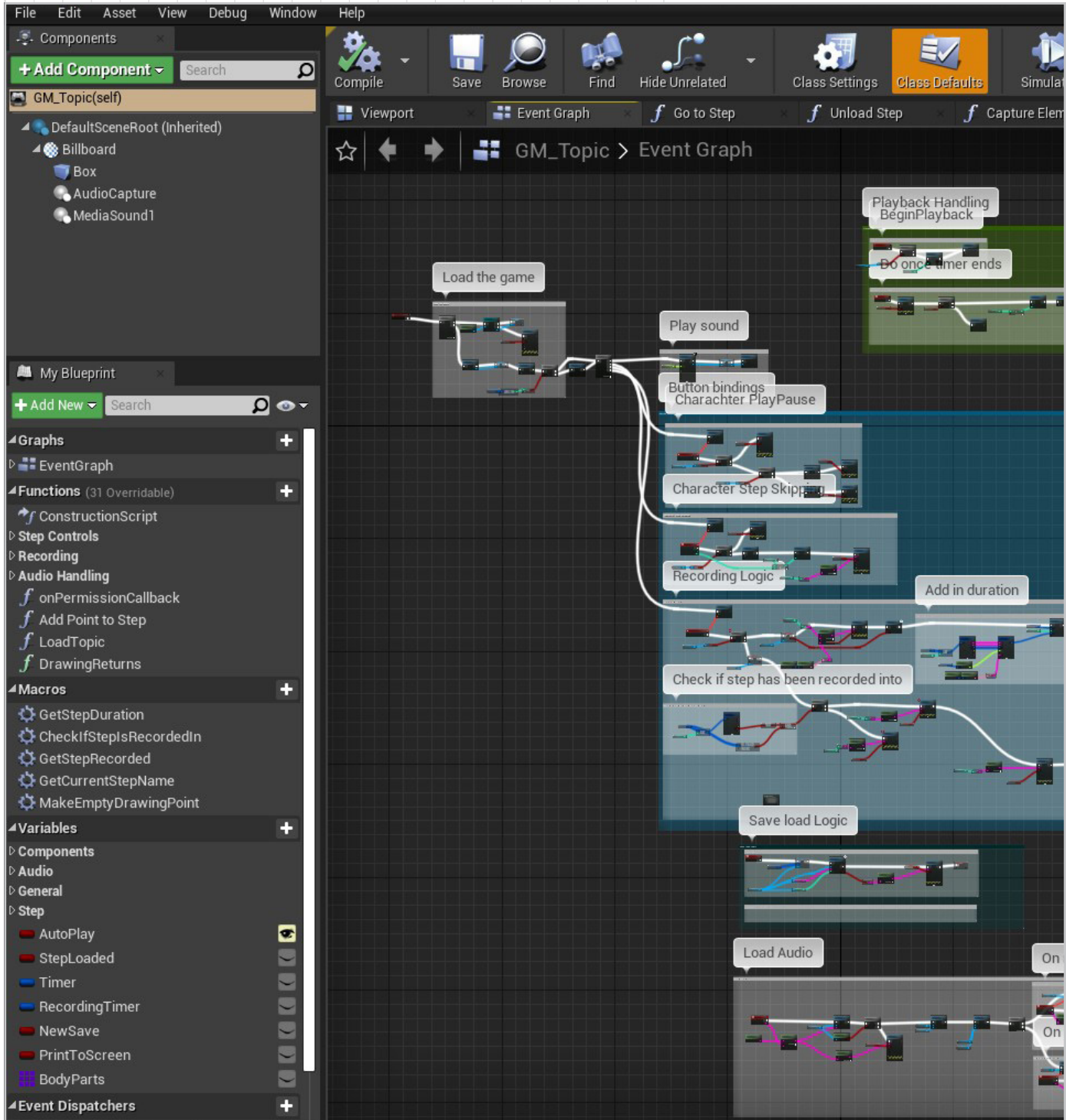


Figure 105: Blueprint code and coding interface for GameMode Topic

on ▶ Play ▼ No debug object selected ▼ Debug Filter

ent: f Add Step f Drawing Returns f Load Step

Zoom -12

BLUEPRINT

Parent class: GM Replay 🔍 🔗

🔍 Details ✕

Search Details 🔍 📄 👁

Actor Tick

Start with Tick Enabled

Tick Interval (secs)

Allow Tick Before Begin Play

Default

Auto Play

Step Loaded

Timer

Recording Timer

New Save

Set Items to End Of Recording

Reset Timeline

Set Active HUD

Print to Screen

Body Parts 3 Array elements + 🗑

Set Play State on Items

Toggle Play

Toggle Record

Set Active Step

Set Record State on Items

Audio

Submit SS_Microphone 🔍 🗑

Max Volume

Min Volume

Media Player MP_Audio 🔍 🗑

FMS Media FMS_Audio 🔍 🗑

General

Save Game 🔍 🗑

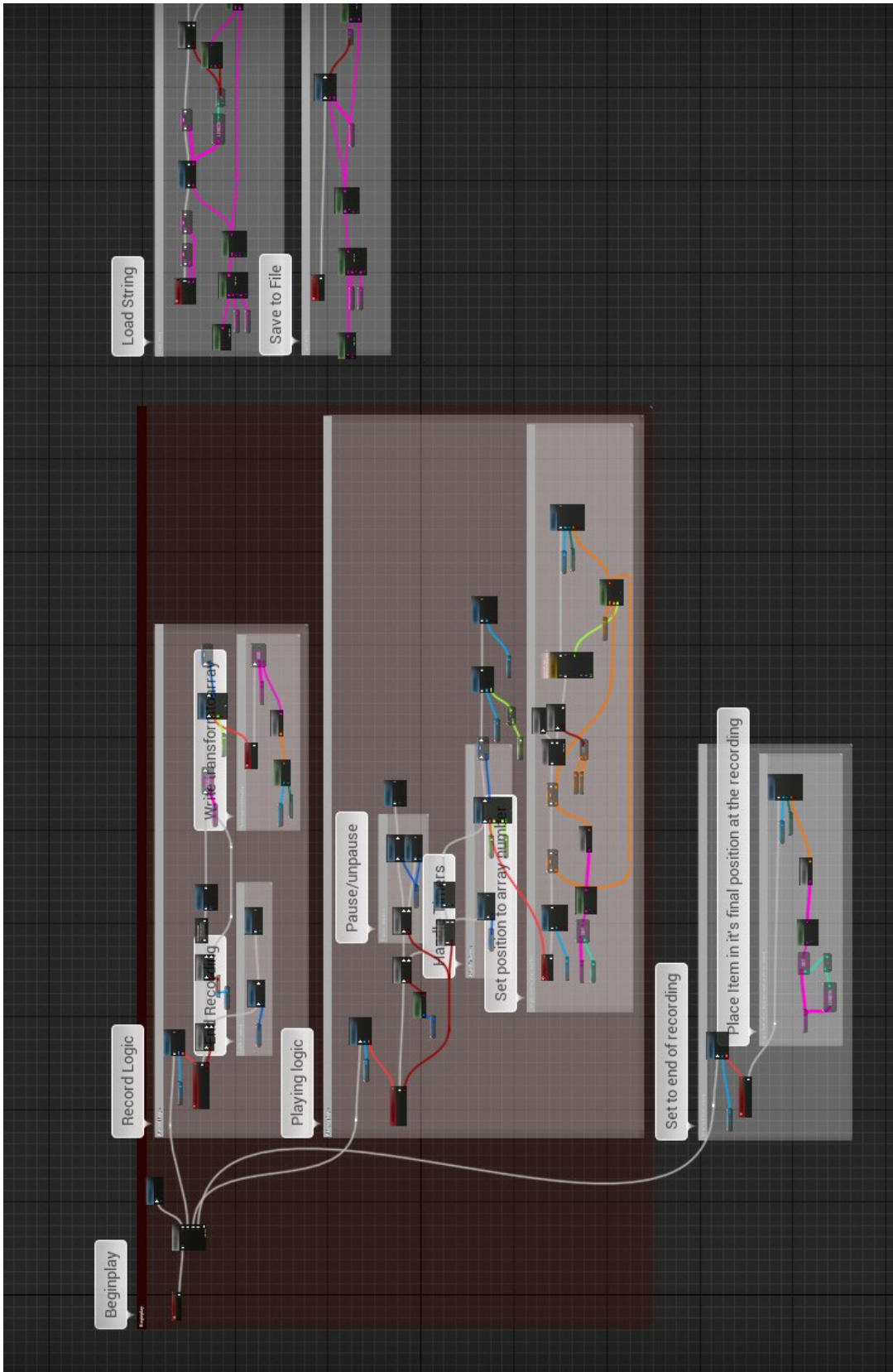


Figure 106: ReplayPoint code for loading, saving, recording and playback of single item

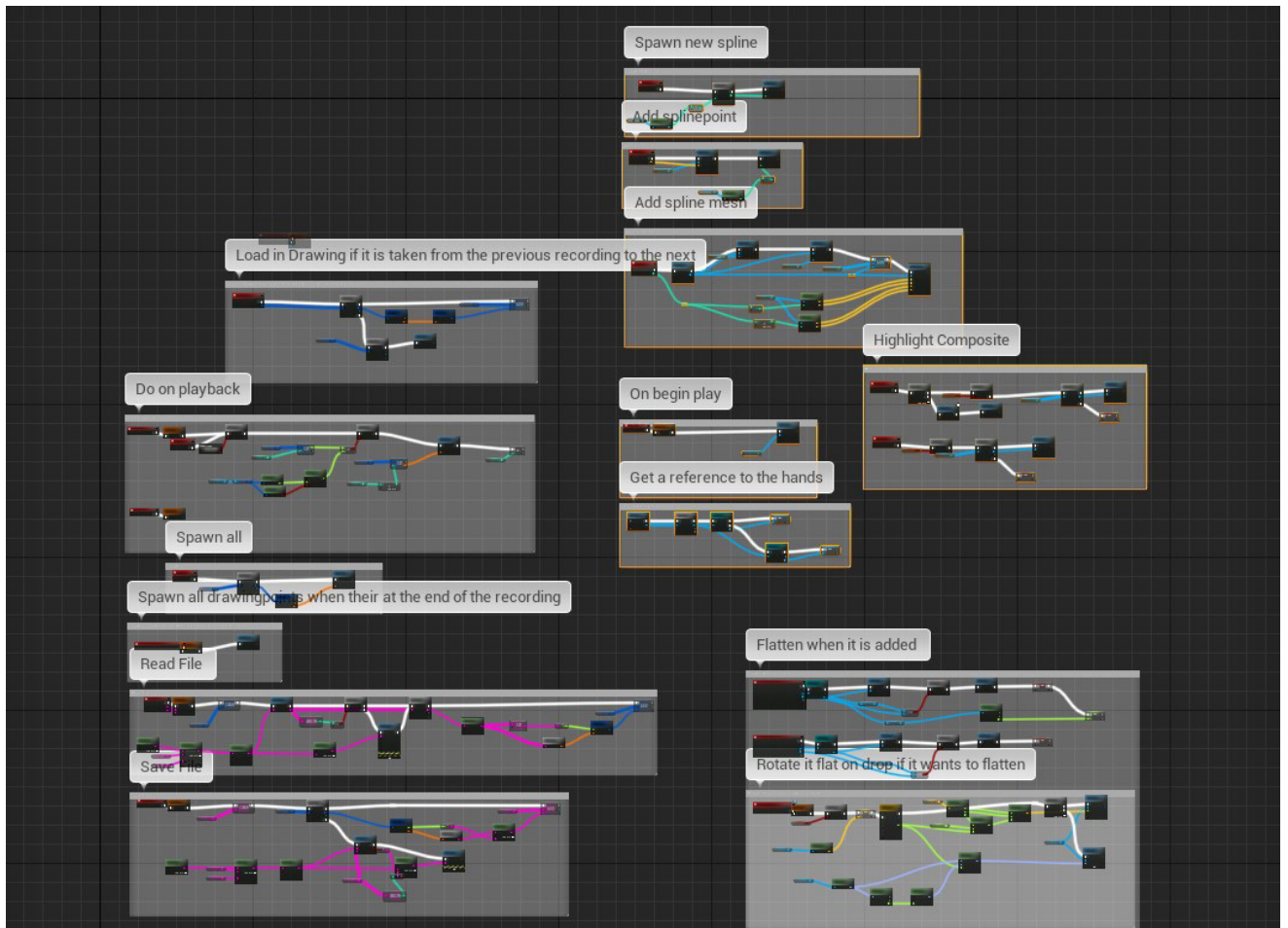


Figure 107: Drawing Container Code, works together with the drawing tool

EVALUATION OF REQUIREMENTS

INSTALLATION

1. Installing a headset should take no longer than an hour.
2. The tool should allow multiple users in an office to share a headset (not at the same time).
3. Hardware should come preconfigured with the software already installed.

LEARNING CURVE

4. An engineer should not need more than 10 minutes to learn the core concept.

ASYNCHRONOUS

5. The concept should be asynchronous, thus incorporating no live, or multiplayer, elements
6. Explaining a concept using the concept should take no longer as it would take to explain the same concept on a whiteboard with users present.

CAPTURE PROCESS EXPLANATIONS

7. A user should be able to convey Mental Models within and about 3D space better than a still image with description.
8. A user should be able to transfer a Mental Model on why a position is chosen.
9. A user should be able to transfer a Mental Model on why air gaps need to be kept.
10. A user should be able to transfer a Mental Model on how air gaps can be kept.
11. The concept should show different steps of the process.
12. The concept should show how

steps relate to each other.

13. A user should be able to see these steps independently of each other, not in one order.
14. Users should be able to draw the attention of the viewer to the desired subject only.

REVISION

15. The concept should allow a user to revise a recording.
16. A recording session should feel relaxing.

CREATE TRACEABLE INFORMATION

17. Mental Models captured in VR should be easily traceable during the project duration.
18. Users must be able to send the information recorded in the VR tool to other users.
19. Users must be able to reference the Mental Models recorded in VR in other mediums, for example a report.
20. Revisions to the process should be kept and be visible over different explanations. In order to understand when a parameter changed or when revisions were made to the explanations.
21. The tool should be able to show or allow an engineer to show their thinking process.

LOW PREPARATION TIME

22. From desk to VR should take no longer than 1 minute, to lower the barrier to entry.
23. Users should be able to prepare their explanation outside of VR and take this into VR.
24. Users should be able to reference information on their PC in VR.
25. A consistent project should exist to keep information permanently.

ALLOW FOR MEDIUM REACTION TIME

26. Users should be able to respond in VR to the Mental Model.

FINDABILITY

27. It should take no longer than one minute to find the right topic and no longer than two minutes to find the right Mental Model in a topic.
28. Information should be able to be kept permanently.
29. Information needs to be findable even for new team members or after half a year.

CONTEXT REQUIREMENTS

30. There should be the ability to import models from the desktop.
31. From desk to VR should take no longer than 1 minute.
32. Can be either used in a separate VR room or at a desk.
33. Must be able to transport the headset to make use of it in other settings.

WATCHING BACK

34. A user should be able to find the information that they are looking for within 1 minute.
35. A user must be able to skip information that is not interesting to them.
36. The explanations must take no longer than 5 minutes to watch.
37. Users should be able to take the information in VR to other mediums.

Requirement category	Requirements							
Installation	1	2	3					
Learning Curve	4							
Asynchronous	5	6						
Capture Process Explanations	7	8	9	10	11	12	13	14
Revision	15	16						
Create Traceable Information	17	18	19	20	21			
Low Preparation Time	22	23	24	25				
Allow for medium reaction time	26							
Findability	27	28	29					
Context Requirements	30	31	32	33				
Watching back	34	35	36	37				

Legend	
Fulfilled	
Fulfilled but not prototyped explicitly	
Probably but insufficient evidence	
Future Work	
Not Fulfilled	

INDIVIDUAL QUESI RESULTS

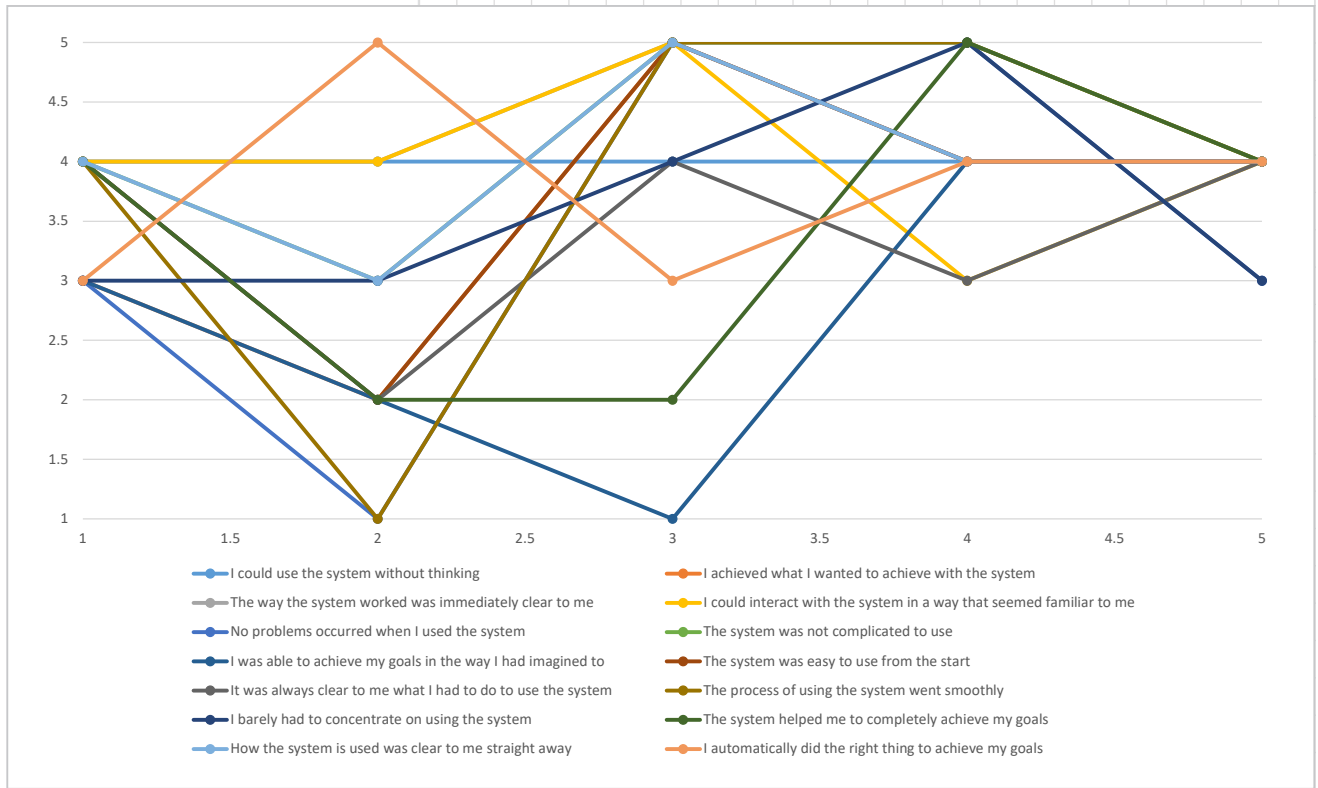


Figure 108: Results for each category, plotted per participant/iteration

QUESTIONNAIRE FINAL EVALUATION

Composite Production Survey

Welcome to this research about composite production. Before we can start, it is important to explain a couple of things about the purpose of this study and what will happen with the data collected. Please read this carefully then go to the next page.

*Required

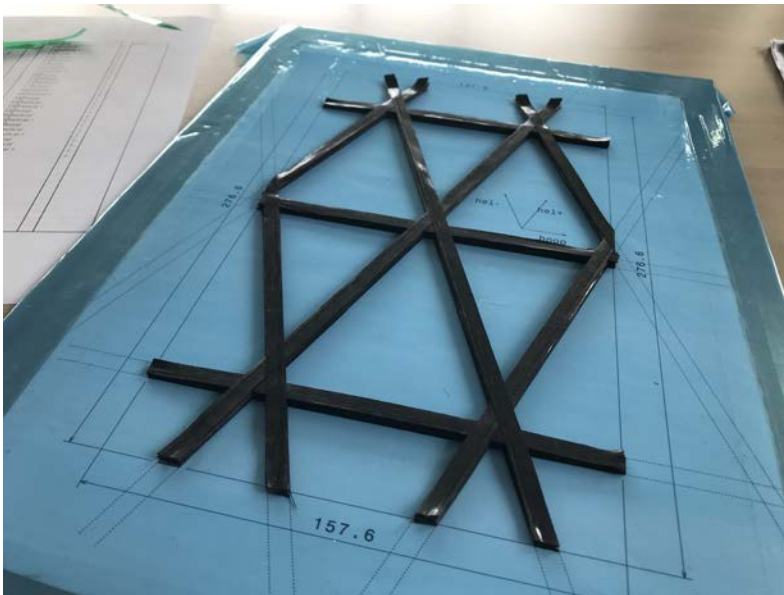
Research Explanation and Purpose

The purpose of this research is to determine the extent to which two communication tools allow the mental model transfer of problems related to composite production. It is done in order to evaluate the design created during the graduation project of Jesse Nijdam.

Don't worry if you don't understand what composite production is yet. The purpose of this study is to compare two different methods of explanation, so hopefully, if everything goes well you will have a better understanding at the end of this study.

As mentioned before, you will be given an explanation on how to make the following composite part during this study. Composites are a type of material that contain long fibres and binding material. Which is kind of like glue. They are used in all kinds of applications to make very strong and very lightweight parts. The explanation will be about how to make this single part out of a roll of the composite material. This is a process called hand lay-up.

A Composite part made of many stacked strips of composite



Consent

1. I volunteer to participate in a product evaluation experiment conducted by the University of Technology Delft, Faculty of Industrial Design Engineering.
2. I understand that the product evaluation experiment is designed to gather information about the appropriateness of the VR Lay-up tool in a specific context and that I will be one of 20 participating in this research.
3. My participation in this product evaluation experiment is voluntary. I understand that I will not be paid for my participation. I may withdraw and discontinue participation at any time without penalty.
4. Participation involves answering personal background questions, reading or watching an explanation, and answering questions about said product. This process will take around 20 minutes.
5. I understand that the data I enter will be recorded. I agree for the use within project presentation, including but not limited to conferences, journal publications, and/or other commercial use. I agree ONLY for the purpose of measuring my responses. The data will be destroyed before the end date of the project. If I don't want this data to be recorded, I will not be able to participate in the study.
6. I understand that the experiment doesn't want to measure my performance, but the performance of the PRODUCT. No specific participant related performance measurement is transferred to any external source.
7. I have read and understood the explanation provided to me. I have had all my questions answered to my satisfaction, and I voluntarily agree to participate in this study.
8. Your data will not under any circumstance be shared with any third party.

Contact

For further information please contact:

Jesse Nijdam (Researcher)
J.A.C.Nijdam@student.tudelft.nl

Doris Asschenbrenner (Chair)
Joris van Dam (Mentor)

Do not use the back button!

Even though, there is a back button you are not allowed to go back during this research. This will invalidate your data so please do not do this.

1. Agreement *

Tick all that apply.

- I understand and agree with these conditions
 I will not use the back button or otherwise go back during this study

Preparation

2. On a scale of 1 to 7, how well do you think you understand composite production or composite hand lay-up? *

A 1 means you have no idea how to do composite lay-up. A 7 means you are experienced with composite production and would feel comfortable doing lay-up yourself.

Mark only one oval.

	1	2	3	4	5	6	7	
Not at all	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Very well

3. What is the current time? *

Please fill in the current time at your location.

Example: 8.30 a.m.

4. Please select the top item in the list! *

This research is between groups. In order to ensure an equal and random distribution between both groups. Please select the group displayed at the top of the list.

Mark only one oval.

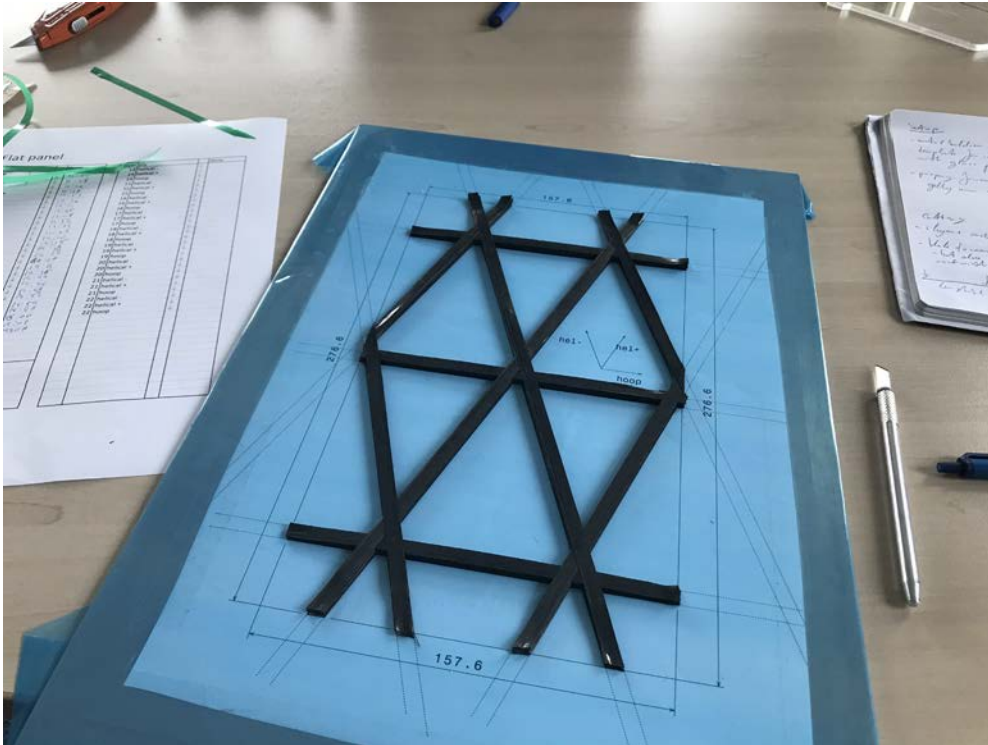
- Group & Skip to question 6
 Group # Skip to question 5

Skip to question 2

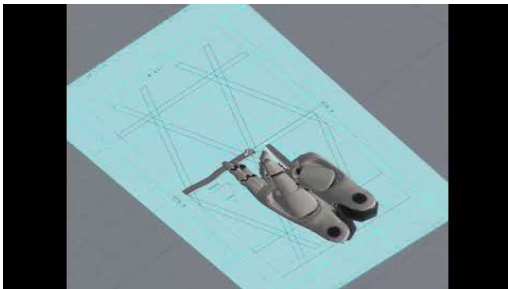
VR Lay-up

You will now be given an explanation on how to make the composite product, pictured below. Please watch the explanation carefully. You are allowed to rewind parts if you don't understand it.

Composite Product



VR composite lay-up



http://youtube.com/watch?v=_GdiC9VA8Ww

5. Did you watch the entire explanation with the sound on? *

Tick all that apply.

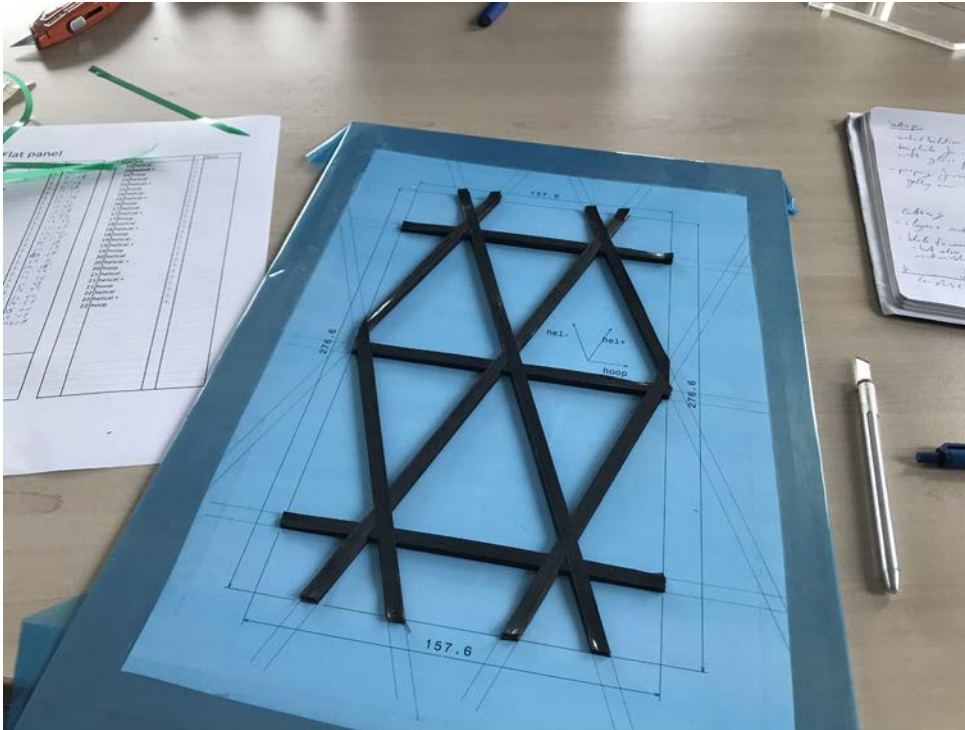
Yes

Skip to question 7

Written Lay-up

You will now be given an explanation on how to make the composite product, pictured below. Please read the explanation carefully. Don't worry too much if you do not understand something.

Composite Product



Placing composite on the cutting template and how to cut it

Place the composite roll on the holder. Place the cutting template in line with the composite holder. Next up, unroll the composite, with the green side up, from the holder onto the template but overshoot slightly on the outer edge. The outer edge is the edge the furthest away from the roll. Make sure the composite is kept straight when placing it down on the cutting template. It is not necessary to press it down hard as this would make it harder to remove. When a strip of the composite is placed on the cutting template first check if it is within the lines. Do this both from above from the sides. Once it is placed correctly, cut the outer edge along the cutting lines on the template.

Be sure to cut straight through the composite in a smooth motion to make a straight cut. If any fibres are torn along the length of the composite then lift the composite and place it down further on the template. Getting the first toes right is very important to get a good result later on.

If the cut is successfully done on the outer edge, cut the inner edge as well. At this point, you have created your first composite toe.

Removing toes from the cutting template

The composite material is slightly sticky. If it is straight out of the freezer it is less sticky which makes it easier to place down and also pick up again. Once it warms up the binder will start flowing and the material will harden, binding the composite material together.

Now how to remove the composite toe from the cutting template. Because of the stickiness, special care should be taken when removing it from the cutting sheet. Often you can just lift the toe upwards but if the material is warmer you will find it sticking to the surface more often.

If it sticks to the surface, you should first try to slightly lift the outer edge of the toe. If this comes loose grab the edge and pull away from the other end. Do not pull the toe straight up. The straighter you keep the toe the better. This prevents you from damaging fibres and pulling other toes with it.

If it still does not want to loosen you can use the face of the knife to push the toe upward while still pulling at one end. Be careful not to cut through the material while doing this, as this would weaken the final product. If all else fails, use the freeze spray on the sticking part of the toe.

Once the toe is loose you can keep it around on the cutting template. It won't fasten if you don't press down on them. Repeat this until you have enough toes for the first layer.

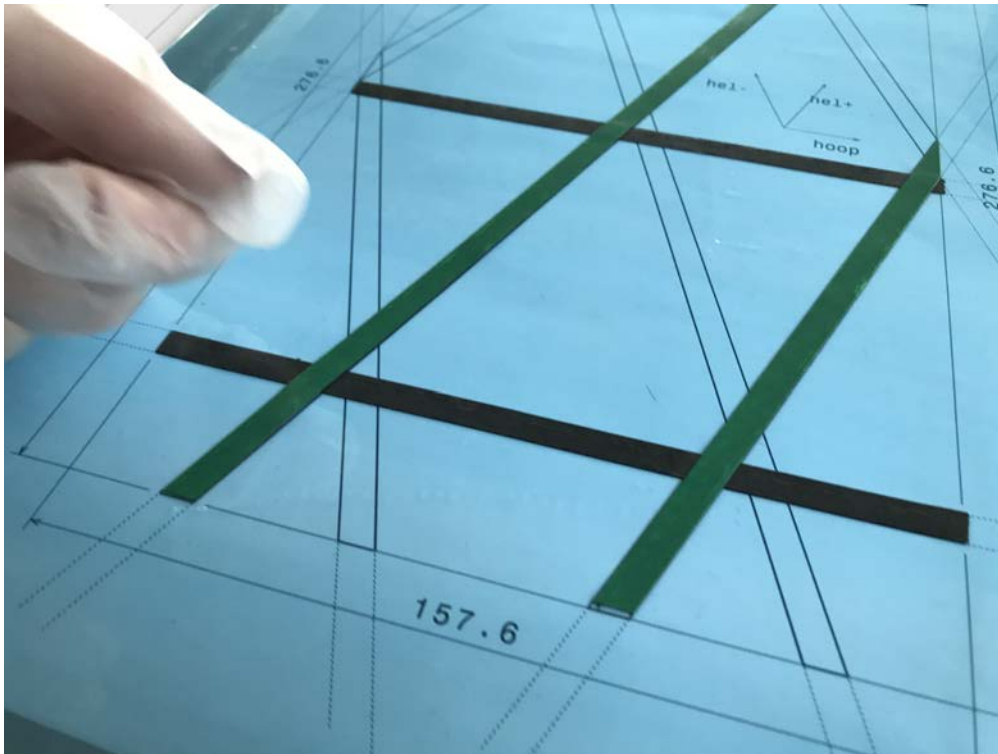
How to place it on the lay-up template

Now that the toes are cut it is time to place them down. That is done on the lay-up template. The lay-up template has lines indicating the grid made of triangle shapes. This grid makes the material able to resist very high loads while being as light as possible. There are several key features we will pay close attention to. These are the outer edges of the template and the place where the composite toes cross each other. The latter are called knots.

It is advisable to start with a hoop toe but in general follow the instructions on the sheet (not provided here). Align the outer edge of a hoop toe first to the outer edge of the lay-up template. Keep in mind to place the green protective film side on top. Then while using one hand to keep tension on the other end of the composite, use the other thumb of the other hand to guide the material down into place. Again keep the material as straight as possible. While you're keeping tension on the material you will notice that there is no stretch to the composite. Exercise enough tension so that the material keeps straight, this is to reduce waviness, but don't pull hard enough that the material starts moving. Try to only press the toe down on the lay-up template where the toes are supposed to cross.

Once the toe is placed properly within the lines of the template and press down repeatedly with multiple fingers on the toe to stick it to the surface. Do not slide your finger over the toe anymore to prevent it from shifting.

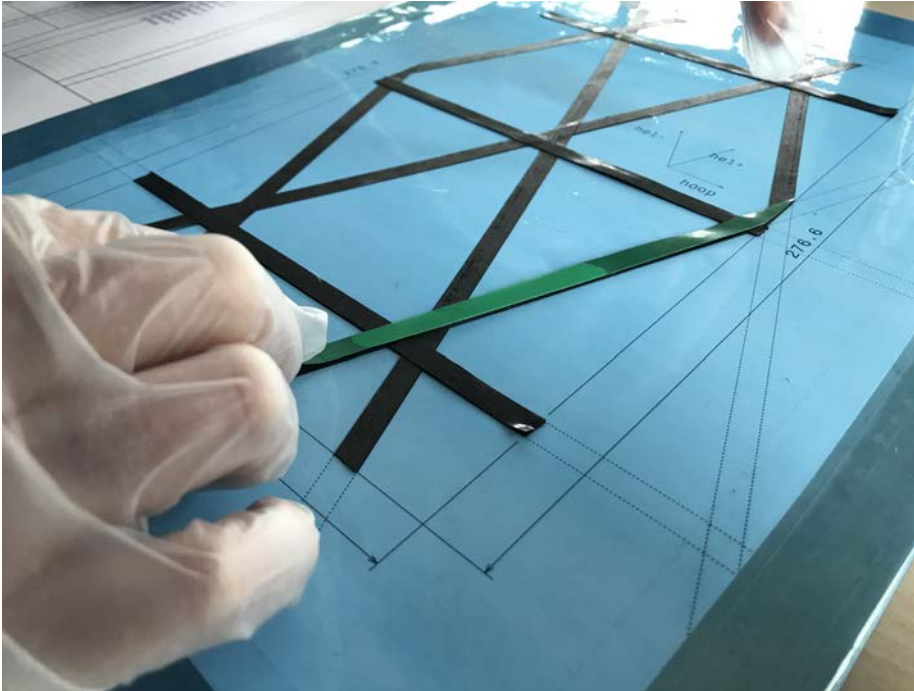
Alignment of the composites on the lay-up sheet



How to remove the protective film

Now we need to remove the protective film. Take the knife and carefully stick the tip, facing down, into the protective film but be careful not to press it through the composite. You then twist the tip of the knife 90 degrees. Then you can pull up. This should create a small air bubble. Now you can easily pull the film off with that start. When pulling be careful not to rip off the side of the composite toe. If the side of the composite toe goes with the film, cut it off with the knife to prevent pulling it further.

Removing the protective film



Next layers

Repeat this process with the other 2 toes in the hoop ply. And then for the other 2 plies (helical + and -) to complete the first layer. Repeat this process for the full twenty layers but do not press down with multiple fingers when it is placed. Placing them down, using your thumb as guidance is sufficient.

6. Did you read the entire explanation? *

Tick all that apply.

Yes

Skip to question 7

Questionnaire preparation

Before we can get started with the questionnaire please fill in the current time again.

7. What is the current time? *

Please fill in the current time at your location.

Example: 8.30 a.m.

Questionnaire

Please try to answer the next questions to the best of your knowledge. All questions are required but do not worry if you are unsure about an answer. It is perfectly valid to fill in what makes the most sense to you. However, whatever you do, do not go back in the questionnaire!

8. What is the name for all the strips of composites in a single direction? *

Mark only one oval.

- Toe
- Ply
- Layer

9. What is the name for a single strip of composite? *

Mark only one oval.

- Toe
- Ply
- Layer

10. Which of these is not a valid composite lay-up direction? *

Mark only one oval.

- Helical
- Hoop
- Horizontal

11. Which edge of the composite is cut first? *

Mark only one oval.

- Outer edge
- Inner edge

12. Why is that edge cut first? *

13. What is the best method to place a second layer of composite strips? *

Mark only one oval.

- Use your thumb to slide between knots
- Press down firmly with multiple fingers
- Place down all at once by grabbing both ends

14. Why is that the best method? *

15. Why is it important to keep tension when placing down composites? *

Mark only one oval.

- To reduce waviness
- To prevent the strips from shifting over time
- To keep the fibres from breaking inside the material
- To reduce the time it takes to align the composite

16. Which word describes the grid shape best? *

Mark only one oval.

- Trapezoid
- Square
- Diamond
- Rectangle
- Oval
- Triangle

17. What was the colour of the protective film? *

Mark only one oval.

- Red
- Yellow
- Blue
- Green
- Black
- The film is transparent

18. How many strips of the composite are used for one layer in this example? *

19. How many layers were supposed to be used in the composite example? *

20. What should you pay close attention to when pulling off the protective film? That you are not ___ *

Select all that may apply

Tick all that apply.

- Accidentally tearing of the sides of the composite
- Pulling up the composites with the film
- Poking through the composite and the film

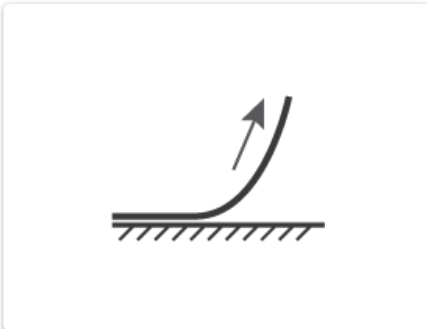
21. How far can a strip of 5cm stretch on average? *

Mark only one oval.

- ~0 cm
- ~0.2 cm
- ~0.5 cm
- ~1 cm

22. Which way should you pull the material when removing it from the cutting sheet? *

Mark only one oval.



Direction A



Direction B



Direction C

23. Which tool should you use first when a composite is stuck in place? *

Mark only one oval.

- A knife
- Freeze spray
- Plastic Plectrum

24. Why is the material kept cold? *

Mark only one oval.

- Otherwise the fibres might shift in the material
- To make the material less sticky during lay-up
- To keep the rolls from hardening

25. Please explain why the strips are placed in a grid *

Closing questions

Thank you for taking the time to fill in the questionnaire. Before we are done there are a few final questions and some personal questions.

26. What is the current time? *

Please fill in the current time at your location.

Example: 8.30 a.m.

27. On a scale of 1 to 7, how well do you think you understand composite production or composite hand lay-up better after this research? *

A 1 means you have no idea how to do composite lay-up. A 7 means you are experienced with composite production and would feel comfortable doing lay-up yourself.

Mark only one oval.

	1	2	3	4	5	6	7	
Not at all	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Very well

28. In how far do you agree with the following statements? The explanation was _____ *

Mark only one oval per row.

	Fully disagree	Somewhat disagree	Neutral/no opinion	Somewhat agree	Fully agree
Clear	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Helpful	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Interesting	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Too long	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Too short	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Uninteresting	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Confusing	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Unhelpful	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Worthwhile	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Disadvantageous	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Personal Data

The answers to the questions will not be shared with any 3rd parties and will not be kept after the end of the graduation project.

29. Age *

30. Gender *

Mark only one oval.

- Male
- Female
- Prefer not to say
- Other: _____

31. How much experience do you have in composite production? *

Mark only one oval.

	1	2	3	4	5	6	7	
None	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Expert

32. How much experience do you have with Virtual Reality? *

Mark only one oval.

	1	2	3	4	5	6	7	
None	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Expert

33. Which of the following have you used before? *

Tick all that apply.

- Dedicated Virtual Reality Headset (e.g. Oculus Rift or HTC Vive)
- Augmented Reality Headset (e.g. Microsoft Hololens)
- Augmented Reality on an iPhone, iPad, Android or similar device
- I haven't used any of these

Thank you

Thank you for taking the time to participate in this research.

34. Want to know the results?

If you are interested I can keep you informed on the progress of this research and my graduation project. Just leave your email here and I will keep you up to date.

35. Any last remarks?

This content is neither created nor endorsed by Google.

Google Forms

