Tip & Top in Virtual Reality

The Integration of Virtual Materiality and Interactive Storytelling in a Historical VR Pop-up Book Experience.

Master thesis
Maarten van Geene
Design for Interaction

Information

Student: Maarten van Geene
Student number: 4665333
Master: Design for Interaction
Chair: Willemijn Elkhuizen
Mentor: Jeff Love
Date: 13-7-2023

Table of contents

1. Introduction

This project focuses on translating a historical pop-up book into a meaningful virtual experience. The project is in collaboration with the National Library (KB) of the Netherlands, which has a special collection of historical pop-up books. The KB will be moving their collections to an external location, making the books inaccessible. These books are meant to be interacted with; however, this interaction also makes them fragile and rare. Virtual reality offers a solution to this dilemma as it can be used to preserve the original heritage while also making it accessible in an innovative way. The use of VR fits within a wider development of new technologies being implemented in museums and cultural heritage institutions. This project creates a VR experience with a pop-up book called: Tip & Top boven de wolken, created in 1964. The project specifically focuses on two different aspects of the heritage: the materiality and the narrative. It researches how these aspects influence the experience in both physical and virtual pop-up books. It also aims to enhance the aspects using the affordances and interactions possible in VR, with the ultimate goal to integrate the aspects into a coherent experience.

The project starts with a literature review, which selects relevant frameworks for characterizing the materiality and measuring the narrative engagement. It is supported with additional desktop research looking into existing applications of VR/AR for (children's) books. Two observation studies were conducted focusing on the materiality and the narrative. The first study compares the materiality of physical pop-up books with that of virtual pop-up books. The second study is focused on the narrative engagement and interpretation of the story of the case study book. These insights form the input for the ideation and conceptualization phases. A creative session was hosted to generate ideas for new interactions with the virtual book that integrate materiality and narrative.

The interactions and general flow of the virtual book were tested using different storyboards, ranging in fidelity from paper to interactive digital storyboards. A new approach to materiality in VR was created to combine the materiality of the artifact with that of the narrative. The insights of the different concepting rounds were incorporated into a final prototype. The final concept integrated the materiality and the narrative through special interactions called material touchpoints. The final concept was compared to the original book and the interactive storyboards and it met all the design goals.

1.1 Report structure

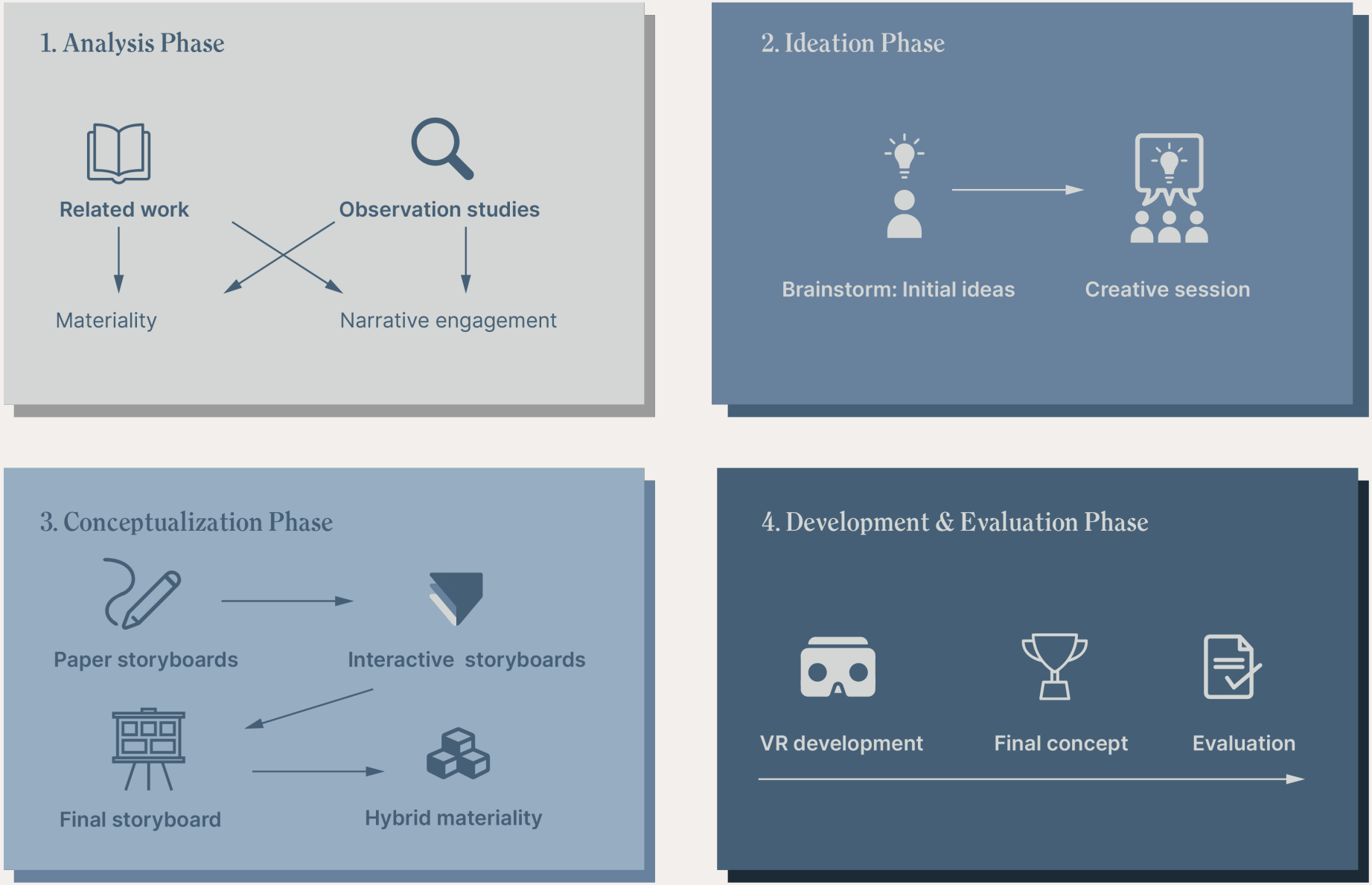


Figure 1: Project phases

1.2 National library and its special collections

This graduation project is in collaboration with the Nationale Bibliotheek. The KB collects and stores historical and contemporary publications in Dutch or about The Netherlands (KB, 2023). It has been doing so for more than 200 years. One of their special collections is their historical children's book collection which consists of around 255 000 children's books and magazines (KB collectie kinderboeken, n.d.). A special part of this collection is their historical pop-up books which are particularly precious as these are fragile and often get damaged during use. A few examples are on display behind glass and can be interacted with on request (Figure 2) (Vingerhoets, 2022). This is necessary to preserve the heritage but limits the interaction with the artifacts, which is a core element of the experience.

One of the core values of the KB is to be open and accessible so people can learn from their collection (KB missie, visie en kernwaarden, n.d.). However, in 2026 their physical collection will move to an external archive in order to expand their collection and store it safely in the future. This means that their collection isn't directly accessible in their original building. This raises the question: what is the function of a library without any physical books? Another core value is their focus on innovation in order to stay relevant for societal changes. For these reasons, the KB is exploring the accessibility of its collection through novel technologies. One of the explorations is using virtual reality (VR) for their historical pop-up books. An initial set of prototypes consisting of four virtual pop-up books has been developed (Figure 3) (Johnson, 2021). These books work well as a demonstrator of the technology and convey a feeling of age but don't express the physical characteristics of the original books, which are lost in the virtual translation. This project focuses on enhancing the material qualities of a physical pop-up book in virtual reality.

Figure 2: Tip en Top op de maan, (Vingerhoets, 2022)

Figure 3: VR book: de Garage, (Johnson, 2021)

The book chosen for this project is named: *Tip en Top boven de wolken* (Figure 4). It was illustrated and crafted by Vojtěch Kubašta in 1964 Czecho-Slovakia. The artist is famed for his minimalistic and ingenious pop-ups that are mostly cut out of one plane. Tip en Top is a series of books about two boys going on adventures in the modern world (Grimes, 2014). The KB owns all of the Dutch versions of the books in the Tip en Top collection (KB Tip en Top, 2022). The book was chosen for the different types of interactive elements which works as a demonstrator and can be applied to many pop-up books.

Figure 4: Tip en Top boven de wolken, (Beeldstudio KB)

1.3 Stakeholders, audiences & perspectives

The target audience of this project is not clearly determined as it is an open-ended project for the public. Different groups have different expectations and perspectives on how the experience should be (Figure 5). These perspectives partially overlap but also contradict each other. From the perspective of the KB the experience should be accessible and engaging to their regular audience as well as appealing to new audiences. It should serve their values and mission. From a pure cultural heritage perspective the experience should be as realistic as possible to honour the heritage.

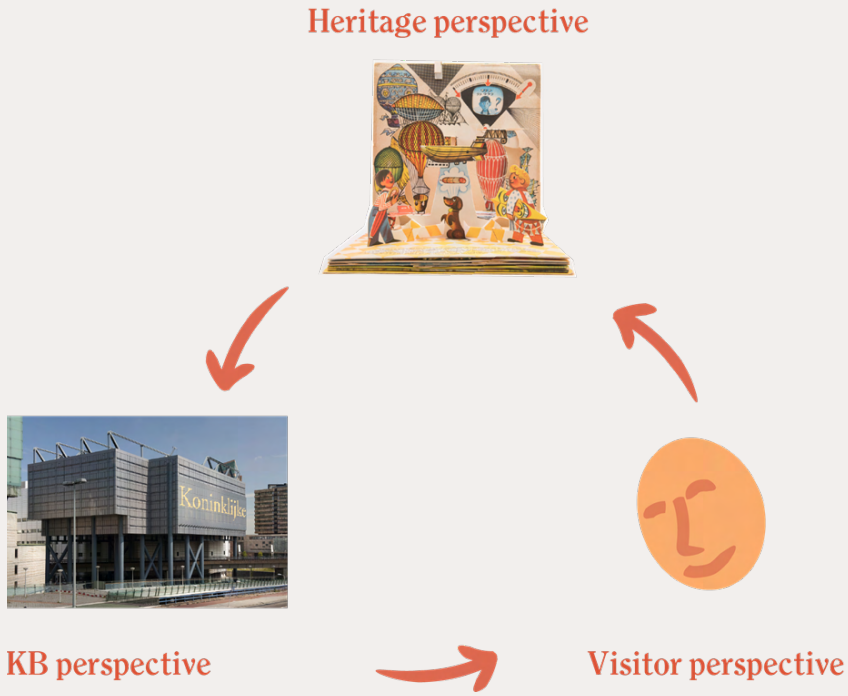


Figure 5: Perspectives on project

The visitor has many different motivations to engage in the experience. The experience will most likely appeal to visitors of museums and other cultural heritage institutions who see it as a type of entertainment or relaxation. It will also attract people that love stories, books and reading. It could provide a new type of experience supplementary to an experience with an actual (pop-up) book. It will also be suitable for people of all ages that enjoy a nostalgic experience and like to travel back in time. Either to their own experiences in the 60s for the elderly or back to childhood for other age groups. A new target group could be attracted: people that are interested in the technology. This can be experienced VR users that like to compare their experience and test the limits of the system or first-time users enthusiastic about the virtual world.

The technology aspect makes it interesting for the KB as it aligns with their values and vision. It is progressive and innovative and might engage new audiences. For the KB it could be an interesting opportunity to target a new audience that doesn't normally visit their library.

One limitation is the minimum age of 13 for using immersive virtual reality through a head-mounted display (HMD). This is recommended by the safety regulations of headset providers. The VR experience should be suitable for anyone above 13. This creates a contradiction in the fact that the book was written and designed for small children. How will the story and the book be perceived by a mature audience? Will VR change peoples' perspectives on the story of the book? These questions will be addressed during the research and conceptualization phases.

1.4 Storytelling and its material form

Pop-up books are a special type of heritage because they are not only a physical artifact but also contain information. Figure 6 shows how the content and the medium of the book are related. The physical book is the medium that consists of the cover, the pages, and the mechanisms which are all made of a material. This medium is the basis of the content which is applied to the artifact. The content includes the illustrations, the text, and the interactive elements which are all connected through the story. The story is a fictional children's story that is meant for entertainment and not for education. The content and the medium are intertwined and interdependent. Paper engineering is an art form in itself but without any illustrations, it is not appealing. The story can be shown with a different medium but it would lose the dynamic 3D effect. The aspects can be synergetic or distract from each other and this influences the experience of interacting with the historical pop-up book. This project aims to discover these relations and influences on the experience.

When translating the book to VR both aspects of the heritage should be taken into account. VR technology offers a lot of new possibilities for enhancing the book, which can go far beyond recreating a replica of the book. The medium of the book is no longer constrained to physical reality and VR technology can offer new interaction types, multisensory experiences and different dynamic effects. The story can be told in many different ways which are no longer limited to a physical book. The challenge is using the new affordances of the technology to enhance the experience without losing the authenticity of a physical pop-up book experience. The relation between content and medium will likely shift when translating the book to VR. Another challenge will be balancing the different senses and affordances between the story and the materiality in order to create an integrated experience.

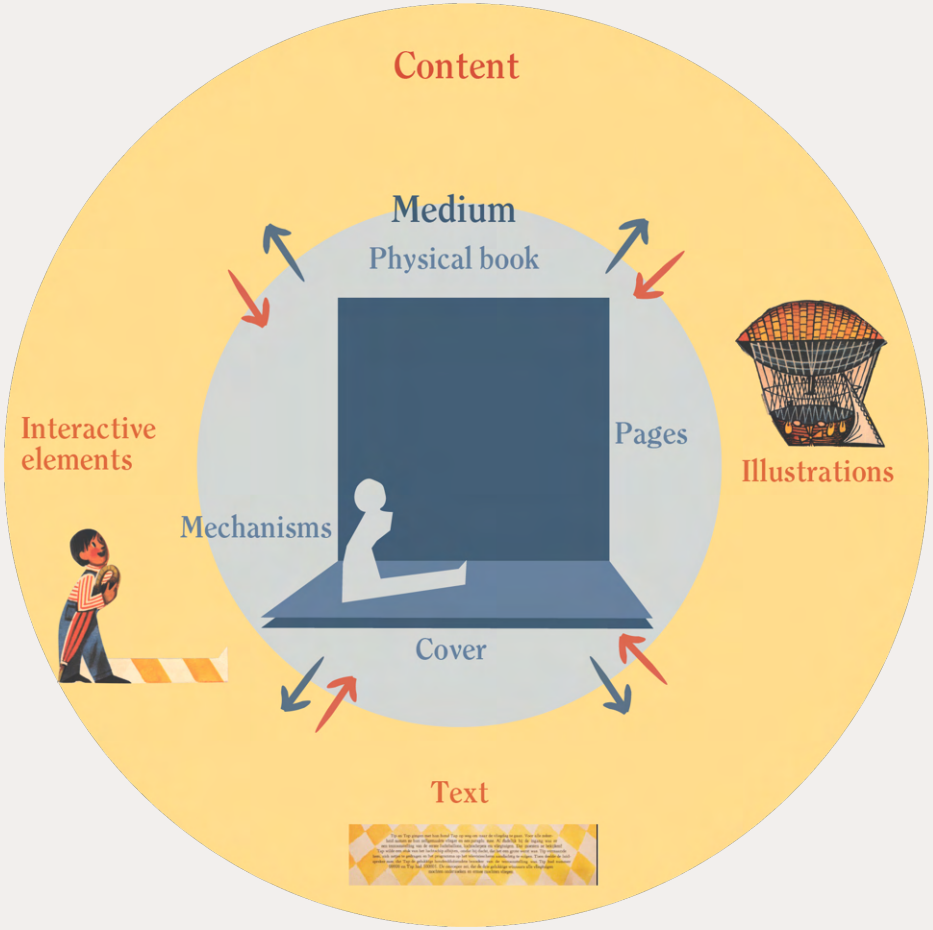


Figure 6: Pop-up books: content & medium

1.5 Research and design questions

This project aims to answer the following research questions through a combination of literature research, user testing and concepting. Research questions (RQ) are the main focus of the analysis phase and form the foundation of the project. These are theoretical and will be answered at the end of the analysis phase through literature, observation studies and interviews. The design questions (DQ) are more practical and will be addressed during the ideation, concepting and development & evaluation phases.

Research questions:
RQ1: How do the medium and its materiality influence the experience of interacting with physical or virtual pop-up books?
RQ2: How do the content and narrative influence the experience of interacting with physical or virtual pop-up books?
RQ3: How are materiality and narrative related in physical and virtual pop-up books?

Design questions:
DQ1: How can the engagement with the narrative of a physical pop-up book be enhanced in virtual reality?
DQ2: How can the material experience of a physical book be recreated and enhanced within a virtual reality pop-up book?
DQ3: How can materiality and narrative be integrated into a virtual reality pop-up book?

Phase 1: Analysis

Research activities

Figure 7 shows the research activities conducted in order to answer the research questions. The research compared physical and virtual pop-up books on two topics: narrative engagement and materiality. The literature review provided a theoretical basis and the frameworks used throughout the project, this was complemented with desktop research into existing XR book applications. Two observation studies gathered insights into people's behaviors and attitudes regarding the physical and virtual books.

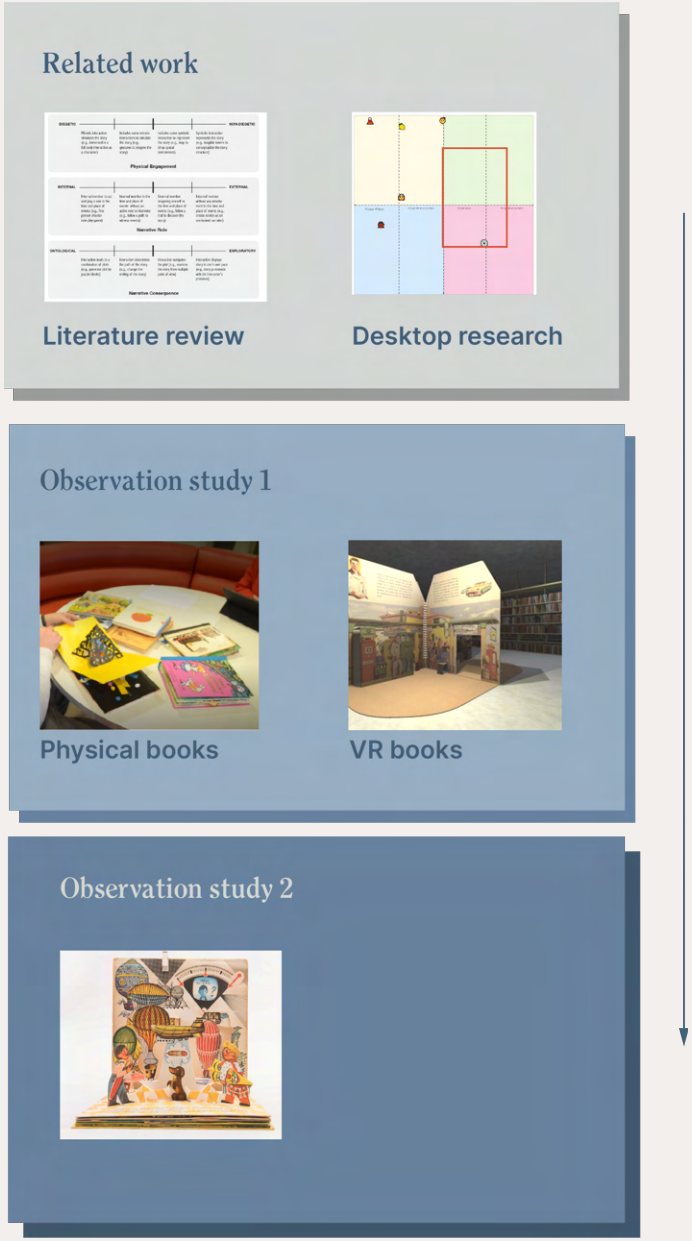


Figure 7: Research activities

2. Related work

2.1 Literature review

Digital technology for cultural heritage

Museums and other cultural institutions have been facing new challenges in the 21st century. They are no longer static collections of heritage but should also stay relevant for modern audiences and engage them in different ways. Digital technologies are being used for many purposes: personalized education, accessibility and preservation of heritage, attracting new audiences and enhancing visitor engagement. Drawbacks of digital technology are the focus on the technology which can distract from the heritage object, technological and financial barriers and the authenticity of heritage. This review focuses on the use and challenges of virtual reality for cultural heritage, in particular historical pop-up books. It dives into the importance and recreation of materiality in virtual heritage. It also addresses how interactions with digital technology should be structured using narrative in order to be meaningful.

Extended reality and cultural heritage
Extended reality is an umbrella term for new technologies like AR, MR and VR which use digital technology to extend physical reality with digital components (Silva & Teixeira, 2022). These technologies lie on a spectrum between the digital and physical world which is called the Reality-Virtuality Continuum first developed by Milgram in 1994 (Figure 8). This spectrum is continuously being expanded with new possibilities and technologies.

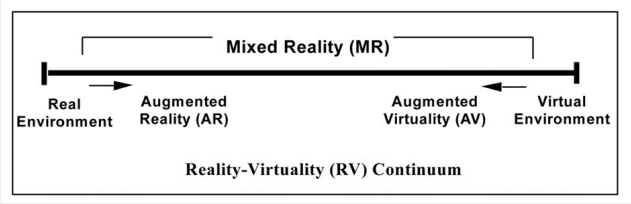


Figure 8: Reality-Virtuality Continuum, (Aniwaa, 2021)

VR
Virtual reality (VR) places the user in a virtual world in which they can interact with virtual objects. Viewing is done through a head-mounted display (HMD) or a smartphone holder. VR is usually controlled using controllers or motion/posture tracking. New technologies like body suits, voice control and eye tracking are being implemented, offering other immersive ways of interacting in the virtual world. In the cultural heritage world VR is often used for virtual museums, archeological locations, architectural sites and historical artefacts. An example is a virtual historical graveyard created by Häkkilä et al. in 2019. The immersiveness of VR can recreate the atmosphere of the site. The mimetic full-body experience of VR allows the user to interact with the virtual world as in real life. However, a limitation of the VR is that the full immersion does lead to an isolated experience, which can be important for a cultural heritage experience.

AR
Augmented reality (AR) overlays the physical world with digital components. AR can be viewed through an HMD with front facing cameras or using a mobile device to interact through the touchscreen. AR in museums is often used for personalization of information and adding elements to presented artifacts. Pure Land AR is an example of an AR application that visualises Buddhist wall paintings in a Chinese cave. Users use their mobile device over a mesh which visualises imagery from the original cave. This created an exploratory and shared experience which is crucial to an museum experience (Figure 9) (Kenderdine et al., 2014).

Figure 9: Pure Land AR - social experience, (Kenderdine et al., 2014)

MR
Mixed or Merged Reality (MR) is still not conclusively defined. It is often described as a variation of AR in which the physical and virtual worlds coexist and interact at the same time (Bekele et al., 2018). Some examples of mixed reality in cultural heritage settings have been found, however these are often regular AR or VR experiences.

Materiality in cultural heritage experiences

Tangible multisensory experience

Digital technology has mainly been focused on providing extra information surrounding cultural heritage objects. This educational use targets the cognitive part of the heritage experience but neglects the emotional experience of handling the object. Tangible heritage artifacts have physical materiality which is an essential part of the experience and evokes an emotional response (Petrelli et al., 2013). The notion that materials can evoke emotions is supported by the material experience framework by Giaccardi & Karana (2015) and the material characterization toolkit by Camera & Karana (2018). The framework states that materials are experienced on four levels: sensorial, interpretive, affective and performative. These levels are intertwined and are experienced simultaneously. The framework and toolkit were created for characterizing materials but the same levels can be applied to objects, in this case: cultural heritage artifacts.

For these reasons Petrelli et al. (2013) propose to integrate digital technology for enabling tangible interactions with cultural heritage. The pop-up books in the KB are on display behind glass and offer only visual sensory cues, withholding the user from tangible interactions. A digital copy in VR offers access to the book but misses the tangible materiality of the real book. Physical books still exist besides E-books even though e-books offer many advantages. People like handling physical books because they provide an emotional material experience (Spence, 2022). Books have distinct smells produced by their covers, glue, ink and paper. The weight of the book can give readers an indication of its quality and price. The texture and thickness of the paper can be felt. All these senses create a personal emotional experience that can bring up memories (Spence, 2022). These aspects are all missing in virtual books. This calls for reproducing the material experience of a physical book through VR technology. VR even offers different material experiences with a pop-up book as it is not confined to the medium of paper and the physical world.

Multisensory interactive cultural heritage experiences

There have been multiple case studies trying to recreate tangible and material experiences for cultural heritage artifacts. Most papers focus on a set of senses or a specific technology. A survey on multisensory VR and AR experiences in cultural heritage has been conducted by Marto et al. in 2021. This paper analyses 25 different cases on the types of senses and their influence. 92% of experiences focused on visuals, 84% utilised haptics, 72% triggered audio, 36% triggered scents and only 8% used taste. The effects of individual senses is hard to discover, and blended it becomes more difficult to distinguish (Marto et al. 2021). The cases have been selected because they try to recreate the materiality from a range of different perspectives, focusing on different material qualities. Qualities covered are: physical resistance, scent, temperature, visual reflectance and passive haptics. The solutions are applicable and relevant for recreating a virtual pop-up book. Due to the scope of this project, no cases targeted at accessibility or disabilities have been chosen as they have a different goal.

The most interesting and clear example is an experience based on 16th-century prayer nuts. The goal of the project was to create a tangible interaction that helps with understanding the historical context of the artifact (Chu et al., 2016). The team uses 3D printed replicas for the users to perform mimic the interactions of the users of the 16th century. The artifact combines visuals, tactile, auditory and olfactory effects. The texture of the prayer nut allowed for touching and opening, mimicking the interaction of the owner in the 16th century. This transported the user into the context and created a feeling of closeness to the artifact (Figure 10). Touching the artifact at specific points trigger projections of details are not visible by looking at it.

By picking up the artifact an ambient soundscape is triggered which projected sounds from the environment like sacred music and marketplace sounds. These contextual cues can only be experienced through the senses and are difficult to communicate through text. The final interaction releases scents when opening the prayer nut. These scents were created with essential oils and have different complexities. The users were encouraged to create their own associations and memories with the scents. However, not much detail was put into the material experience of the tangible replica. Participants mentioned that the 3D-printed objects lacked the authentic material experience.

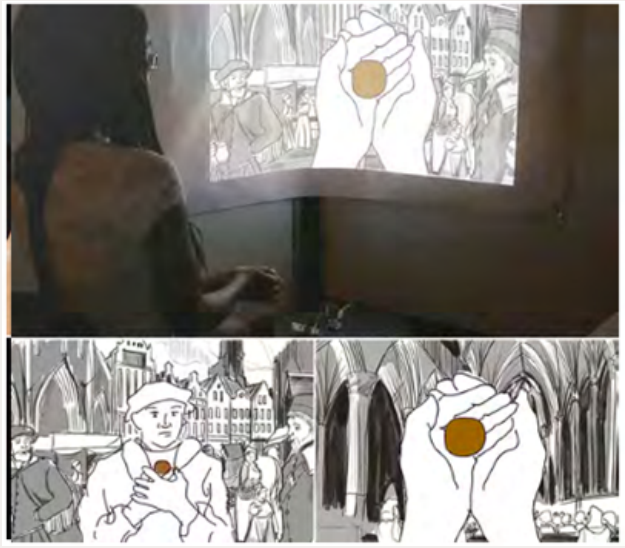


Figure 10: Tangible interaction with multisensory prayer nut, (Chu et al., 2016)

The Museum of Pure Form (Loscos et al., 2004) tries to recreate the feeling of touch with virtual statues in a VR museum. They attempt this by attaching a two-contact-point haptic device to an exoskeleton connected to the arm of the user (Figure 11). The visitors are allowed to touch the virtual statues which normally would be forbidden in a museum. The haptic device can simulate three types of haptics on the finger of the user: frictional forces, contact forces and fixed forces. The users could follow the shape of the statues but it was not perceived as realistic. This was due to the limited haptic on only one finger. Participants also mentioned feeling like they were touching the thimble of the exoskeleton instead of the actual artifact. The extra haptic effect, however, did lead to a higher attention to the artifact and a higher feeling of presence, which are indicators of engagement (Busselle & Bilandzic, 2009). Especially in a cultural heritage setting, tactile experiences are important as they are usually forbidden in a regular museum. This study shows how difficult it is to recreate haptic experiences in virtual reality; however, this study is from 2004 and haptic devices have drastically been improved.

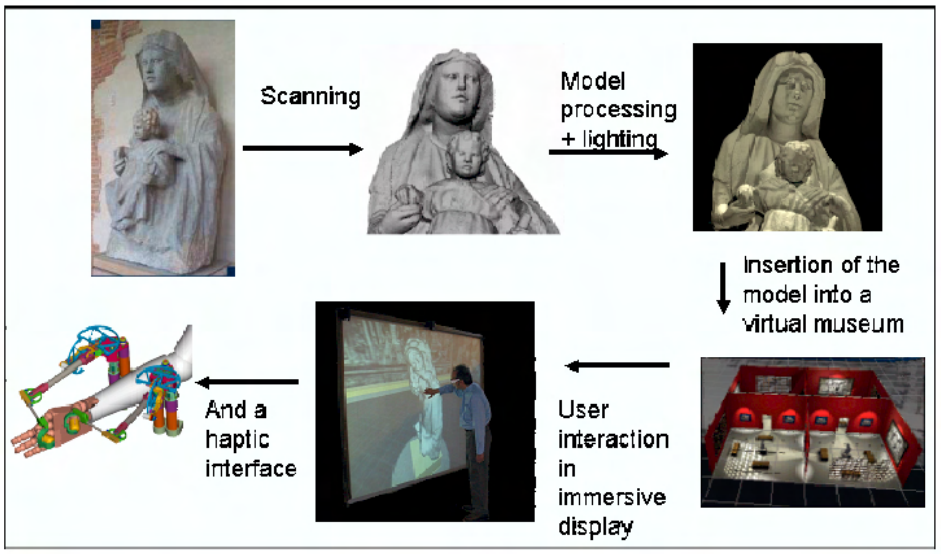


Figure 11: Museum of Pure Form haptic system, (Loscos et al., 2004)

The multisensory virtual experience of medieval tanneries (Dong et al., 2017) focuses on the historical atmosphere and scene of medieval tanneries in Coventry. It focuses on the tangible and intangible heritage. For scenes like this it is important to recreate a cross-modality experience and present a realistic experience of a historical scene. This makes scent and temperature crucial as these determine the experience of the tanneries. This was done by capturing the essential scents from the tannery and reproducing this safely with a perfumist. The scent is then applied through tubes attached above the nose of the participants. The intensity of the smell is controlled by the amount of airflow and the temperature of the air, produced by fans. 3D sound was used as this important to locate and identify objects. It creates a feeling of spatiality. The effects of setup were not tested with participants.

Another case study focuses on enriching VR objects with haptic feedback and realistic surface rendering (Krumpen et al, 2022). The project uses high-quality 3D prints for tangible interactions and focuses on visual reflectance modelling in VR (Figure 14). The physical 3D-printed object is held by the user and overlaid in VR by the same virtual object. This creates a passive haptic effect. However, it requires precise tracking of the object and hands which is done with integrated sensors. Any disturbance of the overlay will severely impact the realism and immersion. The paper shows that handling the VR with a physical object leads to a slightly higher 'object experience'. The technology needed is very complex and the results are minimal, which makes it unsuitable for a pop-up book.

Narrative in interactive cultural heritage experiences

Guidelines and models for interactive experiences

Technology in museum experiences doesn't necessarily lead to engagement or meaningful experiences. There are multiple guidelines for designing interactives and evaluation frameworks for evaluating interactive exhibitions. These have different goals and focus on different aspects of the experience, but the models support certain interaction style and can be used when designing and evaluating the final concept.

Dal Falco & Vassos (2017) combine storytelling with modern technology in cultural heritage settings. Their vision arises from visitors' perception that museums are strict in rules and limited in interactivity, causing low entertainment and engagement. The model tries to combine museum brand identity with interactive storytelling and theme-based narratives to produce a strategy for the museum design of the future. Their vision is to convey the hidden stories stored in artifacts and creating new ones through the interactive experience. The model stays quite general and implementation and testing is limited to student projects. The outcomes show that the combination of interaction design, interactive storytelling and novel technology, enhanced engagement with teenagers and created new relationships between user and artifact. Their vision and goals resonate with this project of creating a new experience with an existing artifact.

Hall & Bannon (2006) present guidelines on how interactive technology can lead to engagement and learning for children in museums. In the paper, engagement is linked to learning behavior. The guidelines argue for a clear objective and narrative to create coherence in the interactive elements. The technology used should evoke curiosity by adding a magical element to the experience, this applies very well to virtual reality.

The type of learning should be exploratory instead of explanatory. It also advocates for learning through sensory experiences. This project will not be focused on children or learning but the guidelines still apply to storytelling in a cultural heritage setting.

The MUSETECH model of Damala et al. (2019) can be used as a tool for evaluating the effects of implementation of digital technology in museums. The unique aspect of this framework is the consideration from three different perspectives: the visitor, the institution and the designer. For this project the visitor and designer perspectives are most interesting as the experience will likely not be implemented at the KB. The framework is structured around different phases, the most relevant being the design phase. It offers a list of steps throughout the process to take into account. These will be used throughout the project.

The visitor learning behavior model (Barriault, 1998) describes three levels of behavior in learning: initiation, transition and breakthrough. It argues that learning behavior can be observed in a museum. In the initiation phase the visitor test the exhibition and get comfortable. During the transition phase the user starts to get engaged in the experience, characterized by emotional responses and becoming more comfortable. The final phase is achieved when the learnings are applied in other settings, for example sharing the experience or associating memories. The initiation phase is very important for VR as the user should feel comfortable with the technology and the controls. The transition phase is an indicator of engagement with the narrative. The final stage would be the highest goal, letting the user reflect on the experience and creating a meaningful experience. In a subsequent paper by Barriault & Pearson (2010) the specific behaviors per engagement phase are listed. This will be useful for evaluating the final concept. The model can help recognize higher engagement levels like: repeating activities, expressing or verbalizing positive emotions, referring to the past or sharing information with others.

Tangible and embodied narrative framework

The most interesting and relevant framework combines tangible interactions with narrative for cultural heritage. This framework will be used throughout the project. Using digital technology for tangible experiences does not always lead to a meaningful connection with the artifact as the technology can divert the attention away from the content (Chu & Mazalek, 2019). In the prayer nut case study Chu et al. (2016) uses a narrative to guide the users through the experience. They use narrative to structure the interactions so the users can create personal experiences and stories. The narrative caused personal interpretations and connections with the tangible artifact, leading to a meaningful experience. This led Chu & Mazalek (2019) to come up with a framework for the role of narrative in tangible and embodied interactions with cultural heritage. The tangible and embodied narrative framework (TEN framework) was the result (Figure 12). It can be used to structure tangible interactions with cultural heritage in a meaningful way. The framework has three axes: physical engagement, narrative role and narrative consequence. The physical engagement determines how symbolic or mimetic the interactions with the objects are. The narrative role is the role of the user in the story as a participant or observer. The narrative consequence determines the amount of influence the user has on the outcome of the story. This framework is useful for designing interactions with cultural heritage narratives to support an experience. The pop-up book is a special case of heritage that has a narrative and has interactions embedded in the material (Performative level material experience model). In VR the positions on the axis are not fixed and the framework can be used during concepting.

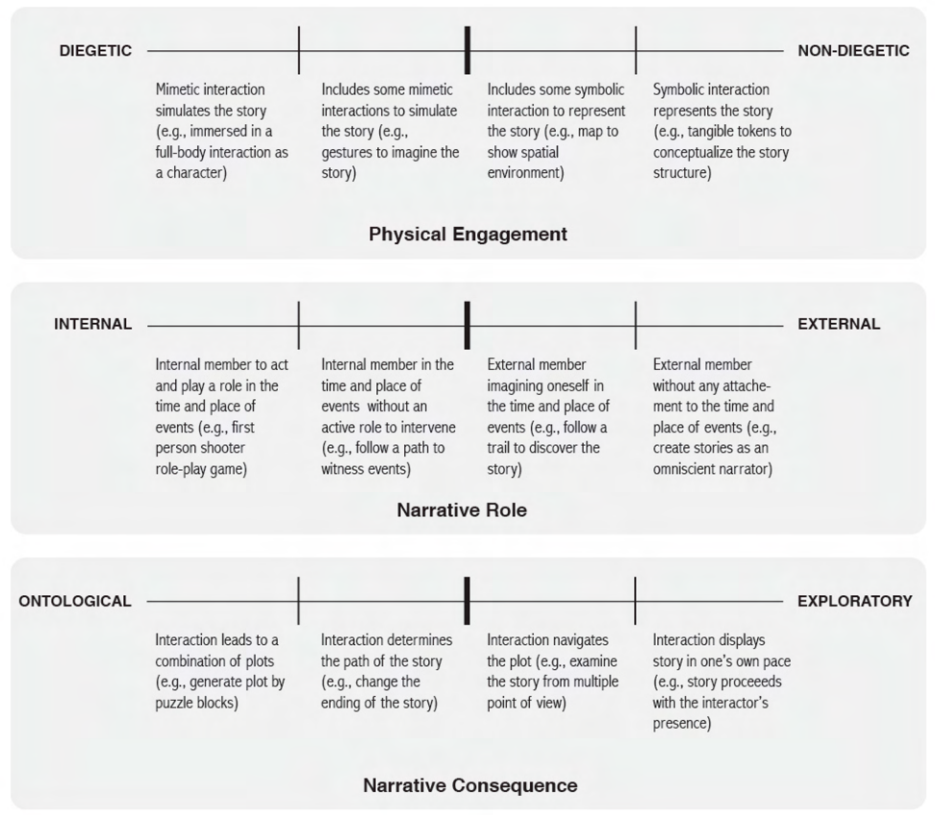


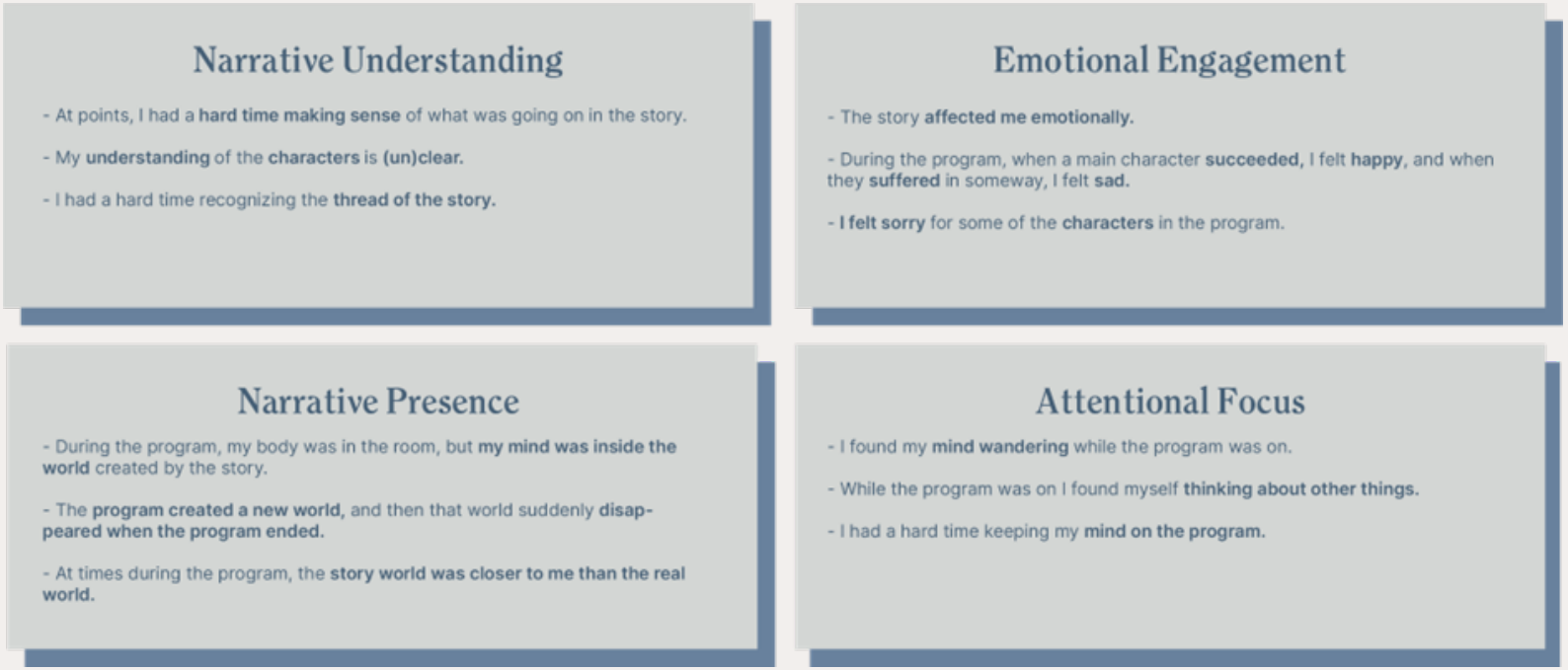
Figure 12: Tangible and embodied narrative framework, (Chu, Mazalek, 2019)

Narrative engagement

The content is also part of the heritage of the historical pop-up book. The book has a story that is communicated through text, illustrations and interactive elements. The visual style is the first thing that draws attention and can set expectations and communicate the tone of the content of the book (Spence, 2020). The story guides the reader through the book and provides the structure for the interactions. A good story keeps readers engaged in the narrative and narrative engagement leads to higher enjoyment of the story experience (Busselle & Bilandzic, 2009). They present the narrative engagement framework (NE framework) for measuring narrative engagement using four subsections: narrative understanding, attentional focus, emotional engagement and narrative presence (Figure 13). Each subsection has three questions which are rated by participants on scale.

The narrative understanding measures how easily the story is understood, it is something readers only notice when they do not understand it. Attentional focus is related to the flow state in which the reader is focused on the story and not distracted. Emotional engagement represents emotional arousal and empathy with the characters. Narrative presence is the feeling of diving into the story world and leaving the physical world behind. This framework was developed for written stories and has not been tested with graphic novels or comic books. The framework will be used to measure engagement with the story of the pop-up book. Measuring the engagement with the story could give an idea of the experience of reading and interacting with pop-up and movable books.

Figure 13: Narrative Engagement Framework



VR, narrative engagement and immersion

VR storytelling as a genre is still being explored by different fields like journalism and cinematography. The immersion creates new opportunities and limitations. The VR experience model developed by Shin in 2018 relates the qualities of VR to the engagement with the experience. The elements of this model are similar to the Narrative engagement framework but are specific to VR experiences and directed at the overall experience, not narrative (Figure 14). The model places Presence (immersion) at the basis of the experience. Presence leads to Flow (state), which is similar to attentional focus but directed at activities instead of narrative. Increased Flow stimulates identification with the characters which can lead to Empathy during and after the story. Combined these elements increase the embodiment and the engagement of the experience. The embodiment of the experience is defined as the feeling of physically becoming part of the story world in which the VR components become part of the physical body. This is an essential element for tangible interactions with cultural heritage in VR.

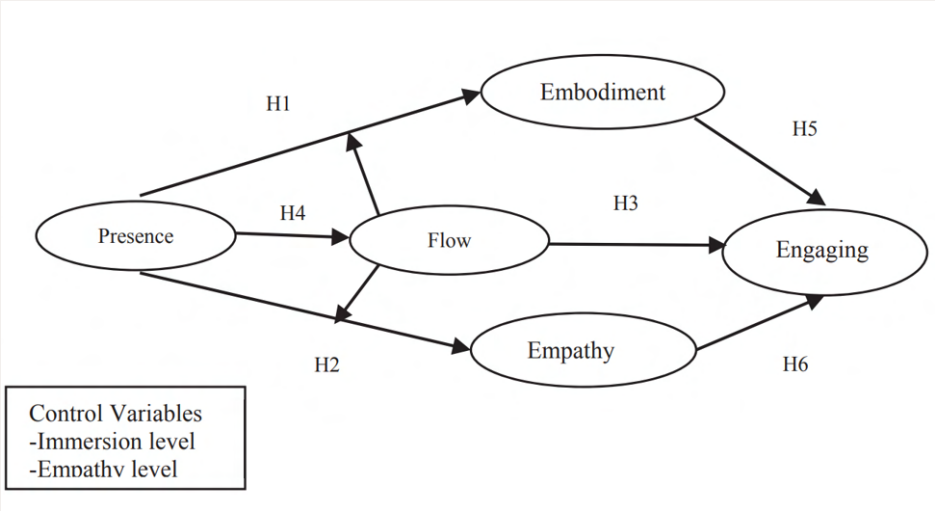


Figure 14: VR experience model, (Shin, 2018)

Other studies support or contradict the findings of the VR experience model. A study by Barreda-Ángeles et al. (2021) compared the effects of immersive VR on the experience of watching a non-fiction video compared to watching it on a 2D screen. The study showed that immersive VR increases the feeling of presence in the story; however, the immersion did lower the attentional focus to the video. It is suspected that this is caused by exploratory behavior due to the 360-degree view that distracts from the story. The novelty effect for first-time users was also stated as a cause for distractions. This novelty effect could negatively influence the narrative engagement with the virtual pop-up book.

Another study by Bujíc et al. (2020) supports the notion that VR can increase empathy in regard to human rights issues (Constine & Milk, 2015). The level of interactivity within the experience enhances this effect; however, interactions don't automatically lead to a meaningful experience. Petousi et al. (2022) studied the effect of agency in interactive storytelling on engagement with cultural content and historical empathy. They define interactive storytelling as the possibility to determine the storyline as a 'choose your own adventure' experience. Their study shows that agency can lead to awareness of the user's influence on the context and the story.

The immersive qualities of VR are not enough to create an engaging experience. Technology should not be the focus of the experience, instead the narrative should be. This has been proven to increase emotional response and engagement (Shin D, 2018).

2.2 Desktop research

Mutiple childrens' books have been designed with VR or AR, these vary in topic and technology used. This case study reviews six hybrid books to get a sense of existing applications and the design space. The cases are all AR or VR children's books and have been chosen to cover a diverse range of topics and technologies. The overview of all the cases (Figure 15) gives a short explanation of the type of story, the technology used and the goal of the book. These case studies were positioned on a matrix and the TEN framework. A high resolution version can be found in Appendix A.

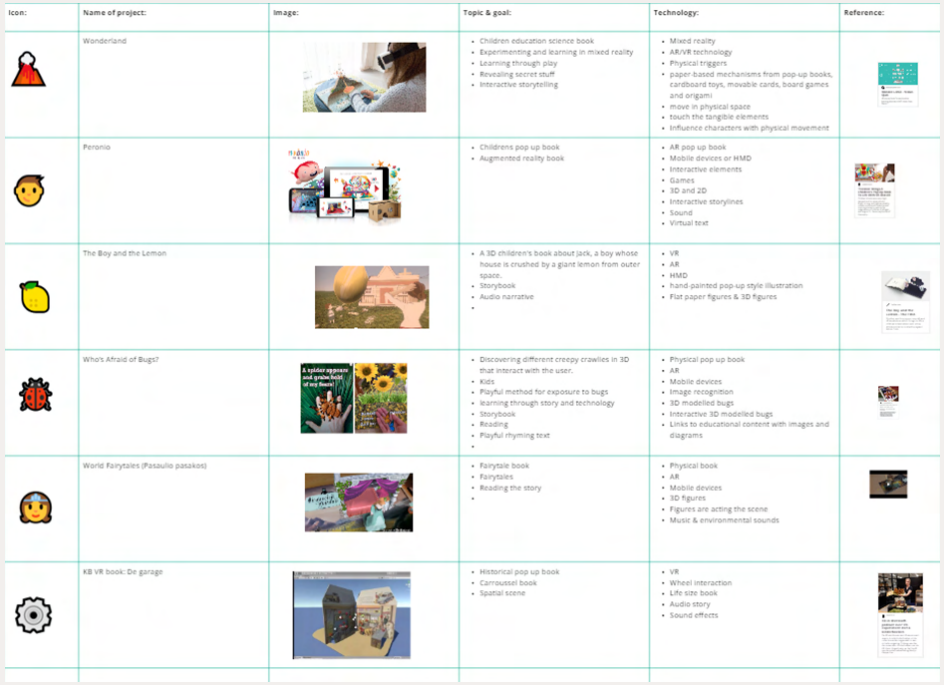


Figure 15: Case study overview

The matrix in Figure 16 positions the cases on two axes. The horizontal axis plots the virtuality and physicality of the cases. The vertical axis shows the amount of reality in the effects. The top of the matrix contains solutions with magical effects that defy reality while the bottom sticks to very realistic effects. It gives an impression on how original or novel the effects are compared to the physical books. It shows that most books are in the magical AR segment which is easy to implement by projecting figures on top of the book with a mobile device. With this project, the aim is to design a VR solution with moderate magical effects as indicated by the red rectangle.

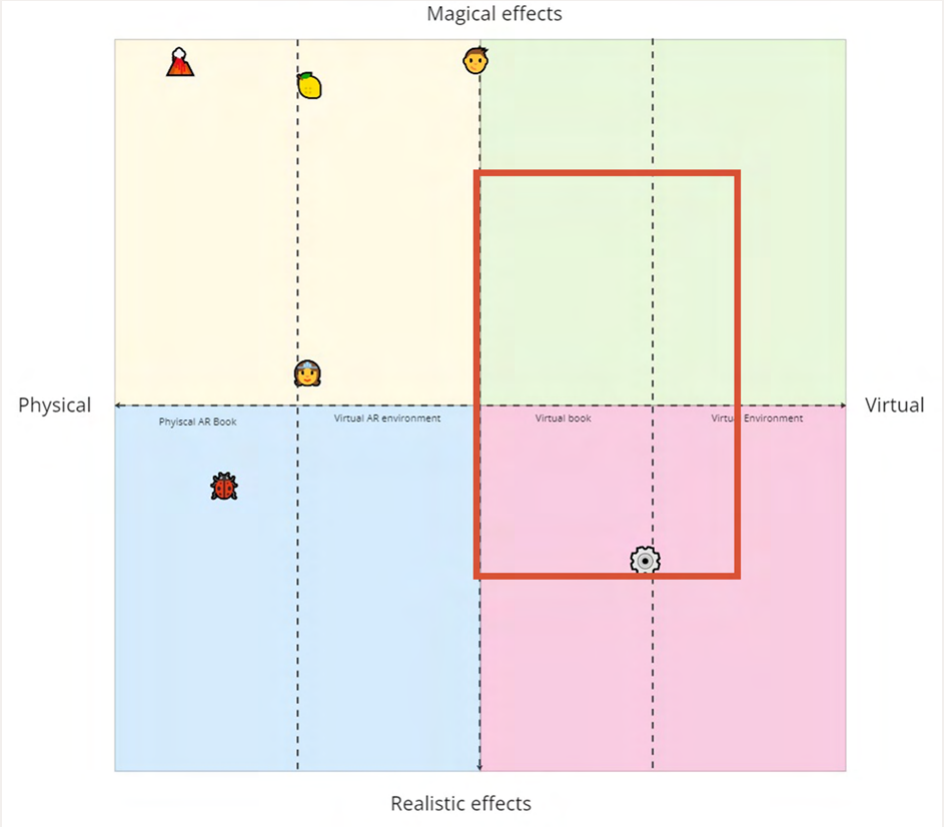


Figure 16: Cases positioned on matrix

The case studies were also positioned on the TEN framework (Figure 17). Most interactions were symbolic as they are controlled by tapping on the screen. The users had an external role in the narrative in most of the cases. The storylines of the applications were mostly linear with little influence on the outcomes of the story. The VR experience ranks differently than the AR because the medium influences the interaction style. For this project the story line is already determined so the solution will likely be on the exploratory side. The diegetic and internal side of the sliders would be preferred for the final concept. The effects of these variables will be tested during concepting.

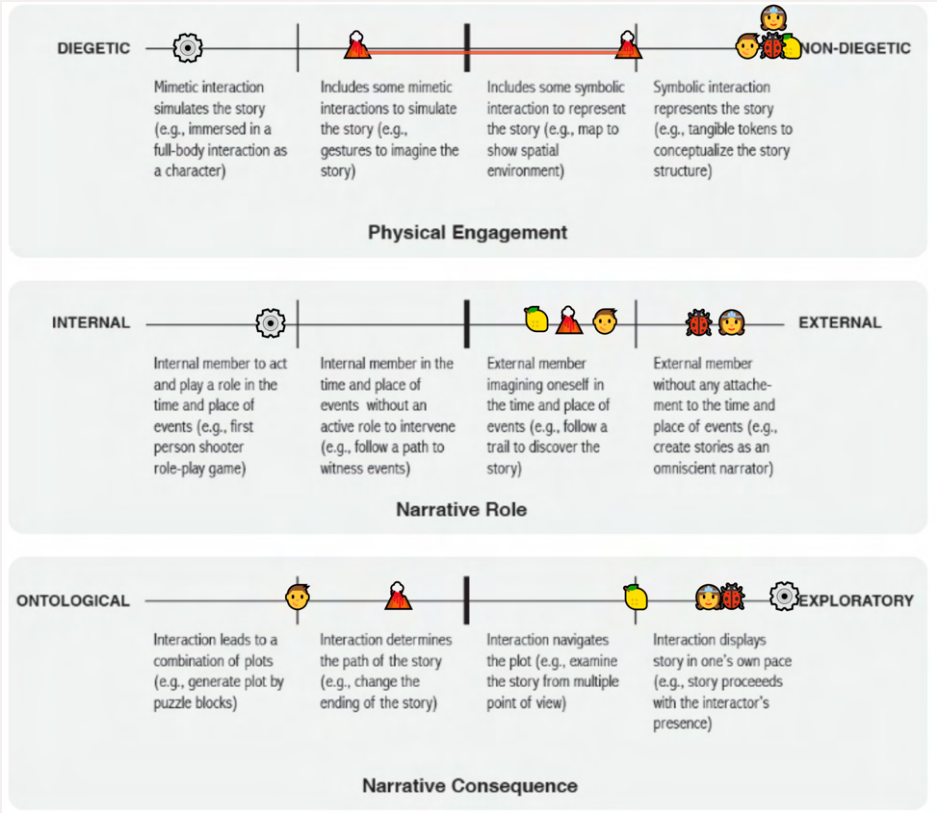


Figure 17: Positioning in TENF, adjusted from (Chu, Mazalek, 2019)

3. Observation Study 1: Physical and virtual pop-up books

This study was performed and supervised by Elkhuizen and the team (Elkhuizen, van Geene, Zhao & Zelenina) as part of her research on materiality in pop-up books. It was conducted outside of my graduation but the dataset of the study was made available for analysis during this project.

General method

The study characterized the material experience and compared the interactions between physical pop-up books and virtual pop-up books. In particular, it focused on the differences in material experience between the two. A large set of pop-up books with different themes, mechanisms and styles were selected (Figure 18). The existing VR pop-up books developed by the KB were used for the comparison. The A/B conditions were alternated to reduce the influence of comparison.

Figure 18: Pop-up books & VR pop-up books used in observation study

The study consisted of observations of the participants while interacting with the physical and virtual books and interviews after the observation studies (Figure 19). The observation studies were filmed and interviews were audio recorded. In total 34 participants participated in the study which was conducted over three days in three different locations. The first 28 participants tested both conditions and this took place in the TU Delft University library and the KB. The third day of testing only tested the physical pop-up books with parents and children to see the social influence of the experience at the children's book museum.

Figure 19: Observation studies with physical and virtual pop-up books

Analysis method

A theoretical thematic analysis was performed using qualitative data analysis software (ATLAS.ti). The material characterization toolkit by Camera & Karana (2018) was used for the analysis. The goal of the analysis was to discover the material experience of both physical and virtual pop-up books.

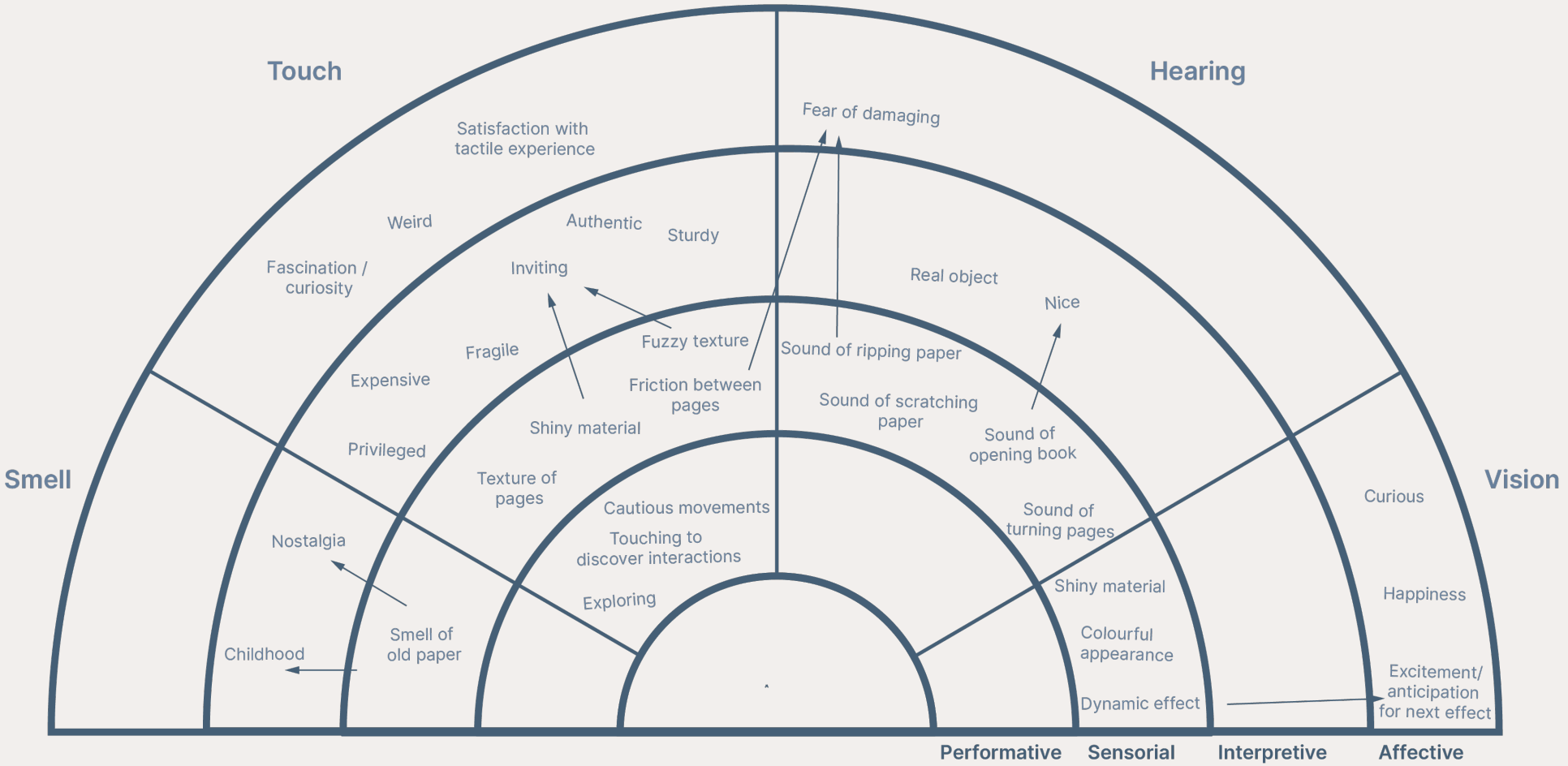
3.1 Materiality in physical and virtual pop-up books

Results observation study 1: Materiality

The results of the analysis were divided between the physical (Figure 25) and virtual (Figure 26) pop-up books for comparison (next pages). The codes were arranged by the senses and missing material qualities were also included. Most answers were given on a sensorial level; however, they sometimes led to higher levels of affection, affection and performance.

3.1.1 Materiality physical pop-up books

Figure 20: Experiential qualities physical pop-up books, adjusted from (Camera, Karana, 2018)



Vision:
The high-quality colorful illustrations were mentioned by multiple participants. These colors made people excited about the books. The dynamic effect of pages exploding open and closing created anticipation for the next visual effect. Participants repeatedly opened and closed pages of the book to repeat the effect and decipher the mechanisms. The differences in textures led to curiosity and engaged users to touch. The layers created depth and made the users turn and tilt the book to discover new perspectives.

Touch:
Physical touch was mentioned most often in the physical pop-up books. First of all, the paper and book had a thickness that could be felt with the hands. This gave the impression of handling an actual material. The different textures first engaged their vision which created expectations and invited the users to touch the materials. The stretchy material in Blue 2 was surprising and a bit weird, especially due to the 3D effect of the texture underneath. The books and pages had a certain weight when handling them. This helped participants make sense of the book by judging the quality and price of the book. A heavier book was perceived as more sturdy, authentic or expensive. The quality of cardboard of the facsimile was easily recognized as a cheap material and not very sophisticated book.

The mechanisms had a certain resistance which was perceived differently. The smooth mechanisms created a feeling of satisfaction and quality, for example in the book with the apple. More elaborate mechanisms like in Alice in Wonderland created more spectacle but also created more resistance. This caused a fear of breaking the mechanisms, which created a negative experience. The fragility of the pages created delicate and deliberate interactions. This differed between participants as this was only apparent in adults. Children were less sophisticated in their interactions.

'This one feels like super smooth, everything moves very nicely and it feels like sturdy. So this one is very satisfactory.'

Participant 2

Hearing:
The sound of paper was mentioned when handling it or when tearing. The sound of opening and closing the books are characteristic for pop-up books. These sounds made the experience feel real; however, not a lot of participants noticed them. Only when the sounds were missing did their absence get noticed. The sound of tearing created a fear of breaking the book which was a negative experience.

Participant 21

'If it doesn't work smoothly and you hear this sound like if something goes wrong, mmmm, or if it's broken, then I don't like it.'

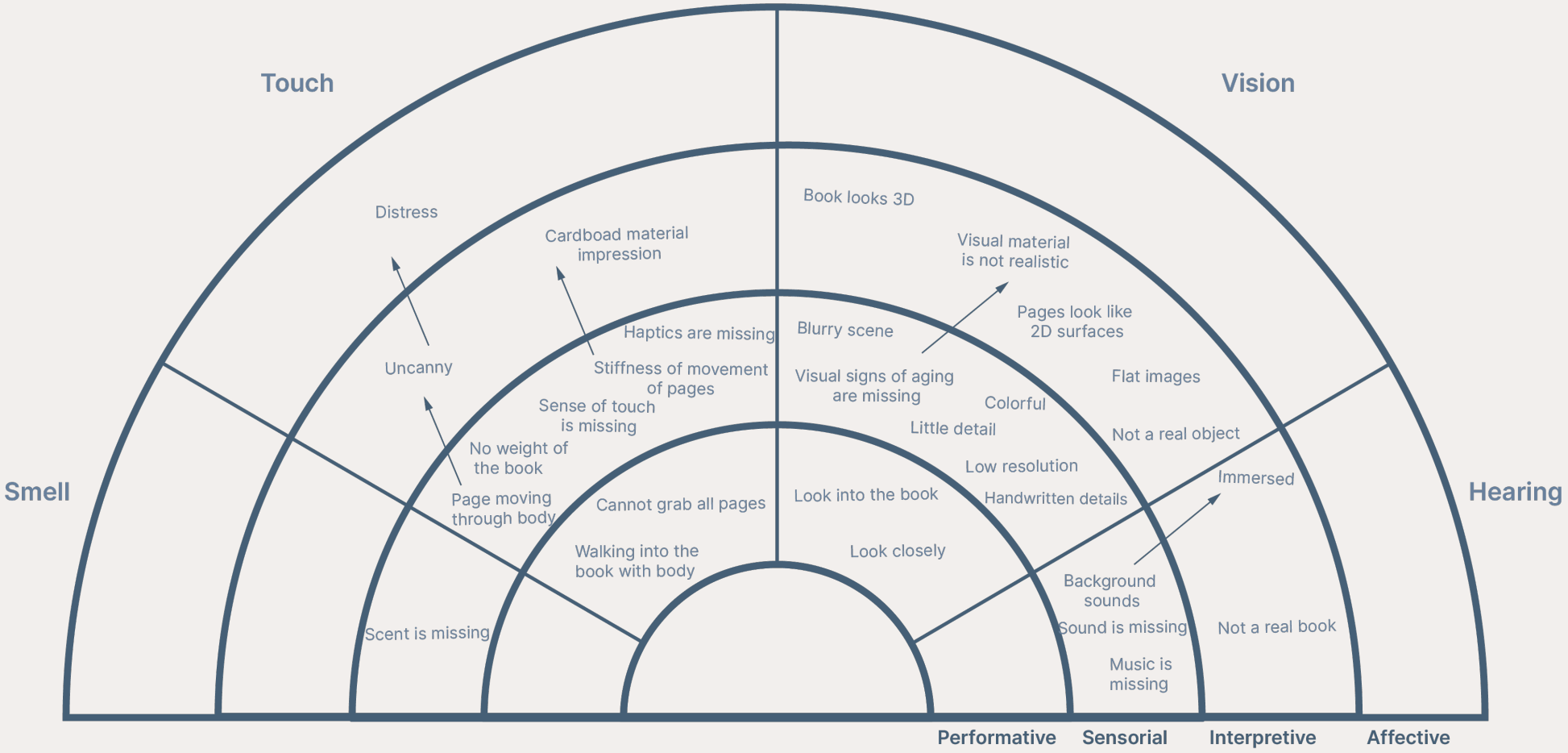
Smell:
Participants mentioned the smell of old books and paper which evoked feelings of childhood and nostalgia. The smell of the glue was a clear sign that the facsimile had been recently made. Some participants mentioned adding scents of the story in the book and turning it into a scratch-and-sniff book.

'So you can really feel the material, you can also smell if the book is made of cardboard.'

Participant 27

3.1.2 Materiality virtual pop-up books

Figure 21: Experiential qualities virtual pop-up books, adjusted from (Camera, Karana, 2018)



Vision:
The visuals of the VR were still colorful and had the appearance of being 3D due to the depth in the virtual world. However, a lot of visual qualities were lost in the digitization process. The resolution was too low to see details for multiple participants. The details of the pages could not be seen which makes it difficult to determine the material of the pages. The aging and wear and tear of the material were also not visible in the virtual books. The flatness and lack of thickness of the pages created the appearance of a digital image instead of a page with material. This effect was enhanced by the rigid stiffness of the pages. The large scale of the book did allow the users to inspect the images from much closer than in a regular book which created new interactions and revealed the pixels.

'Yeah it it was kind of a cardboard or paper in the sense that it was just flats and had the same kind of reflectivity and stuff like that. Of course, when I when I pick up a paper, it's kind of bends and crinkles like that. You don't have that experience [in VR].'

Participant 3

Touch:
The physical interaction of opening a book and turning the pages were the same as with a large physical book. The mimetic interaction created a feeling of familiarity; however, the pages could only be grabbed at certain indicated locations. The participants mentioned that it did not feel like they were handling a real object. This was due to the lack of haptic feedback and physical texture. The book also did not have weight or resistance while opening or closing which are important material qualities. The pages moved through the participants' body without any physical feedback, which created a misalignment of the senses, broke the immersion and caused distress. The virtual material could not break or tear and this caused participants to handle the pages wildly and repeatedly. This was a refreshing interaction for the participants as they did not have to worry about damaging it.

'And in the physical books, it's sort of like the touch because in virtual reality you can have visuals and noises, but you cannot have touch and that will always be like a plus for these ones.'

Participant 2

Hearing:
The sounds of the books were lacking in all four virtual books. A participant mentioned they could not hear the creaking of the pages when turning. However, the VR books did add sounds of the content of the book. One book (*De Garage*) had environmental sounds of the garage integrated. These were perceived as really nice and increased immersion but were lacking in the other books. Participants also mentioned missing music.

'[In a physical book] you can hear the page turning, you can hear it creak. [In VR] you don't have that at all. So if you are able to add sounds, maybe it would be funny to add this so you can hear something.'

Participant 27

Smell:
The scent of old books was missing in the experience which made it more difficult to guess the material and did not evoke associations.

'Or some of the books in their illustration seemed like maybe a bit more older style, but yeah, because of the lack of materiality, you don't really get the same kind of the smell of an old book.

Participant 3

3.1.3 Conclusions materiality

RQ1: *How do the medium and its materiality influence the experience of interacting with physical or virtual pop-up books?*

Physical pop-up books
The materiality of physical and virtual pop-up books influenced the experience on multiple levels. The materiality helped interpret and make sense of the artifacts. The visual appearance of the physical books showed the details of the material and the signs of use which gave away the age of the book. Participants mentioned that they felt privileged because they were allowed to handle a fragile historic artifact. The weight of the book and the material of its pages helped in determining the quality of the book. The resistance of the mechanisms caused satisfaction or fear of damaging the book which in turn led to more delicate interactions. These interaction qualities influenced the experience for the user. The illustration style and the scent of the books evoked pleasant nostalgia to different times. The mechanisms of the pop-up books created fascination and admiration for the ingenuity of the paper engineering. The physicality and tradition of these mechanisms evoked feelings of satisfaction and admiration for a simpler time before digital technology. The minimalistic design of Kubasta's books were especially appreciated. The physical material created an integrated embodied experience that was consistent throughout all senses. The embodiment and freedom of handling the book were preferred by many participants over the VR version.

Virtual pop-up books
The VR books offered a lot of new possibilities but also lacked crucial components. For this reason the virtual material was perceived differently between participants. In general the virtual material was not consistent, not complete and different than anticipated by participants. The VR books lacked multiple sensory modalities which failed to create an embodied experience with the books. In VR the weight and resistance was lacking which caused people to interact more aggressively with the books. This was fun but also felt misaligned. The freedom of interaction was limited to the signified parts of the book, which was unintuitive and frustrating. The visual appearance created the feeling of an image instead of a piece of paper due to the lack of thickness of the pages. Sounds of handling the book were missing which removed the fear of tearing the pages. These missing senses led people to associate the medium with video games or movies, which were sometimes preferred for their ability to convey information. However, the large scale, sound effects and the ability to walk through the book afforded new interactions and experiences that were not possible in a physical book and these were greatly appreciated.

It was interesting that participants mentioned the present material qualities in physical pop-up books but mostly mentioned the lacking qualities in the virtual ones. This could be explained by the fact that in physical reality participants have a frame of reference. In virtual reality, participants started comparing it with physical reality and it was immediately clear which senses were lacking or mismatched.

Improvements for VR pop-up book materiality

The main sense that missed in VR was touch, this has the largest potential for improvement of the embodiment of the experience. Figure 22 plots the effort of implementation with the amount of effect on the experience of all the missing material qualities in VR. The effect on the experience is based on the frequency of comments during the observation study. The effort of implementation was rated with the help of VR expert Pranata Andoko and is dependent on the hardware and software. The setup of the XR zone (Unreal Engine 5.1 and HTC Vive headset) has been used as reference. The Vive does not have hand tracking wich creates the need for controllers, making the interactions less diegetic. The controllers have basic haptic feedback but can't mimic temperature, texture or physical resistance. A senseglove could be used to create physical resistance, mimicking the physical hardness and stiffness of a material (senseglove, 2023). A weart haptic device could be used to recreate temperature cues and textures using microvibrations (Weart, 2023). However, both these solutions are too expensive and complex to use in this project.

The highest impact with the least amount of effort can be made by focussing on the visual and auditory cues and by simulating the physics of the elements. The visual improvements can be made during scanning and photoshopping the pages. The pages should be scanned in high resolution to capture as many details, colors and textures. Thickness has to be added in Blender, creating an extra step. Sound effects and physics can easily be applied in Unreal Engine (UE5). Adding realistic scent requires additional devices, an easier solution could be to add scented oils to the HMD.

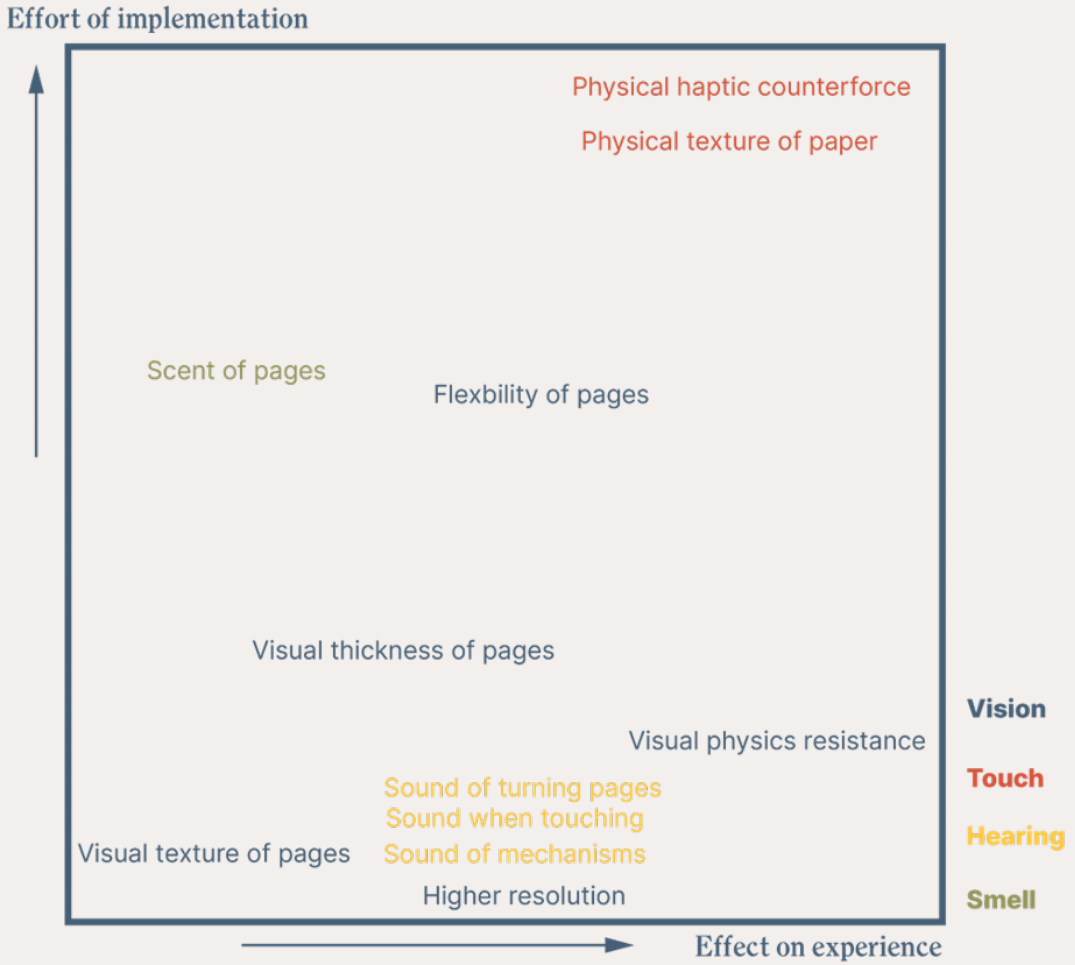


Figure 22: Effort of implementation vs effect of the implementation

3.2 Narrative engagement with physical and virtual pop-up books

The content of the book has a different influence on the experience than the materiality. All books have some kind of narrative. Narrative is the binding element that creates coherence in the content of (pop-up) books. It structures the illustrations and interactive elements. This part analyzed the story internally and externally. The story analysis plotted the narrative from the perspective of the characters. Observation study 1 compares the engagement with the narrative between physical and virtual pop-up books. Observation study 2 measures the engagement and interpretations of the narrative of the case study book. The narrative engagement framework presented in the literature review was used for this. This phase looked into which elements of the experience influenced the narrative engagement and compared the effects of the physical and virtual medium on the engagement.

3.2.1 Story analysis: Tip & Top

The story analysis was performed to plot a baseline of the events and the emotional fluctuations of the characters. This was important to be able to compare the emotional engagement of the the participants and to see how they interpreted the story. The narrative arc developed by Kurt Vonnegut was used to plot this (Openculture, 2014). The arc plotted time on the horizontal axis and positive/negative emotions on the vertical axis. The emotions were plotted from the perspective of the characters. Figure 24 shows the narrative arc for Tip & Top. The timeline was divided per page and each red dot symbolizes an emotional fluctuation. The blue squares illustrate the most significant developments per page. The story starts positively but the emotions go down quickly, ending slightly more positive again. The curve fluctuates a lot which indicates that the story is not very consistent. The peaks and valleys reveal the most significant events of the story and determine the core of the narrative. The characters also differ in attitudes (Figure 23). Top is an anti-hero that is scared and complains about wanting to be home safely. Tip is curious, enthusiastic and likes to explore all the aircraft. Tap the dog is always getting into trouble.

Figure 23: Main characters: Tip, Top, Tap

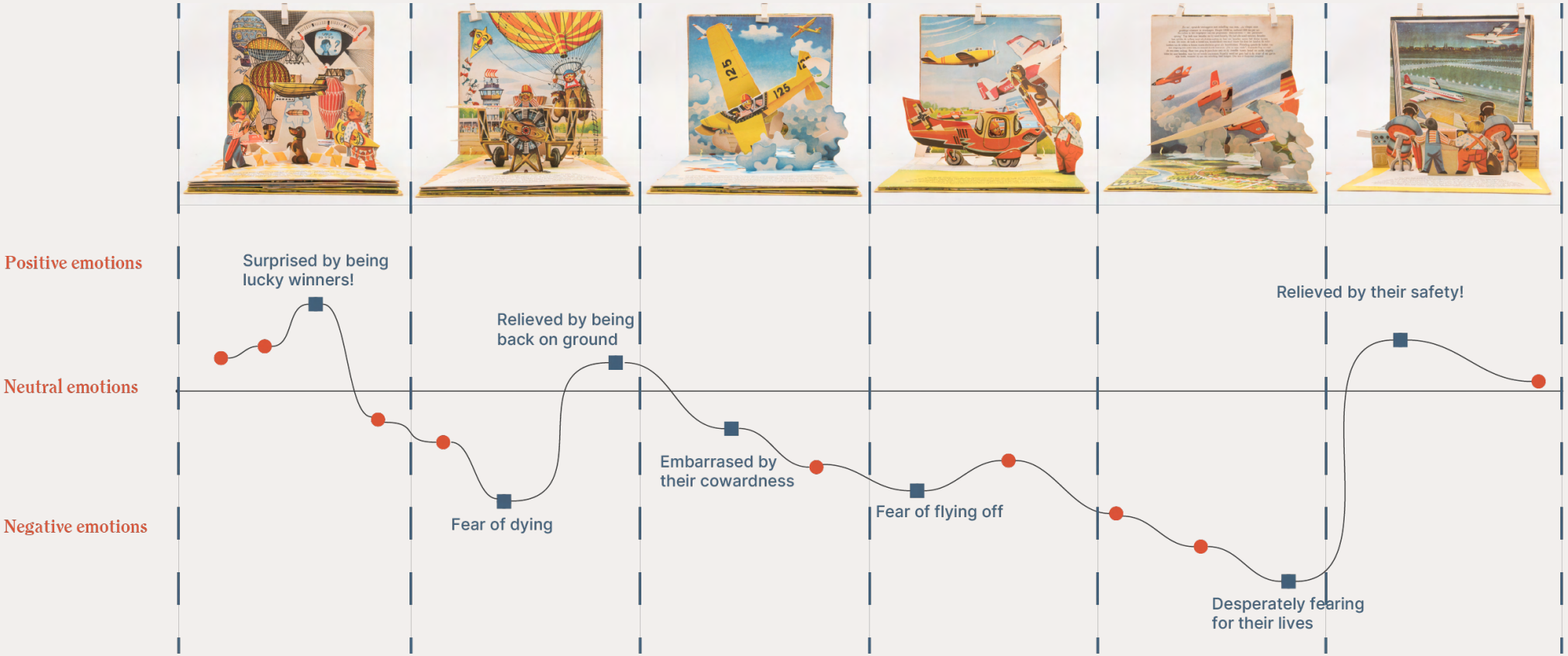


Figure 24: Narrative arc Tip & Top

3.2.2 Observation study 1: Narrative engagement

The goal of this study was to be able to answer three questions regarding the engagement with virtual pop-up books.

1 How are people engaging with the stories of the VR books?
2 To what extent are people engaging with the story of the VR books?
3 To what extent are the stories significant in the VR book experience?

Research method

The narrative engagement with the physical and VR books was measured through a thematic analysis of the data of the observation study. This study was focused on the materiality of the VR books but participants also commented on the content and the stories of the books. The full data set of 27 VR participants was used. Due to the large amount of data and low density of comments on narrative, a regular approach would be too time-consuming. Instead a new approach to filter the information efficiently was developed. All transcripts were scanned using the smart search function within the qualitative data software. A set of keywords was used to search for the relevant data relating to story and content as efficiently as possible. The keywords were chosen based on the NEF and words related to reading and text. The smart search function also included synonyms of search terms and the these were also translated from Dutch to English. The responses were clustered and relevant insights were extracted to answer the questions of the study.

Keywords: *read, reading, story, narrative, context, content, understanding, connect, attention, words, introduction, engage, text.*

Narrative engagement physical pop-up books

The observation study tested multiple different pop-up books with different genres for different ages, the results of which can be seen in Figure 25. Not all books had a story and not all participants could read Dutch.

Figure 25: Results physical book engagement

Conclusions: Narrative engagement physical pop-up books

There was a divide between participants that wanted to read the story and those that were interested in the visuals and interactions. Participants did mention that reading helped understanding the story. People who did not read often didn't understand the book. However, the story was not indicated as an essential part of the experience. The pop-up books offered new interactive and immersive reading experiences compared to regular books. The attention of the participants went to the visuals and the interactions before the text. The participants mentioned that the visuals supported the text and evoked emotions. The interactions were random at points but were connected in some cases like the Alice in Wonderland book.

The study was not focused on reading and narrative engagement so no specific questions about the narrative were asked. The experimental setup, large amount of books and time constraints also distracted participants from reading. The diversity of books made it difficult to compare and generalize any insights on narrative engagement. For this reason a second observation was performed with the case study book (observation study 2).

Narrative engagement virtual pop-up books

The responses were clustered based on the themes of the answers (Figure 26). It shows that the text of the stories was not being read by all participants. The participants engaged in the story in different ways like reading, looking and/or interacting. New senses and affordances added a new level to the experience. Participants mentioned that they missed context or an introduction to the books.

Figure 26: Code clusters narrative engagement virtual pop-up books

Conclusions: Narrative engagement virtual pop-up books

Only two out of four books had any text or story, these were *de Garage* and *de Boerderij*. De Garage also had audio narration which was not triggered by all participants because it was not indicated. All books showed textual metadata about the book in the sky of the VR. This information was not noticed by most participants, and some commented they would have liked some more information before opening a book.

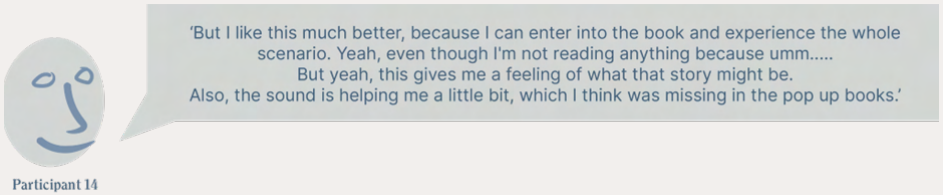
1. How are people engaging with the stories of the VR books?

Participants mostly engaged with the interactions which illustrated the stories to some extent. The interactions were very similar to those of their physical counterparts, which in this case were basic sliders, folding the page and opening the book. These were short and not very inspiring or innovative. This led participants to repeat the interactions often and look for new ones, which did not exist. The interaction time per book was short and participants moved through the experience quickly. The interactions were also not very connected to the narrative which did not contribute much to the engagement with the narrative. This is a missed opportunity and could explain why the engagement with the narrative through the interactions was limited. The VR medium did add new interactions like turning the steering wheel or walking through the book.

The books with text were not being read by the participants. Reasons mentioned were the low resolution or the blurriness of the image. The positioning of the text was also often too high or too low to read comfortably due to the large scale of the books and the close position of the participants to the books. The experimental setup and the fact that a significant part (9) of the participants could not read Dutch made them also ignore the text.

The audio narration in de Garage was hidden and participants were not aware that the books had narration. It was triggered by walking through the centre of the book. It surprised people and they ignored it because they did not intend to trigger the narration. Some participants mentioned they thought the voice and sounds were coming from outside the VR. The sounds helped with giving extra information about the location and helped with immersion in the story.

Participants made sense of the stories through the visuals. They could recognize Noah's ark from the images without seeing any text. They understood that *de Boerderij* was about traditional farm life through the images and interactions.



2. To what extent are people engaging with the story of the VR books?

The understanding of the participants was limited to scanning the visuals, they had a general understanding of the theme of the books but did not remember any details (Figure 27). The interactions and scenes did illustrate the theme well. This was especially apparent in *de Boerderij* in which the interactions demonstrated the different farming activities.

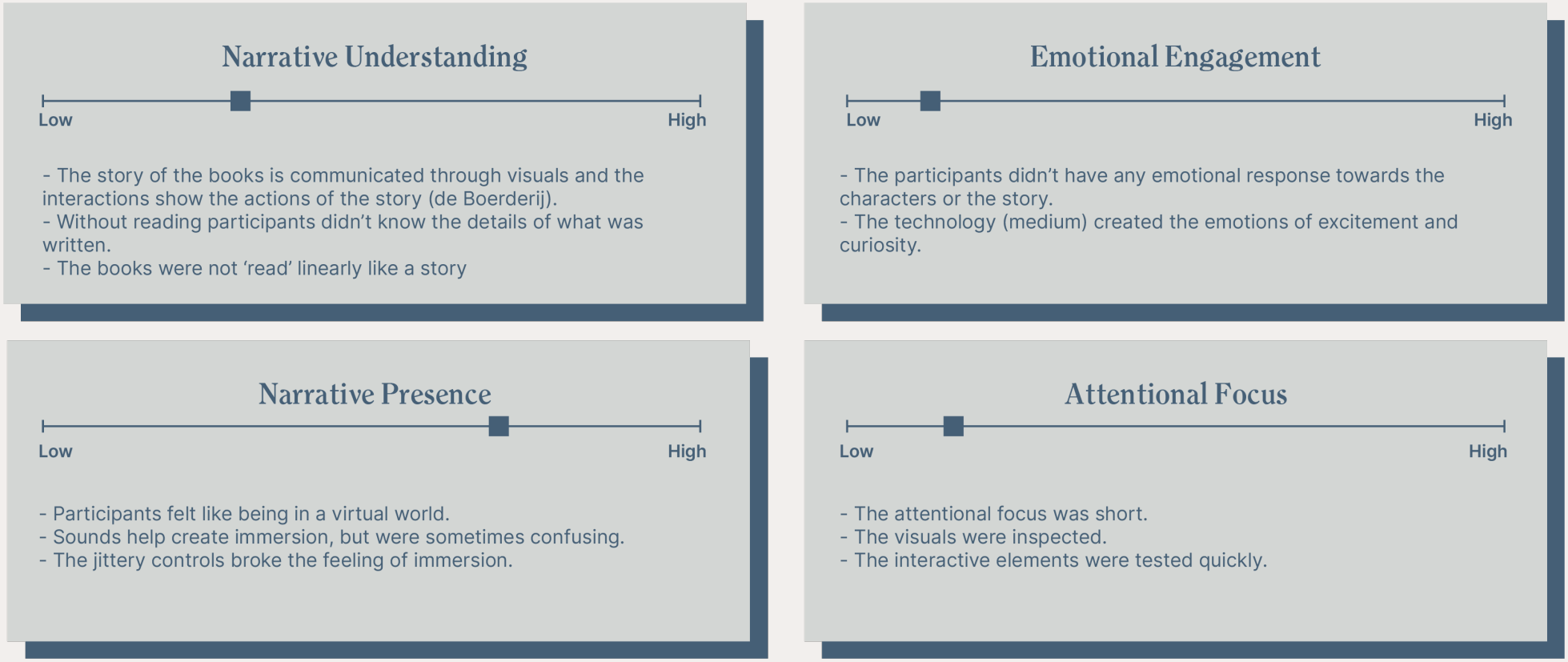
The emotional engagement of the participants was very low because the participants did not read the story. *De Boerderij* and *de Garage* had characters but these books focused more on the scenes than having a chronological storyline. *De Boerderij* did evoke nostalgia. Participants were emotionally engaged by the VR technology and the interactions.

As hypothesized in the literature review the participants experienced a high level of immersion; however, they were not immersed in the narratives but more in the virtual library. The large scale of the pop-up books created a feeling of immersion.

The difficulty with the controls and the jittery navigation reduced the immersion which did not create a feeling of embodiment.
The low level of presence in the story world could explain the limited empathy and understanding, as presence leads to attention (Shin, 2018).

The attentional focus to the narrative was also low like expected due to exploratory behavior of the interactions. This was especially apparent in first time users who got caught up with discovering the controls. The jittery controls and glitchy simulations distracted the users from the story and the virtual world, competing for attention over the story.

Figure 27: Narrative engagement with VR books



3. To what extent are the stories significant in the VR book experience?

The tested books had limited stories and participants did not or could not read the text. The participants were more impressed by the technology and enjoyed discovering the books and the interactions. Participant mentioned that they did not feel the need to read these books to enjoy the experience. This would indicate that for these books the story was not central in the experience. However, they did mention that VR added a lot of new possibilities for storytelling like audio narration. In other books with a stronger narrative the narrative could be important in the experience. The fact that people were not reading is concerning as a book is supposed to be read. It shows that text in VR should be redesigned to support reading.

Figure 28: Setup Tip & Top story test

4. Observation study 2: Case study book

4.1 Narrative engagement case study book

Observation study 1 with multiple pop-up books was not focused on the story and was not specific to the story of Tip and Top. For this reason, a new test has been conducted with the Tip & Top book to get more insight into the specific experience of the book.

Research method

The goal of this study was to measure engagement with the story of Tip & Top and to gauge participants' interpretation of the story. The connection between the story and materiality was analyzed with insights gathered from the materiality study.

The study tested the book with five participants at the faculty of Industrial Design Engineering. The participants were design students between the ages of 20 and 25. The study consisted of an observation study (Figure 28, previous page), a questionnaire and a semi-structured interview. The participants were instructed to interact with the book in any way they liked, without giving any direct instructions. The questionnaire used a 5 point scale to measure the elements of the narrative engagement. The interview questions asked about their experience and their interpretations of the story. Both the questionnaire and the interview questions were in Dutch and can be found in Appendix B .

User types

The test showed two types of users when interacting with the pop-up book: Interacters and Readers (Figure 30). This division was reinforced by the results of observation study 1, the results of this which can be found in chapter 3.2.2. The user types are not distinct personas but can be characterized by two interaction styles that form a spectrum (Figure 29). Readers were generally more focused on the story while Interacters were focused more on the medium. Despite the user types, there were some shared experiences between all users. Nostalgia was an important part of the experience for both types. The paper mechanisms and the surprise elements were shared. As the Readers already engage in the story, the goal for concepting was to also target the Interacters to engage with the story in a way that suits them.

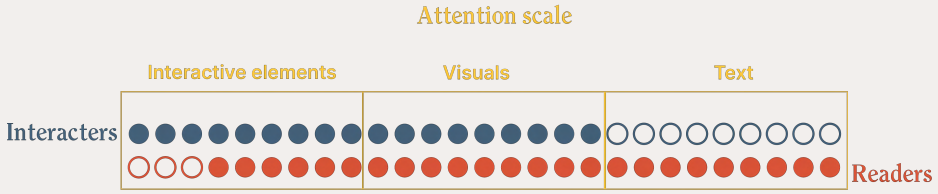


Figure 29: Attention scale and user types

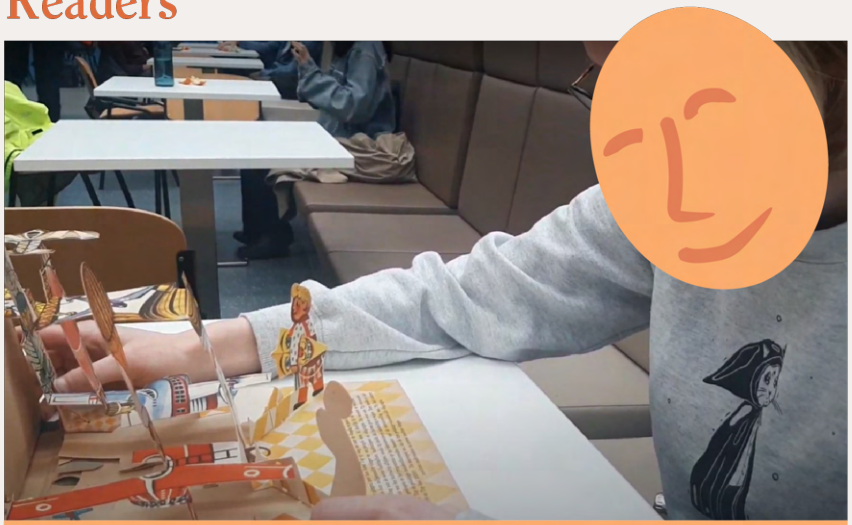
Interacters

"I enjoy playing with all those things and I think I don't need the story to enjoy the experience"

- Focused on **interactive elements and visuals**
- **Searching** interactive elements
- **Touching and playing** with interactive elements
- Go through book **quickly**
- Little to **no attention to text**
- **Make up their own story**
- **Story is not essential** for experience

Why are they not reading?
- Visuals and interactions are more interesting
- Prefer reading with or to someone
- Too much text on the page
- Experimental test setup

Readers



"For me the story is an essential part of the experience, I can make up what is happening by looking at the images but if I would only look at the images I would only see chaos."

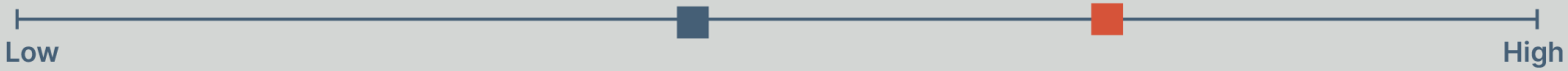
- **(Partially) reading story**
- Text helps with **understanding the book**
- **Searching details in visuals** mentioned in the text
- **Following instructions** in text
- More **deliberate and slow process**
- Notice **nuances in the language**
- **Comparing** text, interactions & visuals

Figure 30: User types

Narrative engagement Tip & Top

Figure 31: Narrative engagement case study book

Narrative Understanding

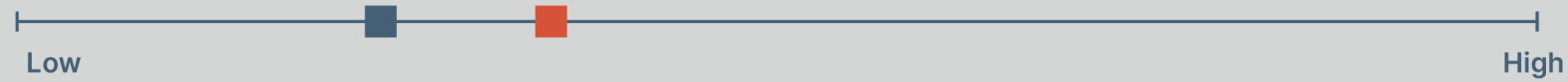


Shared:
- General understanding of story
- Story is short and simple
- The names of the characters are confusing

Interacters:
- Understand the general theme of the book.
- The visuals communicate thread of story.
- No understanding of details of story.
- They are happy making up their own story.

Readers:
- Understand the details of the story and compare the text with the visuals of the book.
- Noticing the abrupt transitions between pages and images.

Emotional Engagement



Shared:
- No empathy for characters
- Story is too short for character development
- Visuals show expression of characters
Characters are cute and funny

Interacters:
- Emotions evoked by paper mechanisms and illustrations

Readers:
- Text explicitly mentions emotions of the characters

Attentional Focus

Shared:
- Focused on their activities
- Faculty is a distracting environment
- Visuals and 3D elements grab attention

Interacters:
- No focus on reading
- Focus on discovering interactions
- Focused on playing with interactions

Readers:
- Scanning the text
- Focus divided between text and visuals

Narrative Presence

Shared:
- The participants felt partially immersed in the world
- 3D pop ups and images help to immerse people
- Background sound and setting break the immersion

Results: Interpretation of story

The story was written for children but tested by adults. The opinions and interpretations of participants were asked to get an idea of how the story was perceived by adults. The interpretations and reactions varied a lot. This could be caused by personal preferences or age. These are their reactions clustered in themes:

Adventure story:
- Discovering the aviation industry and different aircrafts.
- Learning about the history of airplanes.
- Participants loved the Jules Verne type of adventure and exploration.

Story for children:
- The story was funny due to the jokes.
- The characters and illustrations are cute.
- The story was childish and people did not like it.
- The language appeals to small children.

Story is weak:
- The story is too short.
- The premise is bad.
- The story is negative.
- No real character development.
- The characters are confusing.

The story was not really suited for adults. Some participants appreciated the nostalgic value of history and some liked the cuteness of a children's story. However, the majority did not take the story very seriously. This raises a dilemma: How do I keep the authenticity of the story while adapting it to modern times and a mature audience? This will be addressed in the conceptualization phase.

4.2 Conclusions narrative engagement

RQ2: How do the content and narrative influence the experience of interacting with physical or virtual pop-up books?

Virtual pop-up books (OS1)
The virtual pop-up books were interactive; however, these interactions were not very interesting or meaningful as they mimicked regular pop-up book interactions. In several cases the interactions distracted from the story and were not connected to the narrative. The stories were missing in two books so the interactions did not have a narrative structure. This caused short, repetitive interactions that were not very engaging. The visuals showed the theme but the engagement with the story was minimal. The attentional focus, understanding and emotional engagement were low. A chronological storyline with characters could help emphasize the narrative element. This would increase the need for understanding the characters and leads to higher empathy. The interactions should be more connected with the story and integrated in the narrative.

Physical pop-up books (OS1)
The large variety of books made it difficult to compare and generalize the engagement with these books. The variety did show that modern or abstract books appealed to the mature audience because of the simplicity while the children's' stories evoked nostalgia and childhood sentiments. The study showed a difference between user types ranging from intentional readers and avid interacters.

Case study book (OS2)
The engagement with the narrative differed between the user types, especially for the understanding and the attentional focus. Readers had a better focus and understood the story better. For both types the emotional engagement was low, due to the childishness of the story. This calls for more maturity and a better adaptation for an older audience. The immersion was low due to busy environment. The interactions were partially connected to the story, partially missing.

5. Conclusions analysis phase

5.1 Materiality and narrative

RQ3: *How are materiality and narrative related in physical and virtual pop-up books?*

Physical pop-up book (Tip & Top)
The examples in Figure 32 show how content and medium are *integrated*. The affordances of the medium served the story. Some interactions illustrated the story while other interactions showed how the aircrafts function. The text sometimes explicitly mentioned an interaction like folding the airplane. Children could experience aerodynamics of glider planes by folding and throwing the airplane. The materiality can also enhance the dynamic effect of the aircraft like in the example of the jets that wobble when opening the page. These interactions improved the engagement with the story and should remain in the VR experience. They could be enhanced with the additional interactions afforded by the VR.

Some examples (Figure 33) also showed that the medium and the different elements of the story were *not strongly integrated* which can be seen on the next page. The story only showed some snapshots of the stories with the visuals so not all activities of the plot were communicated through visuals. For example: on page 5 the parachute jump was not shown in the image and it is a core moment in the story. The interactions were often not connected and did not contribute to the story like the sliders of Tip and Top or the wobbly guys on the final page. The experience was partially integrated because the story itself was not very engaging and the interactions distracted from the narrative. The goal for the VR pop-up book was to use the interactions to support the story. Another option could be to add more snapshots of events from the stories in the interactions.

Virtual pop-up books
The stories in the virtual pop-up books were not emphasized in the experience, and participants did not pay attention to them. The immersive 3D effect helped users to really stand in the scene and discover different details that were not visible in a physical book. It created new perspectives that can be used during storytelling. The medium also added sounds which helped immerse people in the story world of *de Garage*.

Interactions illustrating story

Page 1 - TV slider

Interactions showing how things work

Page 2 & 4 - Rotating rotors airplanes

Interactions instructed by text

Page 6 - Searching for Tap

Page 3 - Folding the ariplane and flying

Material aspects enhancing story

Page 5 - Moving jets enhance dynamic effect

Figure 32: Interactions integrated in narrative

Visuals missing in story

Page 5 - Parachute jump is missing

Random interactions

Page 1 - Slider Tip and Top

Page 6 - Wobbly guys

Figure 33: Story and medium not integrated

5.2 Design goals

1. **Adapting the story to fit the digital medium and a current day audience, while preserving the original storyline and a feeling of authenticity.**

The original story was written for children and parents reading the book together but it did not engage some adults reading it independently. The story was also outdated which had its nostalgic charm but did not appeal to all adults. The goal is to present the story in new ways so it fits the technology and appeals to current day adults. The storyline should remain the same and the experience should feel authentic.

2. **Increasing the engagement with the story compared to the original pop-up book and previous VR pop-up books.**

The final concept should increase the engagement with the narrative compared to the engagement with the original pop-up book. The engagement of the story can be enhanced top-down or bottom up. Engagement is a derivative of enjoyment of the experience (Busselle & Bilandzic, 2009). Creating an enjoyable experience will likely increase the engagement. The engagement could be improved by enhancing the qualities of the story in VR. Another approach could be focusing on the individual elements from the framework and targeting them.

3. **Creating an interactive storytelling experience of the book in VR in which the interactions support the story and vice versa.**

The story of the book is linear and it is limited to the illustrations and designs made by Kubasta. The outcome of the plot can not be changed; however, VR offers new possibilities in storytelling to improve the connection between interactions and story. The literature points out that interactivity and agency can lead to higher engagement (Petousi et al., 2022).

4. **Designing for a multisensory material experience with the book in VR.**

The recreation of the material experience is the foundation of this project. A real physical experience can not be reproduced; however, a multisensory experience can simulate the experience by triggering the different senses. This is important for the embodied experience of VR and the feeling of history.

5. **Integrating the material experience with the storytelling in VR to create a balanced and integrated experience.**

Story and materiality influence the heritage experience differently and both aspects should be implemented in VR. However, people only have five senses and story and materiality are both competing. This design goal is tied to research question five which looks at the relation between the two in VR. The aspects could contradict each other or be synergetic. The goal is to try and balance or integrate them in a way that the materiality enhances the story and the engagement.

5.3 Interaction qualities

In order to align and integrate the interactions with the narrative, a set of interaction qualities have to determined. The qualities of the interactions should support the desired qualities of the story. Interactivity in storytelling can increase the engagement with the story by adding agency and activity for the user. However, observation study 1 showed that interactivity doesn't necessary lead to engagement with the story and can actually be distracting. The story was interpreted differently, with users interpreting it as an adventurous discovery story for children which was also a bit childish. The feeling of adventure and exploration are the desired qualities that should be supported by the interactions. Qualities related to this feeling are: Surprise, Excitement & Dynamism (Figure 34) . These qualities are likely to be improved in VR as the medium is new and surprising for participants. However, these qualities were not present in the existing VR books and can be improved significantly in this experience.

Figure 34: Interaction qualities

5.4 Design requirements

The design requirements served as a list of criteria to guide different prototypes and the final concept. They were used during designing and prototyping or when taking decisions. Not all requirements can be met at the same time and some requirements are contradictory. They were clustered per topic and are hierarchical, the higher on the list, the more important they are. The list was compiled by me, based on conversations with users, designers and my supervisors.

Materiality
- The VR book should convey the materiality of the physical book.
- The materiality should take advantage of the extra affordances and interactions in VR.
- The materiality should blend qualities from the narrative and the artifact in VR.

Narrative engagement
- Users should understand the plot of the story.
- Users should be able to distinguish the characters.
- Users should have some kind of emotional response to the story and/or characters.
- The story should draw the attention of the user.
- Users should feel present in the story.

Story authenticity and enhancement
- The original plot and the characters should remain the same.
- The physical structure of the book should remain the same, and new elements can be added.
- The historical sensation from the 1960's should be preserved and respected.

Interactions
- The interactions should engage the full body and be largely mimetic.
- The interactions should evoke the interaction qualities: surprise, excitement, and dynamism.

VR technology
- The experience should be self-explanatory.
- The experience should be playable without external instructions.
- The experience should be engaging for first-time and experienced VR users.
- The VR experience should minimize the risk of nausea.

Phase 2: Ideation

The ideation phase consisted of three phases: diverging, reverging and converging. It generated insights and new ideas individually and with a group.

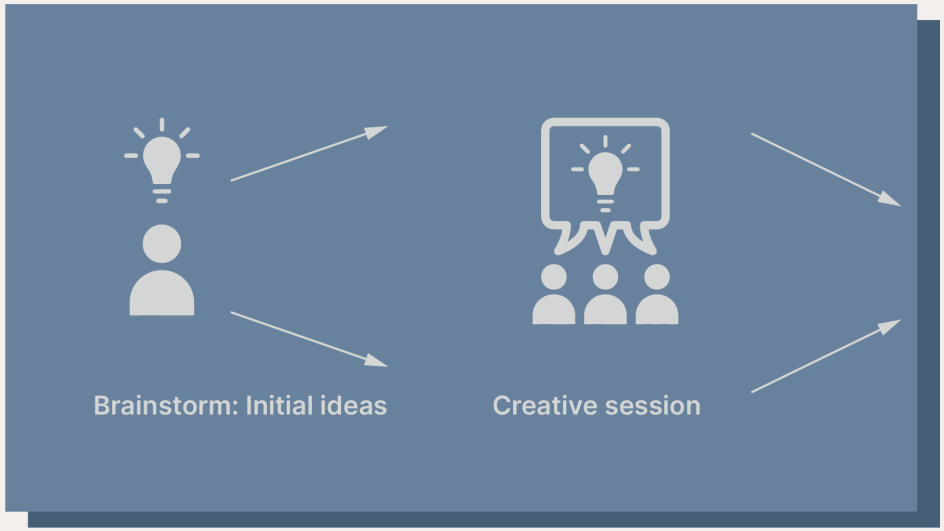


Figure 35: Ideation acitivities

6. Ideation

The ideation phase started with an individual brainstorming session in which I noted down all my ideas that popped up during the analysis phase. These ideas have been divided into different categories (Figure 36). The goal of this session was to collect all my assumptions and ideas and to identify which categories are still limited. It is the first step in order to let go of my previous conceptions and trigger deeper more creative ideas.

6.1 Topics & initial ideas

Figure 36: Initial ideas and topics

6.2 Creative session

Method
The goal of this creative session was generating ideas for new interactions with the book in VR. It addressed design goals 1 and 2 by connecting the interactions to the story and using the interaction qualities to make the interactions better fitted to a mature audience. The input from this ideation session was used for different types of prototypes focused on narrative engagement. Leading a creative session was also a personal goal I wanted to try during graduation.

The activities and structure of the session was inspired by the book: Road Map for Creative Problem Solving Techniques (Heijne & Van der Meer, 2019). The session focused on the first two stages of the creative process: diverging & reverging (Figure 37). The story was introduced using the 2D digital storyboard with audio narration. The prompt for the session was: Which new interactions/ effects could support the story of the book in VR? During the first round the participants were asked to individually purge all their ideas using post-its on a flip-over sheet. After discussing the ideas, the group tried brainwriting with the interaction qualities. Finally the sheet was assessed, the ideas were clustered and the gaps were filled with ideas (reverging).

The session was conducted with 5 design master students (DfI, IPD & SPD) at the faculty and took an hour (Figure 38). I was both the facilitator as the problem owner which can be conflicting. I tried to limit my involvement in the process and stayed as open as possible.

Figure 37: Process

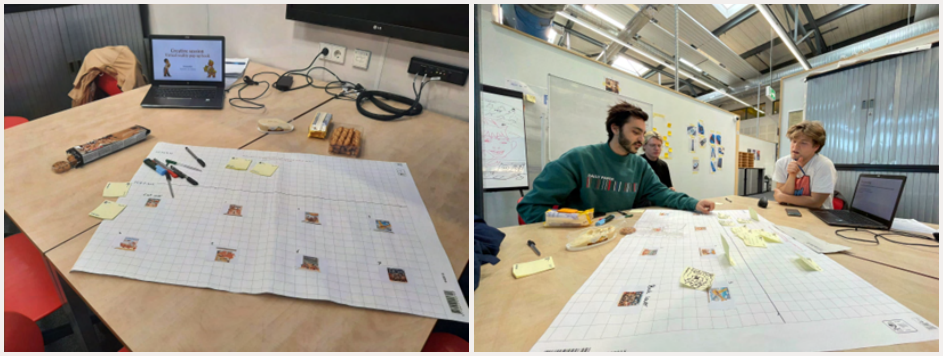


Figure 38: Creative session

Analysis

The session generated 59 ideas and covered many more aspects than originally intended; however, these were also useful and relevant. The converging process was done after the session and was based on relevance, usefulness and feasibility. The ideas started broad and general and became more concrete and useful towards the end of the funnel (40). All ideas were sorted into clusters based on their type of solutions (Figure 39). The full overview of clusters can be seen in Appendix C. The most relevant and useful ideas are presented below.

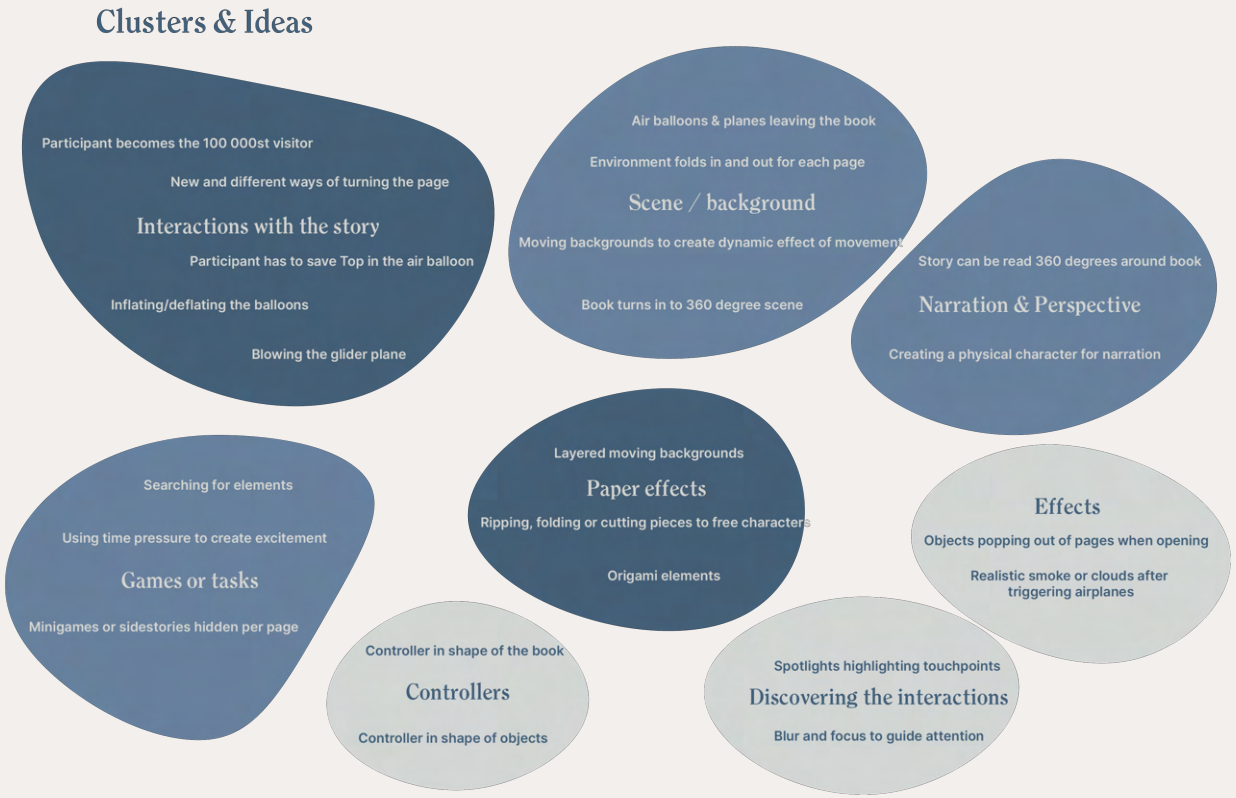


Figure 39: Clusters of ideas

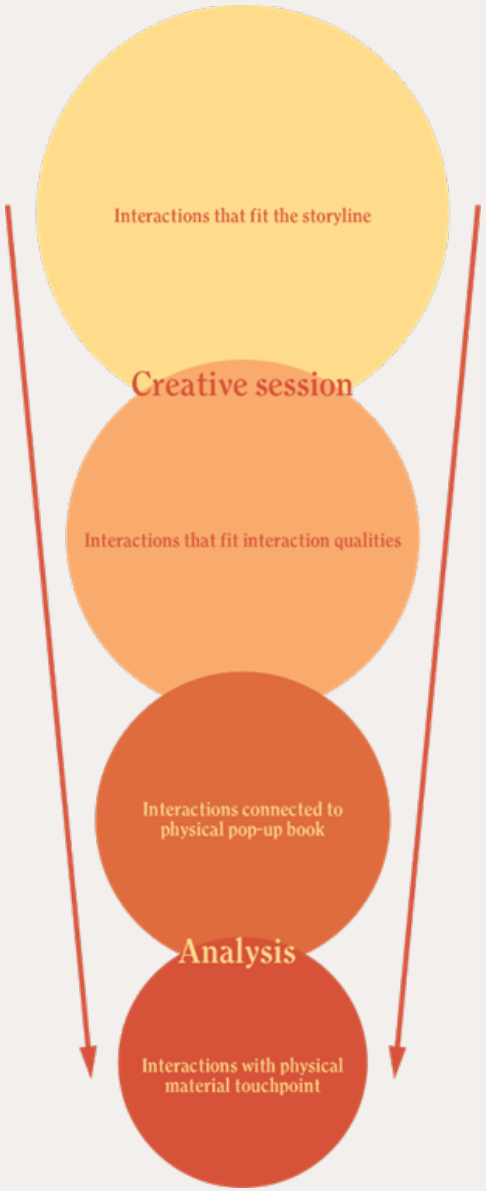


Figure 40: Converging and selection

Phase 3: Conceptualization

Activities

Figure 41 shows the design activities performed during the conceptualization phase. The process was designed to test as much as possible in 2D before prototyping in VR. This sped up the process and eliminated unnecessary development. Each activity focused on different elements of the experience which were all implemented in the final VR prototype. The process was iterative, implementing the insights of previous tests in new prototypes to confirm their effectiveness, while also testing new alternatives

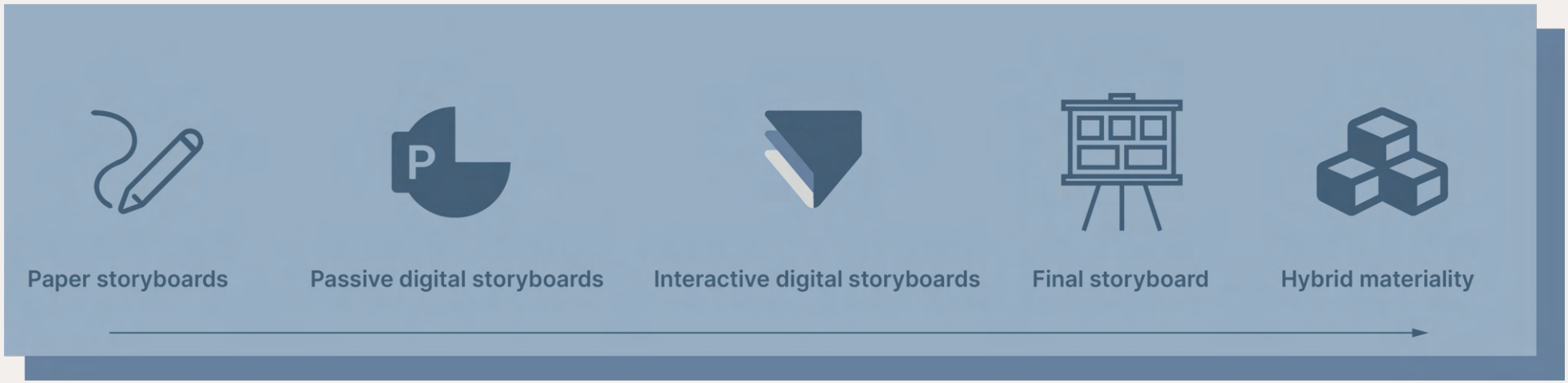


Figure 41: Design activities conceptualization phase

7. Storyboards

7.1 Paper storyboards

Paper storyboards were used in order to rapidly generate and visualize ideas in different stages of the project (Figure 42). The storyboards were used to map out the interactions in different positions on the TEN framework. They were mainly used as inspiration and were not tested with users. It created an opportunity to test many different interactions and effects without taking too much time.

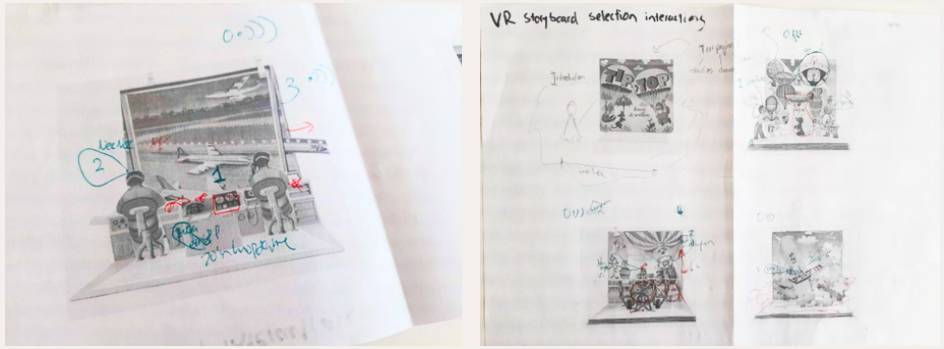


Figure 42: Paper storyboards

7.2 2D Passive storyboards

Method

Goals:
- Seeing the effects of experiencing the story digitally on the narrative engagement.
- Discovering the influence of first-person narration on the understanding of the story.
- Identifying the difference in experience between reading the text versus listening to audio narration.
- Discovering the effects of the 2D digital images on the material experience of interacting with the pop-up book.

This round of prototyping tested two different lo-fi digital prototypes. One prototype (Figure 43) used text to convey the story while the other (Figure 44) used the original vinyl audio narration. The narration and text had already been adapted to the first person in the vinyl recording and were split by me to be triggered separately and chronologically. The interactive elements have been photoshopped to move digitally. The story was linear and passive meaning that the participants just observed the story externally.

The two prototypes were tested with two participants (50-60 years of age), the participants could go through the story at their own pace and were asked to think out loud (Figure 45). After testing a few questions were asked about their experience.

Figure 43: Digital prototype: Comic book version

Figure 44: Digital prototype: Audio narrated version

Figure 45: User test

Results

Narrative engagement

Several aspects of the narrative engagement were enhanced compared to reading the physical book. The digital medium created the opportunity to divide the scene and information over time creating a more linear and understandable story. The first-person narration of the story helped distinguish the characters. This helped with understanding the story as the story progressed clearer and the transitions were less abrupt.

The emotional engagement was also increased compared to the original book, as the participants laughed or commented on the story. Dividing the information helped with keeping the participants focused on the story.

Participants had full attention to the story because there were no interactive elements to engage with and they could observe and listen. Some movement was built into the prototypes but these were mostly unnoticed. The participants had high expectations for the digital prototypes which were not met.

Text

The text prototype required some active participation from the participants because they had to read. The emotional response to this was less because the audio was missing in this experience. It reminded the participants of a comic book; however, the effect was underwhelming as the graphic design was plain and undynamic. Participants were expecting more emphasis and movement in the text. The speech bubbles did create a clear distinction of characters and emphasized the message.

Audio

The audio prototype added a new sense to the experience which helped with the emotional engagement. The voices of the characters expressed emotions and the old-fashioned language created nostalgia. The audio quality created a sense of age. The differences between the characters and the narrator were more clear; however, the source of the sound was often difficult to identify. Participants mentioned that the book was missing sound effects of the airplanes and surroundings.

Recommendations

The test was a good first prototyping step for adapting the physical book into a digital experience. It showed that the medium has a large effect on narrative engagement but that this can have a negative effect on the overall experience. The experience can be improved with some simple adaptations.

- The text can be more dynamic and appealing.
- The background of the book can be used to create a more immersive environment.
- The participants should be able to interact with characters, visuals and narration.
- Sound effects can enhance the experience by making it more immersive.
- The visuals could be more dynamic and can leave the boundaries of the book.

7.3 2D interactive storyboards

The goal of this round of testing was to see the effect of interactivity and agency on the digital pop-up book experience. Another goal was to assess the feasibility of different interactions and effects before developing in 3D. To test this three different interactive prototypes were created based on different positions on the TEN framework. In 2D the physical engagement slider was limited to semi-diegetic interactions due to the constraints of the clickable medium.

Linear storyboard
This prototype took a very linear approach to the narrative of the book (Figure 46). A chronological path of interactions and effects guided the user through the story. Different usecues were used to signify which interaction should be triggered at what time. The user had a semi-external role, triggering the story without being in the story itself.

Exploratory storyboard
The exploratory storyboard allowed for much more interaction with the book and the story was no longer chronological (Figure 47). The user could determine which interactions to trigger in their preferred order on each page. The order of the pages was still predefined according to the original book. Again the user had a semi-external role.

Internal storyboard
The user experienced the story as an internal character from the perspective of Tip (Figure 48). The pages had been photographed from Tips perspective and the user could look around the book and jump into different aircraft. The story was partially linear and partially exploratory.The exploratory storyboard allowed for much more interaction

Prototypes

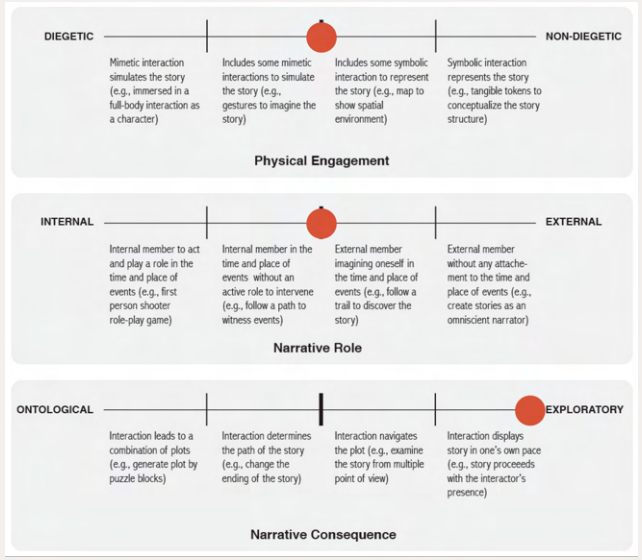


Figure 46: Linear story: positioning and screenshot

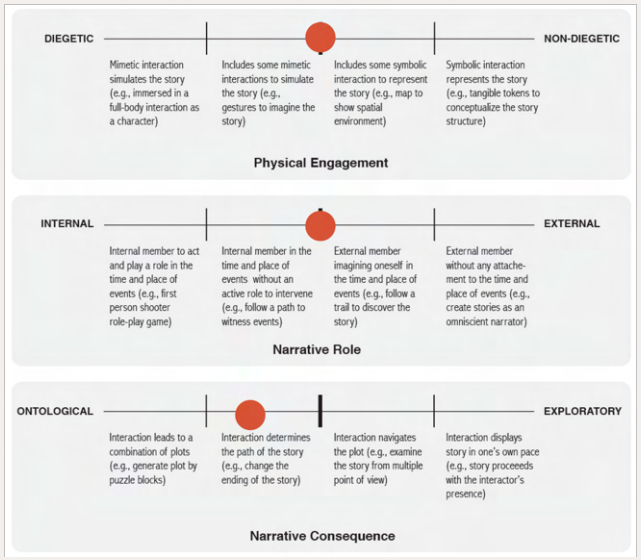


Figure 47: Exploratory story: positioning and screenshot

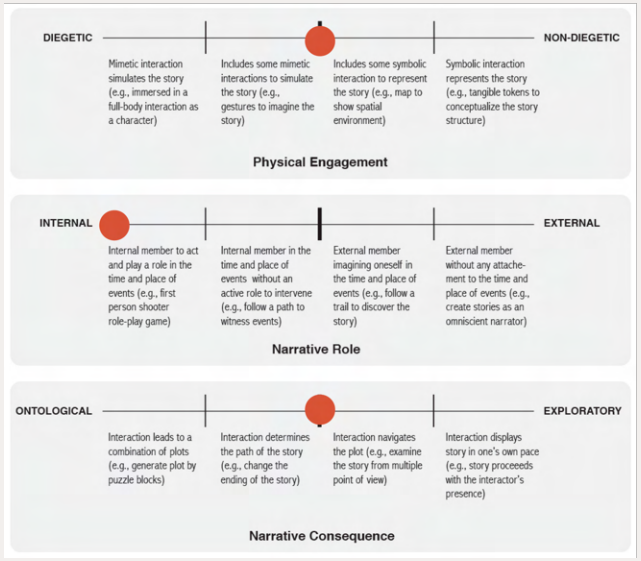


Figure 48: Internal story: positioning and screenshot

Method

Each prototype was tested separately by three participants (Figure 49). The participants were a mix of design and non-design students. Some participants had previously been involved in the project either in observation study 2 or the creative session. These participants had a better understanding of the project and could provide useful comparisons between the prototype and the original book. The prototypes were tested on a mobile phone because this gives the smoothest performance, however the size of the screen was limited.

The prototypes were evaluated through observations and interviews. The questions of which were based on the design goals, narrative engagement and interaction qualities (Appendix D). The amount of control and interactivity was also added as a criterium to test the usability of the prototypes. The criteria (Appendix D) were linked to a Harris profile (Figure 50) in order to compare differences in prototypes.

Figure 49: Test setup interactive storyboards

Harris profile

	--	-	+	++
Prototype				
Adaptation to modern/mature audience				
Originality of experience				
Level of control and interactivity				
Interactions and effects connected to story				
Narrative engagement				
Understandability				
Emotional engagement				
Narrative presence				
Attentional focus				
Interaction qualities				
Surprising				
Exciting				
Dynamic				

Figure 50: Harris profile

Reinterpretations vs authenticity

The maturity and authenticity were similar for all prototypes. Interestingly different participants reacted differently to the same effects. Most participants mentioned that the experience was still suitable for adults for multiple reasons (Figure 51). The experience was childlike but also evoked nostalgia and childhood sentimentality. It was mentioned that for some participants it was not a form of entertainment but more a type of education. The humor and language was dated but this was also seen as a form of nostalgia and authenticity. The experience was suitable for modern audiences as participants liked the cool effects and the pace was good. The experience was perceived as authentic due to the old voices, illustrations and the story itself (Figure 52).

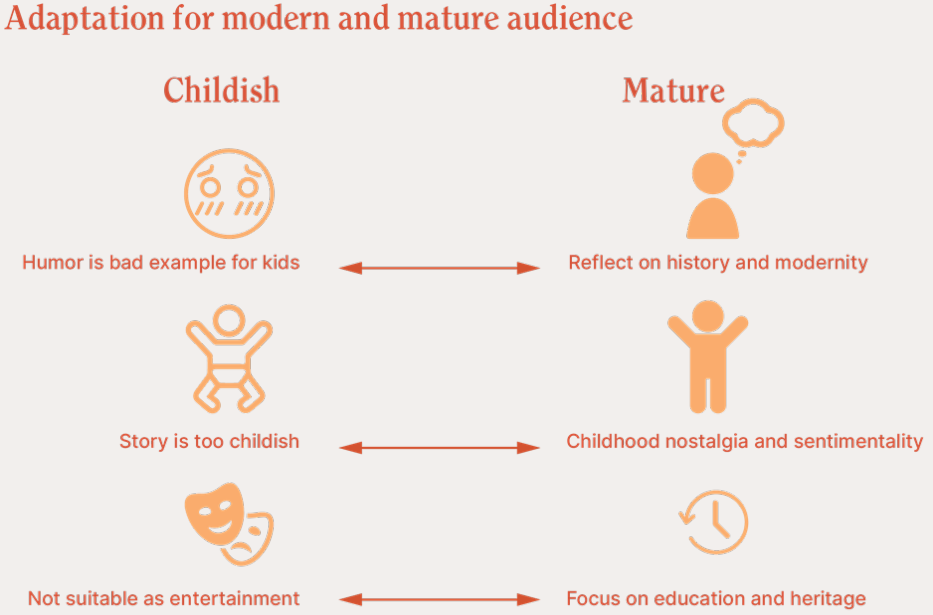


Figure 51: Adaptation for audience

Figure 52: Authenticity

Interactions and effects

The prototypes differed in levels of control and interactivity as plotted in Figure 53. Control refers to the amount of agency or choice the users have over the story. Interactivity refers to the number of interactions and effects possible. These two variables impacted the experience significantly. Generally, higher interactivity led to lower understanding of the story but a higher feeling of surprise and excitement. Lower interactivity made the story a lot clearer but also less exciting. Control led to higher engagement because the users felt like the story was dependent on them. The final concept should be situated in the the high control and interactivity segment.

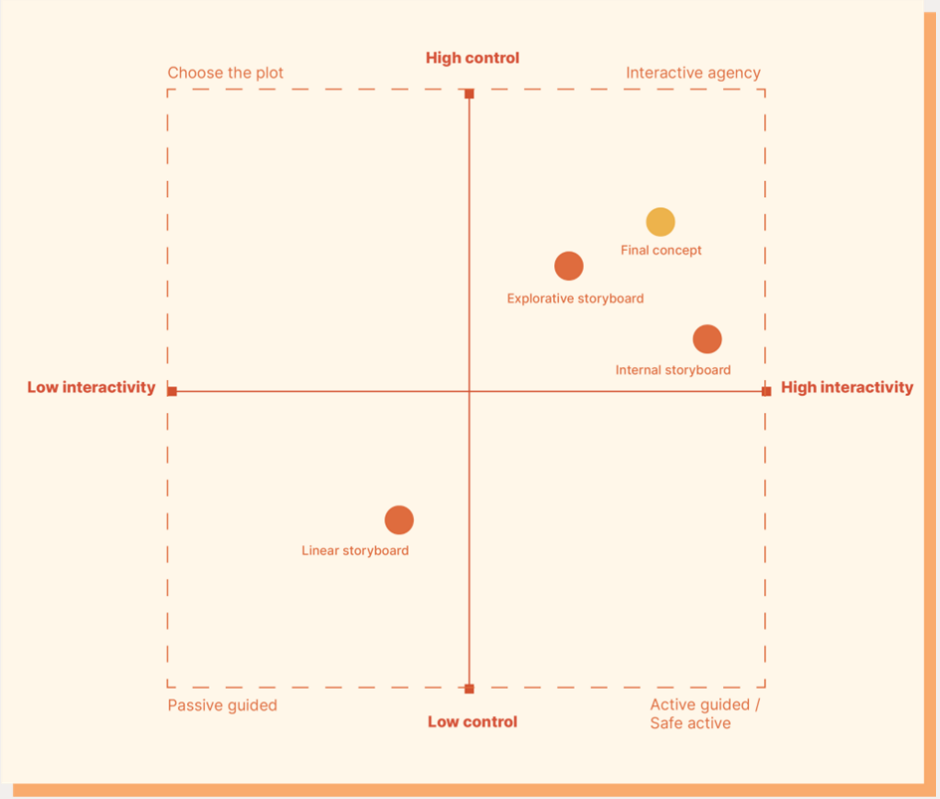


Figure 53: Connection interactions and narrative

Connection between elements

The experience had three types of interactions: narrative interactions, visualization interactions and disconnected interactions (Figure 54, next page). The narrative interactions triggered the narrative of the narrator or the characters. Visualization interactions showed the narration. Disconnected interactions did not have any effect on the storyline. These were a source of safe exploration and were fun without competing with the story. The other two types of interactions were chronological and if they were done incorrectly they messed up the narrative understanding. The usecues and interactions grabbed the participants' attention and distracted from the narration at the beginning of each page. However, the interactions also forced some participants to listen to the narration to understand what to do.

Narrative engagement

The narrative engagement was influenced by many different factors (Figure 55, Page 63). First of all the interactivity of the prototype forced engagement with the story because it did not continue without it. Agency and control also enhanced the engagement by giving the participants a choice. Narrative presence and attentional focus were closely linked, attention led to immersion and distractions from the test environment or from bad UX tended to lower the immersion. Narrative understanding led to a higher emotional response. The engagement differed per prototype.

Connection between elements

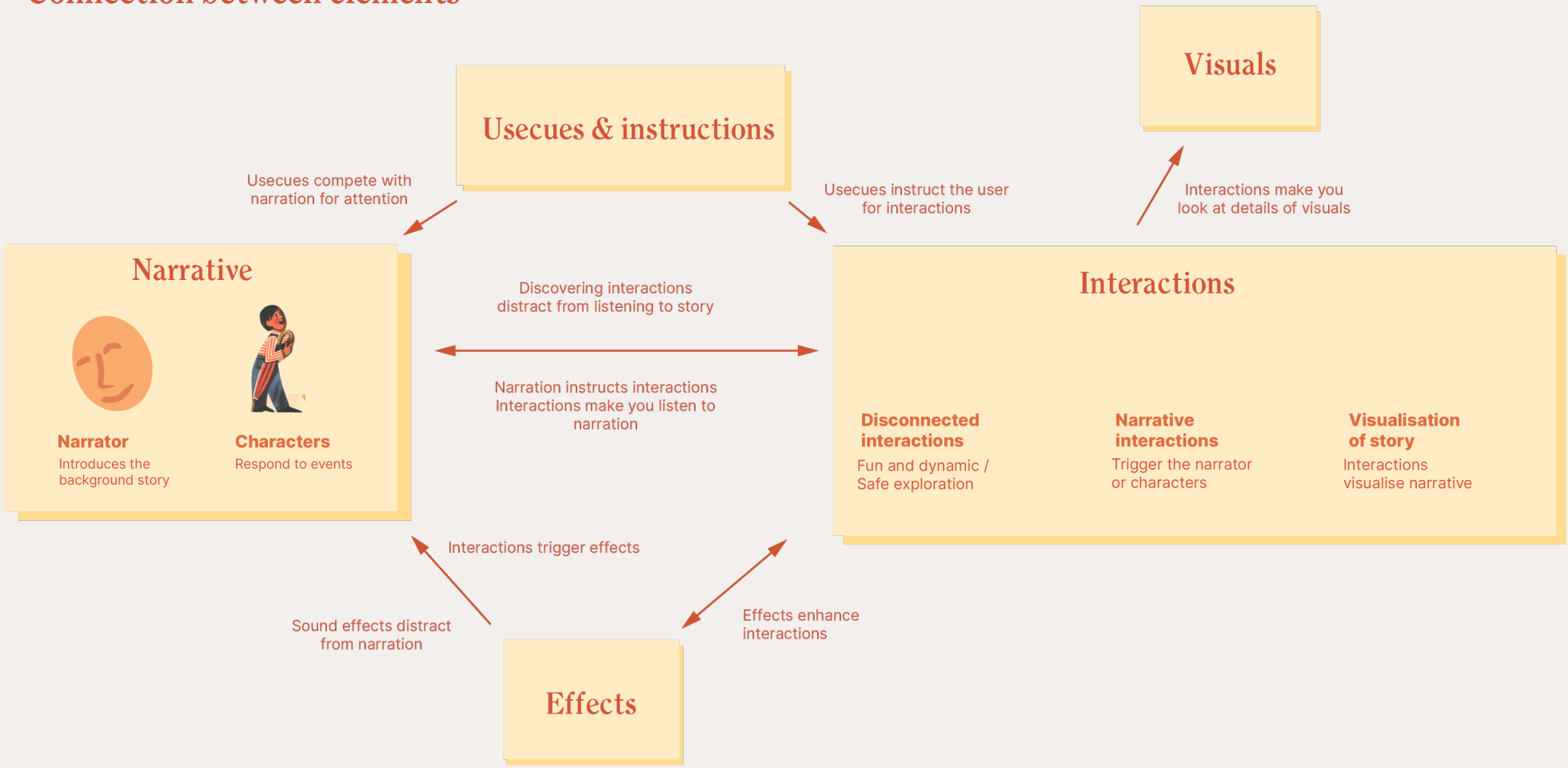


Figure 54: Connection between elements.

Influences on Narrative Engagement

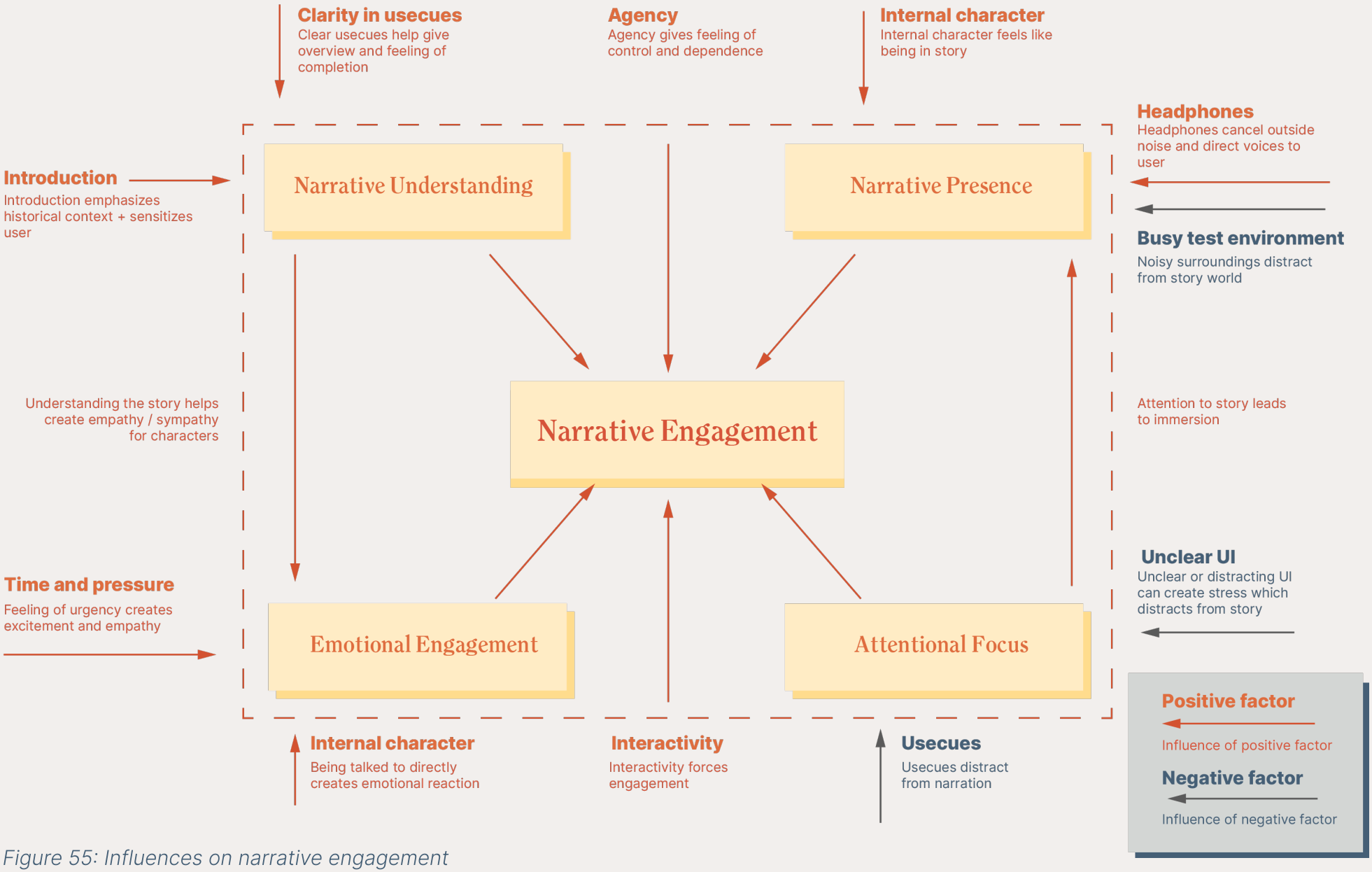


Figure 55: Influences on narrative engagement

Interaction qualities

The interaction qualities were still very similar to the original book, mainly nostalgia, joy and cuteness were given as emotional responses (Figure 56). The intended qualities: excitement and dynamism weren't met. The only interaction quality that was met was surprise as many participants mentioned exploration, anticipation or surprise. However, negative surprise was also often mentioned when interactions were not as expected

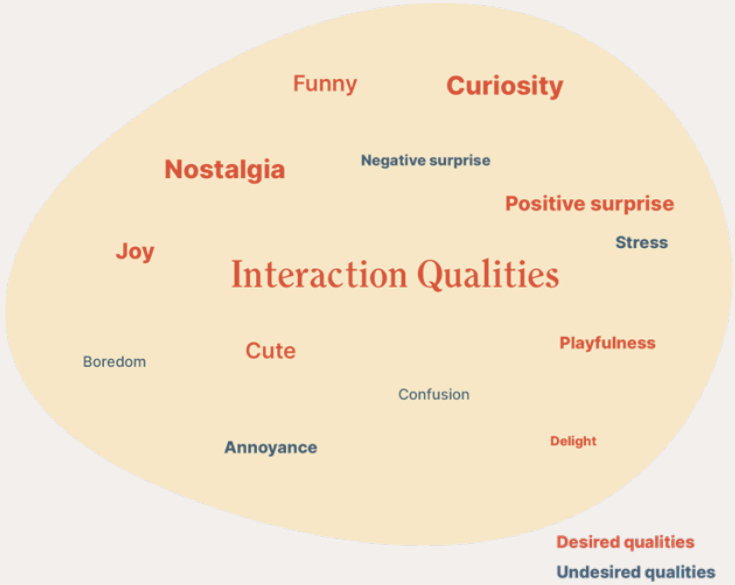


Figure 56: Interaction qualities

UX

The UX and usecues of the experiences had a significant effect on the engagement and the interaction qualities. Bad UX distracted the users and guided them to the wrong interactions which led to chaos. This broke the immersion and attention and also left the users feeling stressed or afraid of messing up. This made users stick to the obvious interactions which led to fear of missing out. On the other hand, inconspicuous usecues led users to be confused which led to random tapping and swiping..

Individual prototypes

***Linear story**: Safe but boring*

The linear story prototype understood well as the user was guided through the story chronologically. Cause and effect were really clear and the instructions were easy to understand. This made the users feel safe, it also increased attentional focus and presence as a result. The level of control and interactivity were low leading to a passive experience. However, the experience did not encourage exploration which made it quite boring.

***Explorative story**: Chaotic but exciting*

The explorative story prototype was more exciting and surprising because of the high level of interactivity and control. The emotional response of participants was higher due to the amount of effects. However, some interactions were still chronological which led to confusement and a lower understanding of the story. The experience was overwhelming with a lot of usecues distracting from the story. This lowered the immersion and attentional focus.

***Internal story**: Immersive, explorative but confusing*

The internal story offered the most exploration as it allowed the user to shift perspectives and access the airplanes. This revealed the layers of the pages. The perspective made it interesting and immersive. However, not all participants noticed that they had become a character of the story. The perspective changes were generally clear but it did become confusing which interactions had been triggered and which were new. This lead to a fear of missing out and annoyance due to repetitiveness. This led to the lowest understanding and attention to the story of all prototypes.

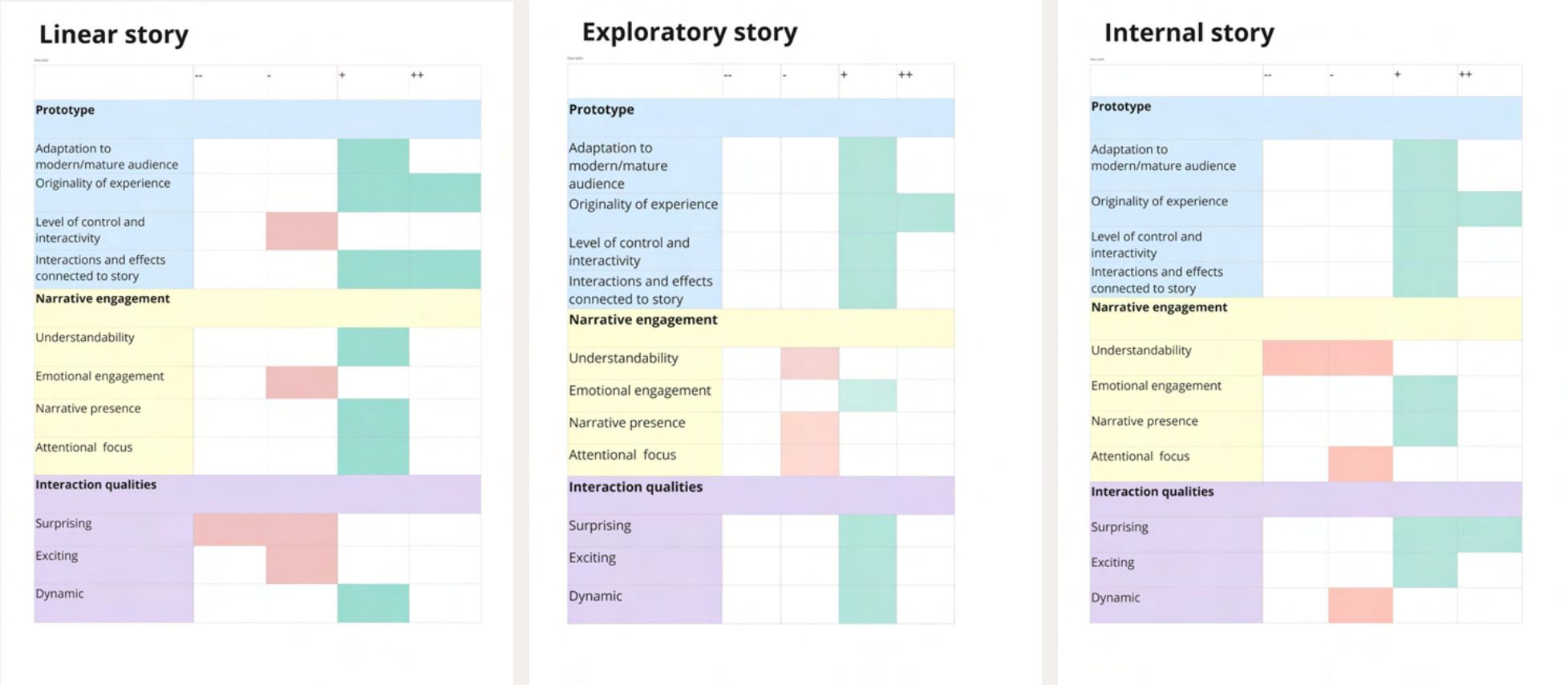


Figure 57: Harris profiles interactive stories.

Conclusions

Chosen concept and improvements

There was no conclusive winner between the three prototypes as they each created a different experience with different qualities. The Harris profiles (Figure 57) did not serve as an objective measure but more of a visualization of the differences between prototypes. However, certain criteria were more easily adaptable and weighed more than others. Elements of each storyboard were combined to create a new concept.

The explorative prototype was chosen as it was the most exciting and surprising, which were desirable qualities. The biggest issues with this prototype were the non-chronological interactions which caused a low understanding of the narrative and the chaotic usecues that distracted the attention from the narration.

In the final concept the interactions were divided into core narrative interactions and exploratory interactions to counteract these issues. The core interactions were guided and chronological in order to follow the main narrative of the story. The exploratory interactions did not have any influence on the narrative and can be done in any order. They focused on details in the illustrations and layers. The usecues appeared after the narration of each page to not distract the user.

Influence of medium on the experience

The 2D medium had a significant influence on the experience of a pop-up book (Figure 58). The 2D front-view perspective flattened all the layers making the scene chaotic. It made it difficult to distinguish the layers and the characters. This reduced the immersion and also lowered the attentional focus on the narrative because participants had to focus on the visuals. The 3D effect only came alive when things moved in front or behind other layers, which caused surprise. The fixed viewpoint and the lack of opening mechanisms reduced the magic of handling a physical book and turned it into a static experience. A participant mentioned he would rather handle a real book so he could discover all the mechanisms. The digital platform did offer more dynamic effects, however the layers did not create an impression of materiality.

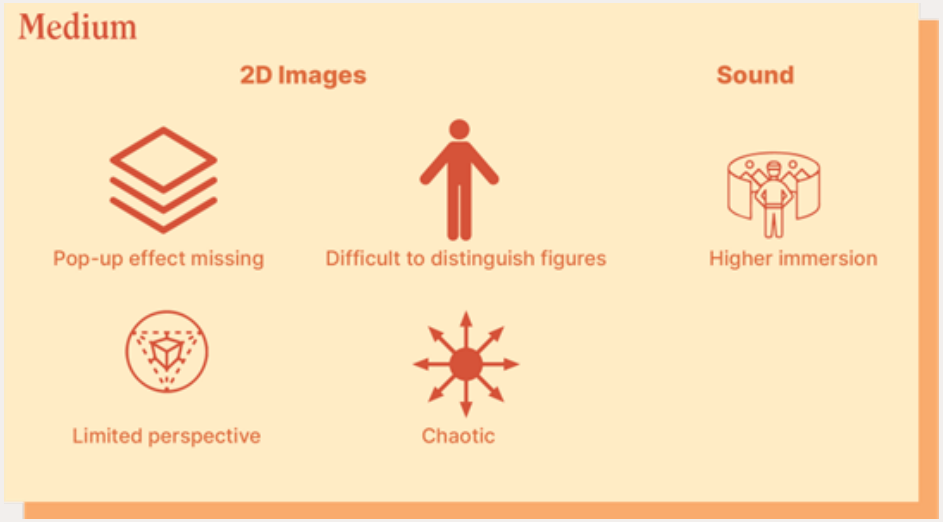


Figure 58: Influences of medium

8. Virtual materiality

8.1 Hybrid materiality

The physical materiality of the pop-up book can partially be recreated in VR; however, this is difficult and will never be as authentic as the original artifact. It raised the question: why should I try to recreate an experience poorly in VR that already exists and can be interacted with in real life? Recreating makes sense for the preservation of delicate and fragile heritage, as it makes the artifacts accessible again. However, this severely limits the freedom of interaction. VR offers a new range of freedom in interactions and materials which can add to the experience and justify the complex technology. It is not restricted by physics of the physical world. However, this freedom does not mean neglecting the original materials and artifact, as this would defeat the point of preserving heritage. This called for a new type of virtual materiality in which the authenticity of the material and the affordances of the technology are finely balanced in a surprising way.

The aim of this project was to create a new type of virtual materiality, which I defined as hybrid materiality (Figure 60). This material originated with the physical materials of the pop-up book but allows the user to interact with the artifact in new and surprising ways that are not possible with a physical pop-up book. It used the limitations of the physical materials and artifacts to afford new interactions in VR (Figure 59). For example: tearing out pieces of the book and throwing the book. In VR the material extended the physics and stiffness of the original, this added interesting possibilities like scaling up the book or walking through the pages. 'Hybrid' materiality refers to blending the materiality of the book with that of the narrative. The narrative of the book contained aircraft with a range of interesting material qualities. Mixing these qualities can create surprising interactions and interesting misalignments that play with the senses.

New materiality played a role in bridging materiality and narrative engagement. Instead of competing with the narrative, the material experience was designed to support the interaction qualities of the narrative: dynamism, surprise and excitement. The materiality was extended to the usecues, creating cues with similar material qualities that support the interaction qualities. Comic books were used as an example of how visual stories can be told through a paper medium. The genre has developed a style and set of devices to maximally engage and immerse readers into the story.

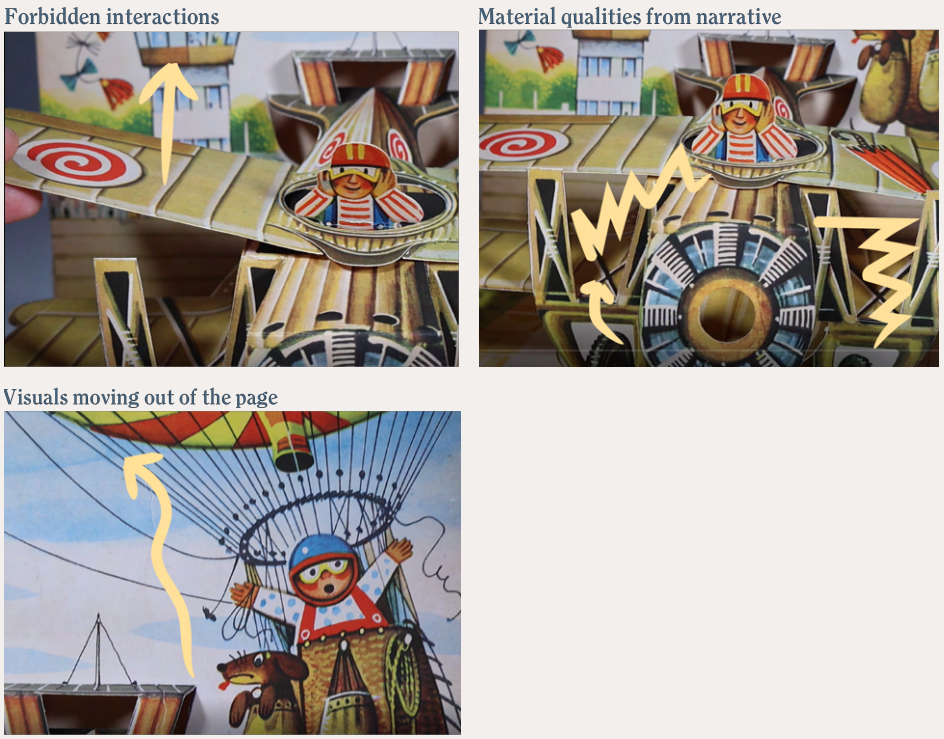


Figure 59: Hybrid materiality examples

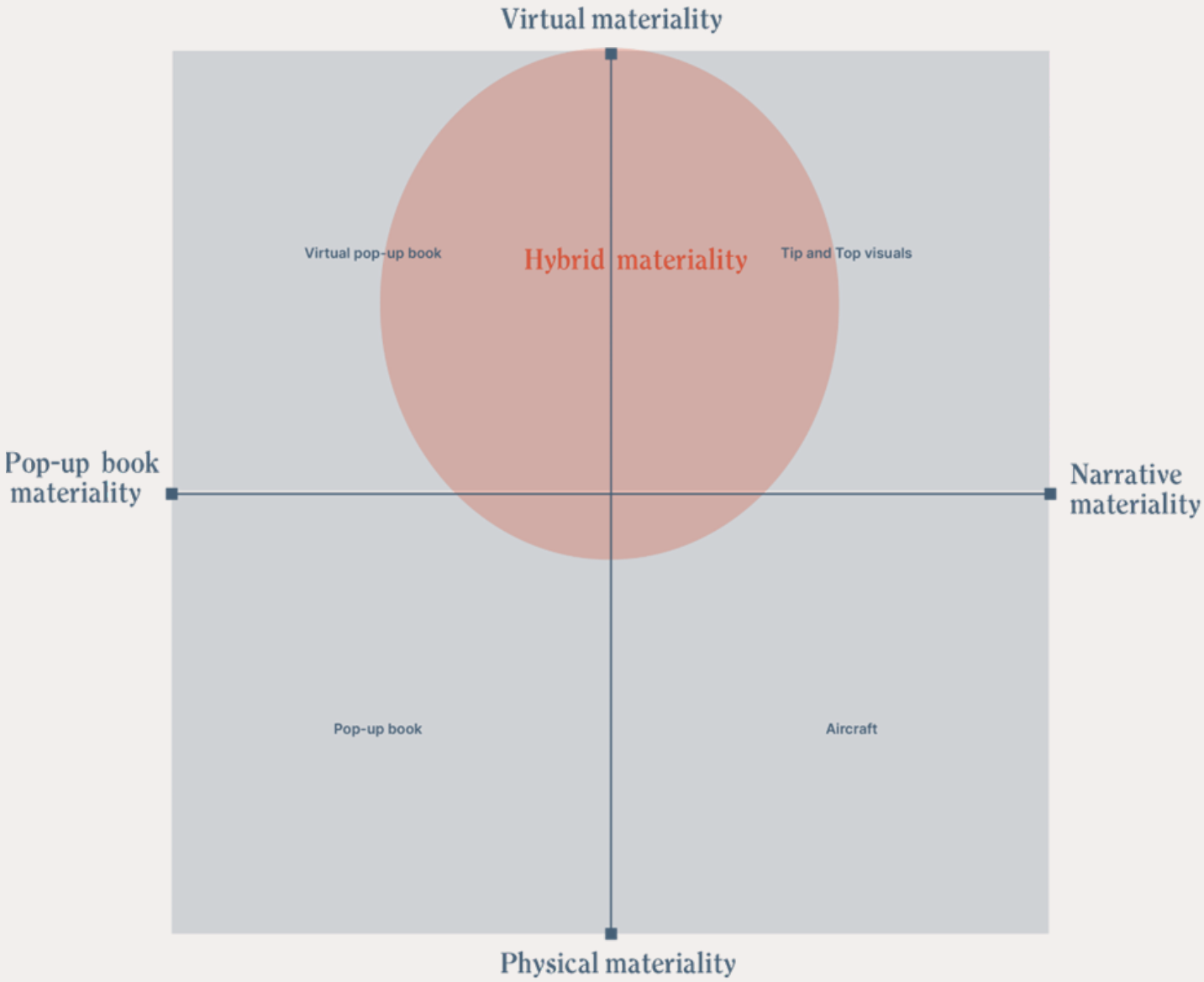


Figure 60: Hybrid materiality matrix

8.2 Material Touchpoints

The VR pop-up book was designed with special interactions that combine materiality and narrative. These were called material touchpoints as they were the interface between the user, the narrative and the material. Each page was designed with one or two touchpoints embedded, an overview can be seen in Figure 61 below. The touchpoints used materiality to enhance the interaction qualities and consequently the narrative engagement. The final concept tested test two high-fidelity material touchpoints in VR which can be seen in Figure 62. These were situated on page 2.

Figure 61: Overview of material touchpoints

Implemented Touchpoints

Rope tearing when pulling Top down

Interaction qualities:
- Excitement
- (Time) Pressured
- Illusion of agency

Material qualities:
- Resistance when pulling (weight of balloon)
- Tearing paper sounds
- Visual tears in background
- Awkward thin rope to pull

Turning the propeller

Interaction qualities:
- Dynamic
- Forceful
- Hazardous

Material qualities:
- Materiality of actual airplane propeler
- Resistance when turning
- Speed and acceleration of propeller
- Sound of engine and propeller

Figure 62: Selected touchpoints

8.3 General materiality

Besides the touchpoints the materiality was also integrated into the book, the usecues and the virtual world. This general materiality determined the look, feel and aura of the book. Not all material characteristics could be recreated as the technology is limited and not all the senses could be evoked. In the analysis phase, the material qualities were positioned on a matrix of effort and effect (Figure 22). The goal was to focus on the solutions which were easy to implement and that had a large effect on the experience (Figure 63). The workflow and possibilities in Unreal Engine also determined which qualities were implemented or not. The goal was to target multiple senses and use as many physical elements as possible. During observation study 1 it was shown that small details of use and aging, help create a feeling of history and authenticity. *For this reason, multiple paper and cardboard textures with printed and hand-drawn details have been scanned and edited to be applied on the layers.*

General materiality

Figure 63: General materiality

Visual paper texture

- Visual grain and coloration on the unprinted sides
- Texture of the scanned pages exaggerated
- Crumpled paper and torn edges
- Handdrawn details
- Wear and tear

Paper thickness and physical texture

- Blemishes on the surface of the book
- Damaged edges and corners
- Wear and tear on the book

Physics / weight to the book

- Physics constraints in Unreal Engine
- Range of motion of physical book
- Resistance in movement

Sound of book

- Sound of turning page
- Sound of sliding or turning mechanisms

Haptic touch effect

- Subtle haptic effect when touching or grabbing the book or pages

Resolution and image details

- High resolution images
- Quality lighting
- Visual wear and tear

Scent of old books

- Scent of old books
- Old paper torn up in scent dispenser
- ‘Paperback’ fragrance
- Dispenser under headset

Vision

Touch

Hearing

Smell

Phase 4: Development & Evaluation

The development & evaluation phase starts of with the goal for the final concept. The VR development process is explained, using this project as the example. The final concept integrated the general materiality and the material touchpoints. All of this was evaluated and recommendations were made.

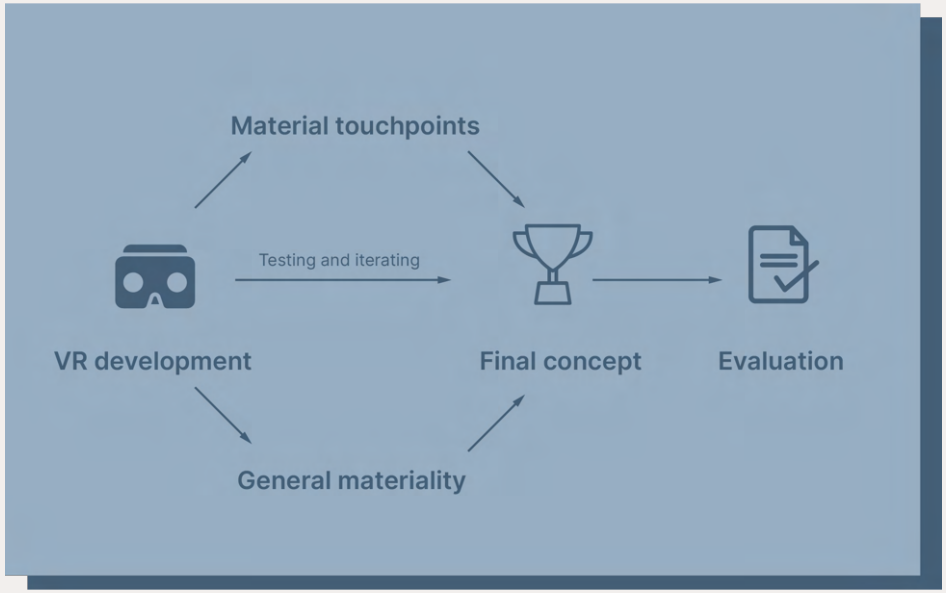
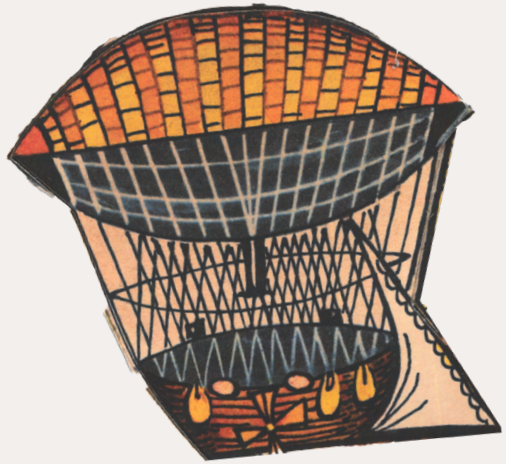


Figure 64: Development and evaluation phase



9. VR development

9.1 Final concept goal

The goal for the final concept was to create a demonstrator of the book in VR that meets the design goals and answers the design questions. This included at least three pages of the books with the accompanied interactions and touchpoints and started with an introduction to the story and the controls. The main experience was positioned as semi-exploratory, semi-internal and diegetic on the TEN framework (Figure 65). The story will be sequenced in linear parts and exploratory in other parts. The flow, virtual world and usecues were also integrated into the experience

During observation study 1, multiple participants mentioned they had to get used to the controllers and the virtual environment. This lead to creating an introduction area in which the users could get used to the controllers and the different types of interactions in a safe way without messing up the story experience. The introduction included the cover of the book which served as an introduction to the book and the story world.

The chosen pages were page one, two and six. These had been chosen because they form a condensed version of the plot (introduction, middle, ending). It ensured a variety of different effects and interactions and allowed to test the flow through the individual pages and narrative to give an idea of the full experience. The hybrid materiality was applied to all aspects of the experience.

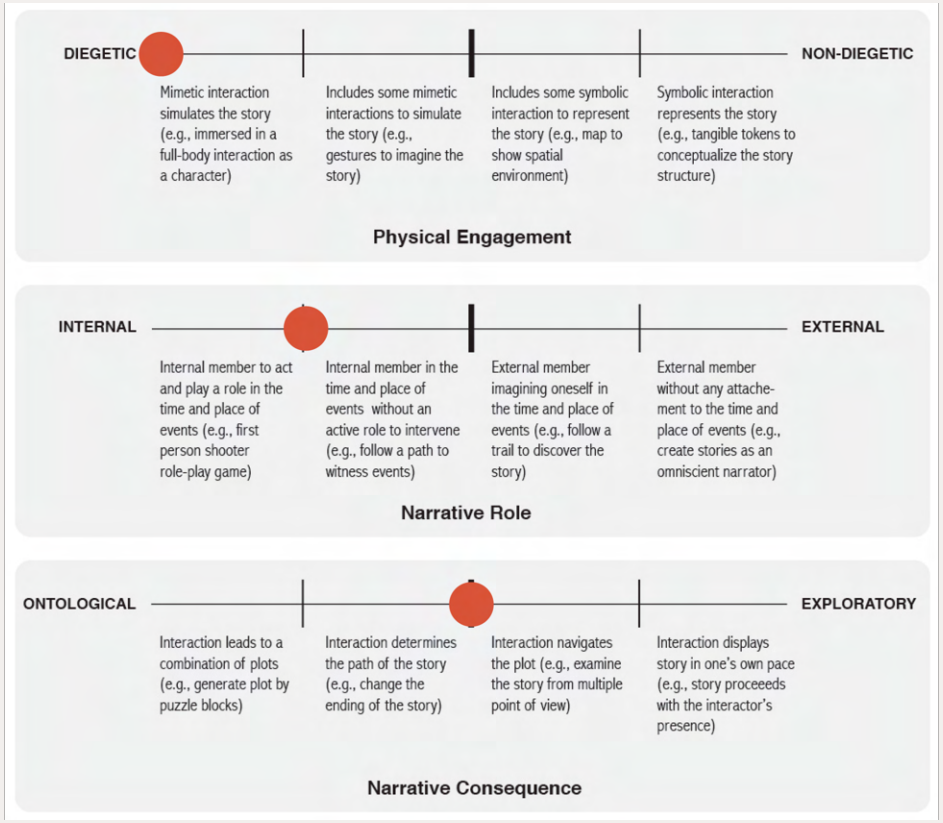


Figure 65: Positioning TEN framework

9.2 VR workflow (for designers)

VR development is a complex and difficult process, containing many different steps and requiring different skills. As a total beginner that wants to develop a final concept within three weeks, this process was quite intimidating. An expert VR developer (Pranata Andoko) from the TU Delft XR zone was consulted on how to approach the VR development workflow. The workflow differs for experts and beginners. This project focused on developing a workflow adapted for beginners and designers. The phases of the VR workflow, visualized in Figure 66 are: software and hardware, storyboarding, asset building, animating and debugging & usability. This chapter summarizes the process towards the final concept.

Figure 66: VR developtment

Software and hardware
The first step of the process was to determine which software and hardware was most suited to create a VR pop-up book. Unreal Engine 5.1 (UE5) was chosen for VR development as it contains a large number of templates and pre-programmed options which made it manageable for beginners. A Vive headset and controllers were used as these had a lot of processing power and a high resolution. Ease of use and efficiency were the determining factors for choosing the software and hardware.

Storyboards and the adaptation to virtual reality
In the VR process the interactions and effects are designed by creating storyboards. This allows a lot of freedom in designing without technology or time constraints. The storyboards have been designed and tested in different fidelities in the conceptualization phase. However, the VR technology offered a range of new affordances were not testable in the 2D storyboards. Depth, scale and full body interactions were missing in the previous tests. The use and influence of these affordances had to be thought out to optimize the experience and utilize the full potential of the technology.

Asset building
After determining the interactions, the assets were created and collected online. The assets included all the characters, interactive and static objects, usecues and the virtual scene. All 3D objects consisted of a mesh and a UV map. A UV map is a 2D projection of the texture that is applied to a 3D object (Figure 67).

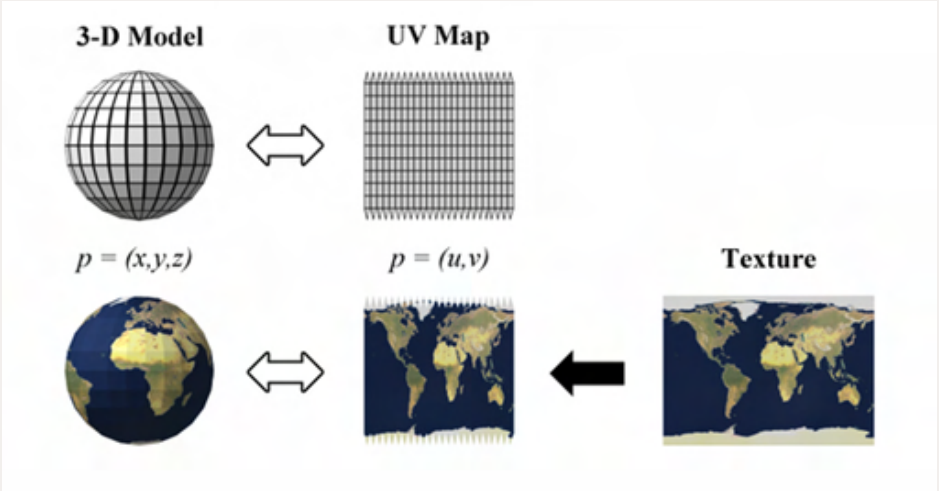


Figure 67: UV mapping (Tschmits, 2008)

The pop-up book was referenced by photographing and measuring its dimension in order to replicate the mesh of the original object. This step was performed by the team (XR zone, Elkhuizen and Zhao), who created base models and UV maps for the individual pages based on the scanned pages (Figure 68). These models were flat meshes that could be rotated into position. Some new meshes were created by me to design the interactive elements with thickness. The meshes were created in Blender which were exported as FBX files and UV layouts. These layouts were imported into Photoshop and the UV maps were created by overlaying the correct images and textures (Figure 69). In UE5 the UV maps were turned into materials which were applied to the FBX files. Any adjustments to the mesh or the texture had to be redone in Blender, making the process very inefficient for designers. Some basic editing tools in UE5 would really improve the workflow. Meshes and UV maps for the world elements like coins, posters, stamps and the radio were collected online (13.2 VR model and image references). Sound effects were collected from freesound.org and edited in Audacity.

Figure 68: Meshes VR zone

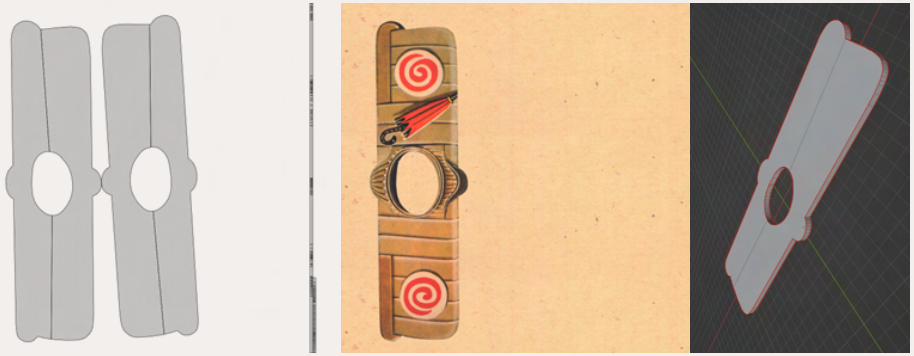


Figure 69: UV layout, UV map and 3D Mesh of wing

Animation and integration

All objects had to be animated and made interactable. This was done by turning the objects into actor blueprints in UE5. These blueprints are a visual coding system allowing for interactive, customizable and repeatable actions for objects (Figure 70). The interactions had a cause (input) and an effect (output) which had to be designed separately and connected. The type of input was important for the usability as it determined the amount of control of the user. Some designed triggers were the trigger box, on-grab action and on-release action. The effects had to be designed with precision, ensuring the timing was realistic and aligned in all senses. The integration and connection between the interactions was difficult as it required linking together different blueprints. The designed effects were: playing sound, moving object along spline, activating or deactivating physics and moving/rotating objects.
Interactions were animated using placeholder meshes (Figure 71), these simplified meshes allowed for adaptability and rapid prototyping. Once the animation worked the meshes were replaced with the final meshes and the final adjustments were made to integrate all elements on the page.

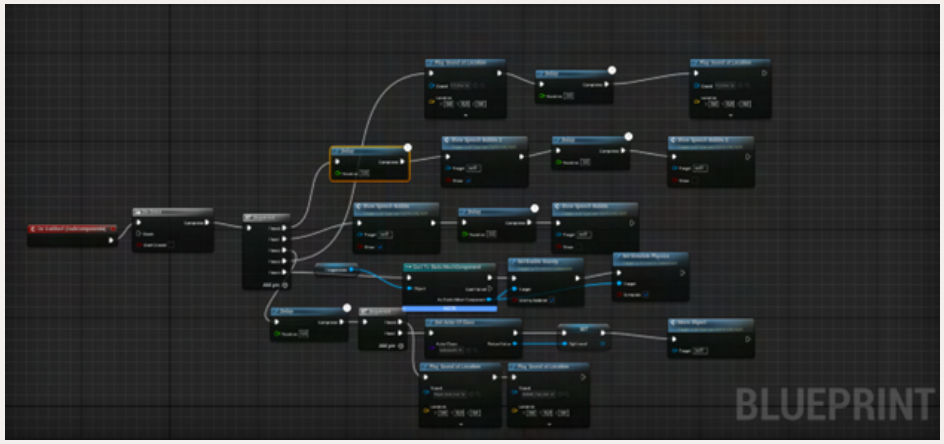


Figure 70: Blueprint example

Figure 71: Placeholder meshes

Debugging and usability - Intermediate testing

The final step was usability testing and debugging. The experts debug alone as they know how to fix problems and understand the software. For this project the experts of the XR zone helped with debugging and explaining all the problems, they were really patient and helpful. Once the software and hardware worked, the usability of the project had to be tested with users to see if the experience and controls felt intuitive.

The usability was tested with a quick intermediate user test with peers. It was tested after finalising the first page with the touchpoints (Page 2). This allowed for enough time to adjust the usecues and to implement the feedback on the other pages and introduction. The test was evaluated through observations and an informal conversation about the experience. Points of interest were the usecues, the sequence of interactions and the general emotions during the experience. Two participants tested the experience (Figure 72).

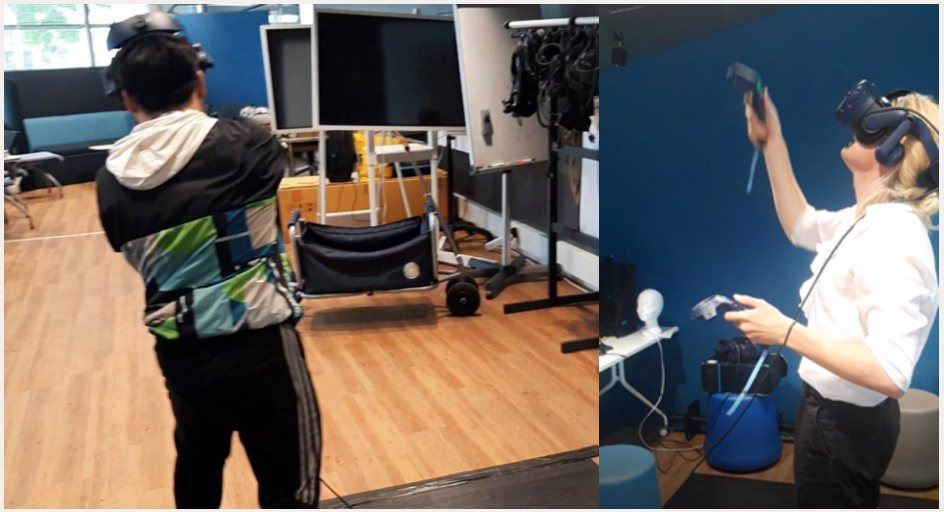


Figure 72: intermediate testing

Insights

Controls

The controls were difficult to understand, especially teleporting. The users were not used to this type of transportation which made it disorienting. This triggered all kinds of narration and messed up the experience. This is a general VR issue that hinders the experience. This supported the idea of creating an introduction area.

Usecues

The usecues were generally clear. The participants recognized the difference between the 2D and 3D elements and what they signified. The interactive elements were discovered quite quickly. The experience was exploratory, the participants walked around and through the book to look at different angles. Through grabbing and interacting the participants made sense of the material and their ranges of motion. The direction of movement was not clear during the grab. At the end of the page the participants did not know if they were done so they tried grabbing everything. The style of the speech bubbles was authentic and fitted the experience.

Interactions / materiality

The materiality and the interactions were surprising for the participants. They lifted the wing, which tore off. Tearing apart the book was fun; however, the physics were not disabled so the wing hovered on the screen. One participant then placed the wing back to be tidy and to continue to the other interactions. The participant accidentally triggered the tearing sound when pulling the figurine which did create a feeling of stress because that was not his intention. When the balloon left and he was instructed to grab the rope the participant felt powerless due to his inability to teleport and the awkwardness of moving around.

10. Final concept

This chapter shows all relevant design decisions for the final concept. The experience is structured into pages, interactions and touchpoints. A separate paragraph explains the general materiality of the experience. Some final considerations regarding the flow through the pages, the virtual world and the usecues are presented at the end of the chapter.

10.1 Pages, interactions and touchpoints

Cover and introduction

The users started in the dedicated introduction area. This area was marked by a large piece of paper with hand-drawn corners as a visual barrier (Figure 73). The first interaction was handling a digital copy of the book that showed the cover, the back and the edges of the book (Figure 74). The purpose of the book was to introduce the characters, book and setting. The users could walk over, grab and throw around the book. The introduction narration of every pages was triggered by picking up the radio, which showed the main message of the narration in one sentence (Figure 75). Other interactions in the introduction were inspired by the interactions in the book, without directly copying them. The users could slide Tap around, pull the lever, swing the rope and anchor and throw around some coins. This sensitized the users to recognize the different interactions on the pages.

Figure 73: introduction area with interactions

Figure 75: introduction area with interactions

Figure 74: introduction area with interactions

Page 1: Airport

Figure 76: Page 1

Lever interaction

The lever of the page was too high to reach in VR and would be too close to see the effect. Instead, a second freestanding lever was designed next to the page (Figure 77). The lever rotated at the same point as the lever on the page and the rotation of the two levers was synchronised on release. The slider on the page got flipped once the lever was switched. The lever created a solid lever sound and a heavy resistant movement. After activation, the TV narrator started to speak. Exclamation and question marks fell from the sky like confetti, to enhance the surprise and celebratory effect. The marks were photoshopped from the slider to create coherence with the style of the book.

Figure 77: Lever interaction

Tip & Top sliders

The individual sliders of Tip and Top sliders only moved in the y and x-axis and rotated vertically (Figure 78). They were no longer bound to their original range of motion and were free to move and leave the page. By dragging or grabbing their narration started and a speech bubble appeared. Top only started speaking after the lever interaction had been activated to create a sequence of events.

Figure 78: Tip & Top sliders

Page 2: Balloon and airplane

Figure 79: Page 2

Touchpoint 1: Propeller turning
The propeller was constrained to the book with a linear and angular physics constraint (Figure 80). The angular rotation was dampened to create resistance and the feeling of weight. The propeller generated sounds during rotation. The propeller stopped turning after grabbing it. The controller gave haptic feedback when touching the propeller. The intention was to create a dynamic effect in which it feels like your hand is being vibrated by the turning propeller. The original goal was to add a visual wind effect with pieces of paper blowing around the page; however, this was not feasible within the time.

Figure 80: Propeller touchpoint

Touchpoint 2: Rope pulling

The interaction was triggered by grabbing a paper usecue hovering in the air (Figure 81). The cue showed Top in the balloon with an arrow pointing up. The interaction started with Top telling that he will let up the balloon and Tip alerting the user that Top is flying off. The balloon, the rope and the anchor were three different meshes that had been joined by physics constraints. They dangled and swung like a real paper rope (Figure 82). The balloon flew out of the page with a tearing sound, leaving behind a torn cardboard background (Figure 83). The balloon and anchor started moving off along a spline into the air towards the user and Top let out a cry for help. The user got the chance to pull down the balloon, however when releasing the rope teared and Top flew off into the sky with high speed. The goal was to create a false sense of agency by letting the user think they could save him.

Figure 82: Dangling physics

Figure 83: Cardboard tear texture

Figure 81: Balloon touchpoint

Wobbly figurine
Tip was constrained to the airplane by a linear and angular physics constraint. He was fixed in position but could tilt on the Y-axis just like the physical book. Flipping Tip triggered the narration and the speech bubble (Figure 84).

Wing tear
The goal of the wing tear interaction was to let the user interact with the paper book in a way in which they are normally not allowed to (Figure 85). It was designed with the idea of tearing apart the book after grabbing a piece. The wing was chosen as it is in sight and reach. On grabbing the wing a tear sound was generated. After releasing the wing, gravity was activated and the wing fell to the ground. The wing was permanently broken and after attempting to put it back in place, it fell back to the ground.

Figure 84: Wobbly figurine

Figure 85: Wing tear

Page 3: Control room

Figure 86: Page 3

Airplane slider
The goal of the airplane slider was to launch the airplane into the air and let it fly off the page (Figure 87). However, simulating all the physics and conditions proved to be too difficult within the timeframe. So for now the airplane gets pulled out of the page with a loud tearing sound. After release, the airplane disconnected from the slider and fell through the ground. The interaction was not fully finished but still allowed for a new type of interaction with the material.

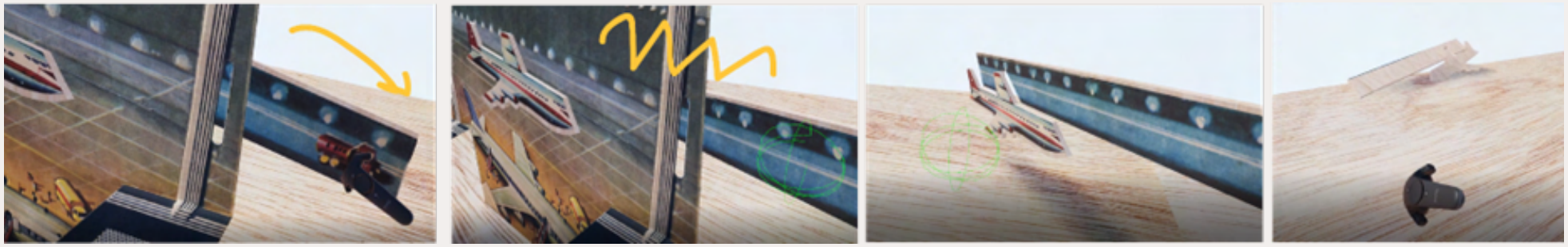


Figure 87: Airplane slider

Tip and Top & Air traffic control

Tip and Top can be slid left and right and the paper made a sliding noise (Figure 88). They started speaking and showed narration. The air control guys rotated on their on chairs and which squeaked like regular desk chairs. They started talking and speech bubbles appeared (Figure 89).

Figure 88: Tip & Top

Figure 89: Air traffic control

10.2 Materiality of final concept

Book physical and visual texture
The virtual book of the introduction was modelled to recreate the thickness and bumpiness of the original cover. The virtual cover was irregular and an extra material layer had been added to the spine. The sides had been given relief to create the appearance of consisting of multiple pages (Figure 90). The UV map was created from the pictures of the original book. They had been cut out and applied to all sides of the book. The overlap of the image texture and the relief created a quite realistic effect of shadows and pages.

Figure 90: 3D texture of book

Paper physical and virtual texture
The paper of all pages had been modelled to simulate real paper. Interactive elements had a thickness to them. The pages had an embossed texture applied to create an irregular texture and reflection (Figure 91). Because the pages had been scanned, all the discolorations and imperfections were captured in the VR pages including the rope that binds the pages (Figure 92). The backsides of the pages had been textured with old paper and cardboard scans (Figure 93). The background of page 2 was edited to appear like the balloon has ripped out and left ripped paper on the cardboard.

Figure 91: Embossed texture of cardboard

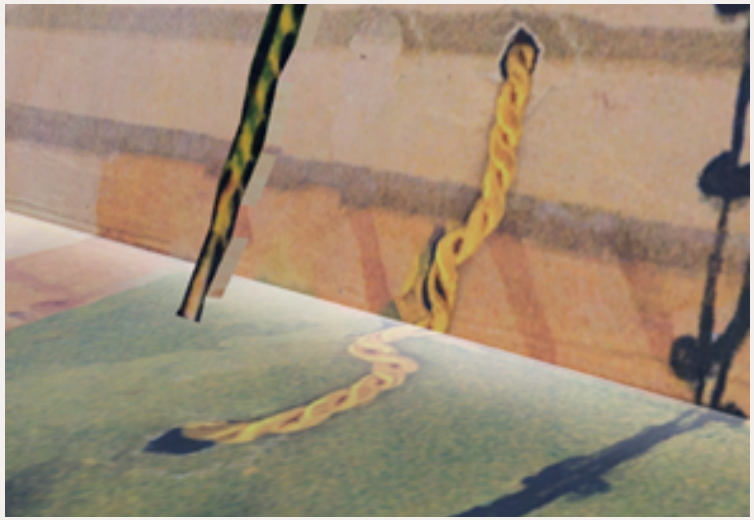


Figure 92: Material details in the scan

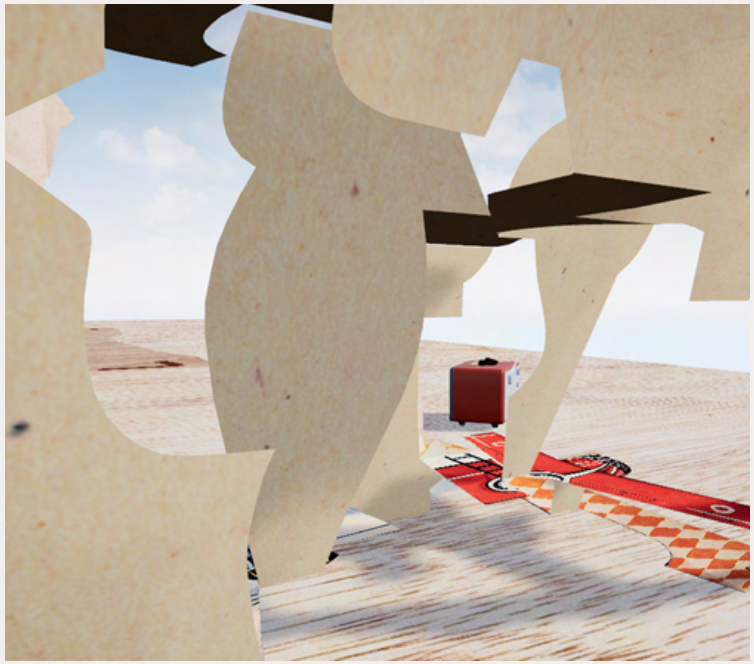


Figure 93: Cardboard texture on back of pages

Scent

The scent of old books was added to the experience with the hope of evoking associations or an extra dimension. This was done by adding a fragrance with the scent of books called 'paperback' to a bandage attached to the HMD right above the nose (Figure 94). The scent had been left to dissipate for a few days to reduce the intensity. The scent was not super realistic but with a bit of imagination smelt like paper books. A drawback was that the scent had the same intensity throughout the experience.

Figure 94: Scented bandage and fragrance

Sounds

Sounds were added to the experience, both sounds of the narrative and from the paper material. These include the thump of a falling book, paper sliding upon paper and a page tear (Figure 95). Narrative sounds were the sound of the lever, the propeller and the squeaking chairs. The difficulty with the sound effects was creating subtle and unique sounds that corresponded with the applied physics. An example was synchronizing the speed of the sound with the rotation of the propeller, which did not work. The timing of the sounds was also very important.

Figure 95: Tearing sound

Physics

The physics were easy to apply to the object by checking a box called: physics enabled. The linear and angular damping can be adjusted to reduce the speed of the movement and rotation. This allowed for some basic weight and gravity animations. Objects were linked to each other using physics constraints. This created chains of object like the dangling rope and anchor. The physics constraints also limited the range of motion of the object (Figure 96) The interactivity of objects was applied through a collision component which registers when an object is in contact with the player, the floor or other objects. This allowed for many complex interactions in which multiple objects influence each other upon collision.

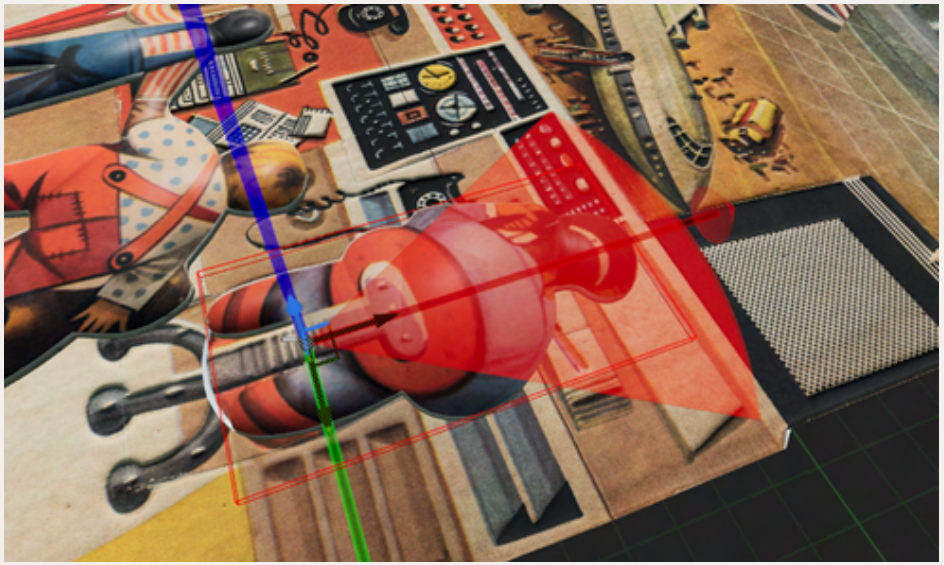


Figure 96: Physics constraint: rotation

Haptic effect

The haptic effect was used in the propeller, the initial idea was to integrate it in every interactable object. However, this would become distracting. The haptic effect was a simple repetitive pulse (Figure 97).

Figure 97: Haptic effects

10.3 VR design interventions

Usecues and controls

The usecues were designed to reduce the number of direct hints and let participants explore their options safely. The search for the usecues was designed to be a surprising activity on its own. The materiality was used to signify the usecues, as they are indicated by the thickness of material (Figure 98). The users have to learn how elements respond through interacting with them. This is an intuitive way to interact with the virtual book, similar to physical pop-up books. The physics and constraints of the objects allowed for safe interactions and guided the user in which direction the objects can move. This integrated the materiality with the usecues and instructions.

Figure 98: Thickness in material and paper texture

Not all interactions could be signified through their materiality. Other usecues like arrows, speech bubbles, the introduction area, narration texts and the balloon trigger had to be created . A full overview of the usecues can be seen in Appendix E. These have been hand-drawn, printed (Figure 99) or created using comic book speech bubbles from the internet (Reference). All usecues had a material texture applied. The speech balloons had been programmed to always face the direction of the user to be readable at every location (Figure 100).

Figure 99: Hand-drawn paper instructions

Figure 100: Speech bubbles

Flow and control

The act of opening and closing the pages is a core part of the experience in a physical pop-up book. However, in VR this was extremely difficult, especially after adding extra layers and interactions to the pages. This was addressed by walking around the pages like in an exhibition of a museum. The sequence was guided by paper arrows on the floor (Figure 101). This was not as surprising and magical as opening the pages but did offer a new style of interaction.

The timing and control over the interactions and narration in the pages was also crucial. Negative surprise and confusion could be higher in VR than in 2D and this should be avoided. For this reason the control was designed at the side of the user and the narration only got triggered through active interactions. The linear story parts were triggered in a chain of interactions which the user could follow.

Figure 101: Flow through book

Virtual world

The virtual world allowed for 360-degree views around the pages which had the potential of distracting the user from the story. The virtual world was designed to represent a large desk with an open sky above (Figure 102). The virtual elements were directly linked to either the story, the cultural historical setting or the materiality of the book. The open sky and the airplane theme of the poster and the stamps refer to the aviation theme and introduced the user to the world of the story. Old Czechoslovakian artefacts from the 1960s had been added to the world to transport the user back into the time and place of the author. These included old coins, stamps, a poster and a vintage radio (Figures 103, 104 & 105). These world elements all had distinct material qualities which could be interacted with. The 'floor' had an oak wood texture that was meant to represent an old desk.

Figure 102: virtual world

Figure 103: Coins

Figure 104: Stamps

Figure 105: Themed poster

11. Evaluation

11.1 Evaluation plan

The goal of the evaluation was to test the different aspects of the final concept and how well these are integrated into a coherent experience. The evaluation consisted of observations during testing and an interview afterwards. It evaluated the general experience and focused on the themes of the project: materiality and narrative engagement. The material touchpoints were evaluated to see to what extent these themes were connected. The qualities of the different interactions were tested to see if the interaction qualities were met. The evaluation was concluded by comparing the final concept with the original book and the 2D Interactive storyboards using the design goals.

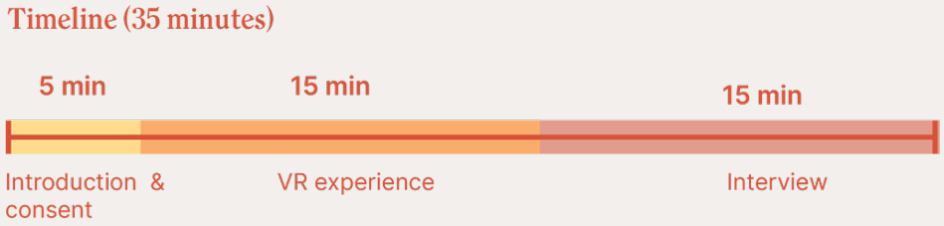


Figure 106: Timeline

Method
The final evaluation tested the prototype with nine participants. The evaluation took place in the XR zone of the TU Delft between 26 and 30 June. The Dutch participants were a mix of design and non-design students that had minimal or no involvement in the project. The tests took around 35 minutes per participant (Figure 106) and consisted of an introduction of five minutes, the VR experience of fifteen minutes and an interview of fifteen minutes. During the introduction the participants signed an informed consent form. The introduction also explained the controls.

Audio and video data of the users were collected during the evaluation. The videos and images are unrecognizable because the users were wearing a HMD covering their face. These were recorded to analyze the different mimetic interactions of the users and for images in the report. The virtual world was recorded using OBS screen recording software to observe and analyze the interactions in the virtual world. During the interviews, the answers of the participants were annotated and recorded for later analysis. All data will be deleted after the graduation date.

Observations

The observations during the tests were done by observing both the live screencast and the physical interactions of the users. It focused on how users interpreted different usecues in VR and how they responded to certain interactions. The observations were used to gauge the interaction qualities, the affective level and the performative level. These are small spontaneous reactions that the users are likely not to mention during the interview. The framework of Barriault & Pearson (2010) was used to make sense of the behavior and engagement of the user (Figure 107).

Interview

The interview questions were developed to gain insights on the different themes and to be able to test the design goals. The questions start general and become more specific, as to not steer participants. A lot of questions had been copied or adjusted from the previous tests or the frameworks. The final question tied all elements together. At the end of the interview, a set of control questions were asked. An overview of questions can be seen on the next page.

Initiation behaviors	
1. Doing the activity	In passing, not done completely Doing the activity somewhat completely Doing the activity without further exploration or testing of variables
2. Spending time watching others engaging in activity or observing the exhibit	Looking at the exhibit working, or someone doing the activity Watching the exhibit or person using exhibit with expressed interest in the activity (facial expression or verbal) Interested in learning outcome or in learning the activity; visitor does the activity after observing.
Transition behaviors	
3. Repeating the activity	Doing the activity two to three times to attain desired outcome, to master the exhibit's function. Enjoyment of outcome Changing the variables once looking for a difference in outcome; becoming involved/engaged
4. Expressing positive emotional response in reaction to engaging in activity	Smiling, pleased with exhibit Stronger signs of enjoyment such as laughter; verbal references to enjoyment Obvious signs of eagerness to participate; excited disposition;
Breakthrough behaviors	
5. Referring to past experiences while engaging in the activity	Reference to past experience with exhibit or science centre Simple reference to comparable experience in visitor's life Reference to comparable experience in their life as well as making comparisons and deductions based on observations of similarities and differences
6. Seeking and sharing information	Calling someone over to look at exhibit, or to ask them to explain an exhibit; asking a question to staff or family member without lengthy discussion or exploration of topic. Reading signage; having conversations about exhibit and related science with staff or family member Sharing experience and information with others by explaining the exhibit to them, giving them details about gained information and observations; discussions and questions about exhibit with staff or family member/friend
7. Engaged and Involved: testing variables, making comparisons, using information gained from activity	Engaging in inquisitive behaviour, exploratory actions such as repeating the activity several times, reading signage, asking questions; remaining on task for 2–3 minutes Concentration and motivation are obvious; doing the activity as a means to an end, or meeting a challenge; length of interaction significant, 3 to 5 minutes; outcome or result of activity important Experimenting, testing different variables, looking for different

Figure 107: Observational behaviors

Interview questions:

General questions:
· What did you think of the experience in general?
· To what extent is the experience with the book authentic and to what extent was it innovative? How is the balance between the two?
· Which emotions or associations did the experience evoke? Could you give examples?
· On a scale between 1 - 5 how dynamic were the interactions and effects?
· On a scale between 1 - 5 how exciting were the interactions and effects?
· On a scale between 1 - 5 how surprising were the interactions and effects?

Narrative questions:
· Was the story engaging?
· To what extent did you understand the story and its characters? Were there things (un) clear?
· Which parts of the experience grabbed or held your attention? Why?
· To what extent did you empathize/sympathize with the characters or the events in the story? Why?
· To what extent did you feel immersed in the story world? What caused this immersion?

Materiality questions:
· To what extent did the VR experience create the impression of interacting with a real material or artifact?
· To what extent did the experience feel like interacting with an existing or novel material?
· Which material qualities did you notice while interacting with the book? Which senses were triggered?
· How did you respond to these material qualities (emotionally or associatively)?
· Which material qualities did you notice when Top left the page and you had to save him?
· How did you feel at that moment? What caused this feeling?
· Which material qualities did you notice when rotating the propeller?
· How did you feel at that moment? What caused this feeling?
· To what extent did the elements of the experience (story, material and interactions) feel integrated or disconnected?

Control questions:
- What is your age?
- How often do you visit a cultural institution?
- Do you read books for entertainment?
- Do you have any VR experience?

Analysis methods and frameworks

The the data was clustered per topic on Miro. Multiple toolkits were used to present and analyze the insights, these have been used throughout the project. The narrative engagement framework was used to rate the different aspects of the engagement. The materiality of the experience was processed using the material characterization toolkit by Camera and Karana (2018). Due to the sheer amount of data this framework has been divided into general materiality, material touchpoints and other material interactions. The material qualities of the touchpoints were linked to the interaction qualities which also influenced the (narrative) engagement. The interaction qualities were assessed directly using scales and indirectly using associations and emotions. The cause and effect of the interaction qualities are presented.

Pilot test

A pilot test was conducted with one participant to test the practicalities, questions, timeline and to discover last minute bugs or issues. Some minor changes were made to the test setup and prototype. Some usecues like the location of narration text was changed to make it more clear. Some redundant interview questions were removed to speed up the interview. Overall the test was useful and the relevant data has been included in the final evaluation.

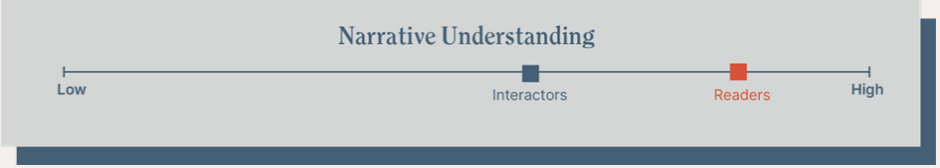
11.2 Observations

Observations:
The observations made during the tests were integrated into the results of the different aspects of the analysis. Participants thought out loud, had emotional responses and used their whole body for the interactions (Figure 108). Often there was a difference between the observations and the interview. Based on the model of Barriault & Pearson (2018), all participants initiated in the experience. A large amount of participants were observed engaging in *transitional behaviors*. Some examples were repeating an interaction multiple times to see if the outcome differed, like the sliders or the radio. Putting back the airplane wing multiple times. Grabbing and pulling the propeller to make it rotate properly. Participants showed responses ranging from chuckles and gasps to exclamations like: 'Sick!' or 'Oh no'. Some participants were also observed engaging in *breakthrough activities*. For example two participants mentioned airplanes and adventure stories were a childhood interest and were drawn to the topic, personally reflecting on their past. The creativity of some participants was also interesting. Participants tested and compared the physics of the virtual objects to real objects and reasoned and challenged themselves to shoot away the anchor or attach it to another object. One participant actively reflected on how the physics of the experience in VR compared to the real world.

Figure 108: Observed behaviors

11.3 Narrative engagement

The narrative experience has become more engaging with 3 out of 4 criteria improving compared to the physical book and the digital storyboard.



The **Narrative understanding** was judged quite low by participants but in their recollection of the story they remembered a lot of details. In general, almost all participants had a basic understanding of the story, this is logical as it is a simple story. Participants mentioned that they felt like parts of the story were missing, this is true as three pages were missing. The fact that they noticed is a sign of attention to the story. Another thing participants encountered was that the sequence was not clear in the story or that they would have preferred a fixed sequence. However, the sequence was only off in Page 3. Another interesting observation made was the fact that about half of the participants actually started each page by reading the text. Afterwards they would pick up the radio and started the narration. Some participants compared the text with the narration which is a sign of understanding. However, it was also noticed that the narration and text were not fully aligned which caused confusion. This shows that there still was a divide in users between interacters and readers, with readers having a significantly higher understanding of the story in the story.

The **Attentional focus** was still mostly focused on finding the interactive elements and interacting with the objects. The interactions, however, did visualise parts of the narrative giving the participants an idea of the story. An important insight was that all participants started each page by either reading or listening to the narration. The narration was finished by all participants before starting the interactions and only one interaction was triggered at the same time. The readers were observed switching their gaze between the text and the scene to compare the text with the visuals. Some participants also observed the visuals in great detail by walking through the book.

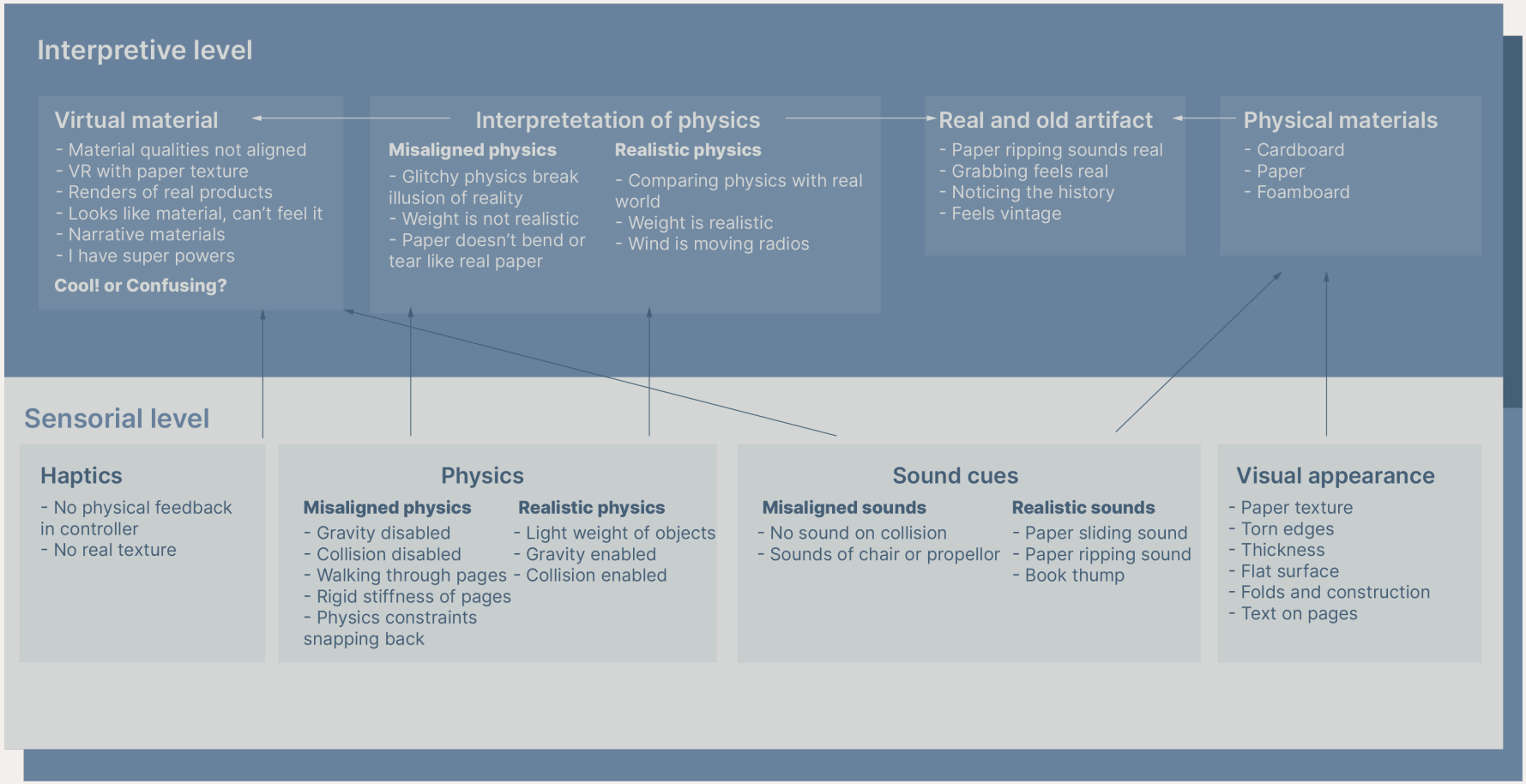
The **Emotional engagement** was rated quite low by participants during the interviews; however, during the observations the participants did respond emotionally to some parts of the plot. Participants laughed at some points of the story and expressed shock or concern. This was most apparent in the interaction that Top flies off and they try to save him but they fail. Participants said things like: ‘don’t worry Top, I have got you’. The illusion of agency over his fate enhanced the emotional reaction and created a feeling of guilt or indifference. In general the pages with clear actions like Page 1 and 2 created a higher response because the characters had an active role in the plot.

The **Narrative presence** was the only factor of the engagement that was rated consistently low by participants. This was due to the large empty virtual world with open sky. The pages were placed too far apart to create a feeling of immersion in the story world. This was done to create enough space to interact with the pages without triggering the next page. Participants also mentioned that the transitions between pages were very abrupt, which did not help with creating and immersive story world. This showed that virtual reality does not necessarily lead to higher immersion as hypothesized in the literature review. The background within the VR was still distracting from the actual pages. This exemplified that low immersion can also lead to lower attentional focus to the story. Some participants did mention that within the pages they felt immersed due to the large scale of the pages and the fact they could walk through the pages. One participant mentioned that they felt immersed due to their active participation in the story.

11.4 Materiality

The materiality has been divided into a multiple models: a general model, the material touchpoints and a model for other interactions. This was done due to the sheer number of different insights and causes. The first model looks into the general material experience, linking sensorial qualities to the interpretations of the material (Figure 109).

Figure 109: General materiality model



General materiality

The different sensory material qualities led to different interpretations of the materials and consequently objects. All objects had cues that either aligned or misaligned the different senses. This alignment changed the perspective of the authenticity of the objects and materials.

The physics of the objects were the strongest material indicators. Objects were perceived as realistic when the physics of the virtual paper corresponded with the light weight of the physical material and the collision and gravity of objects was enabled. The ability of interactive elements to collide and influence other interactive elements was interpreted as realistic objects. The physics were misaligned when the gravity or collision was disabled and object fell through the floor or passed through other meshes. This was also the case when walking through the book. Glitches in the physics and unpredictable physics constraints also created the feeling of a simulation instead of reality.

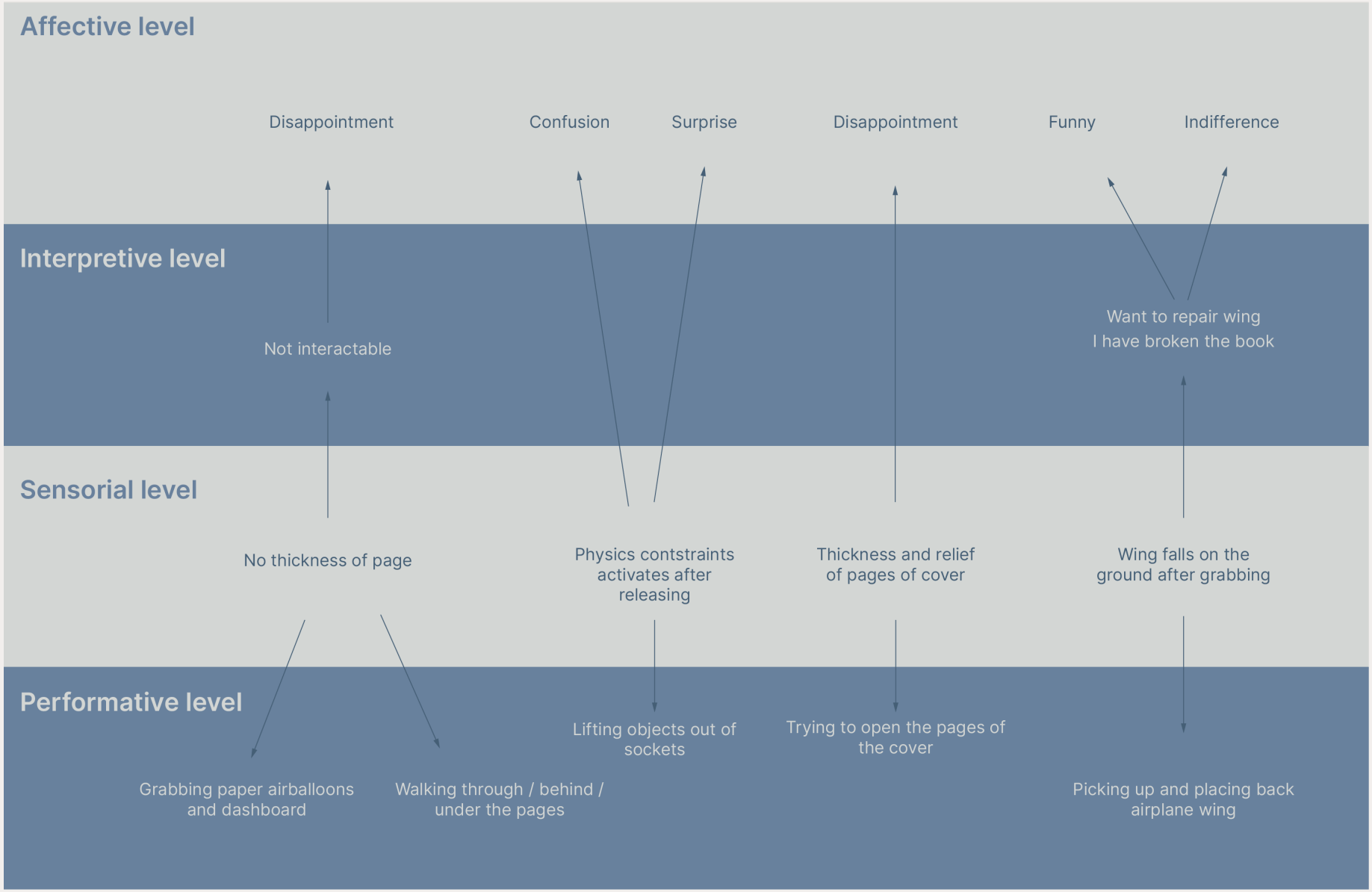
The largest indicator of virtuality and lack of embodiment was the missing haptic effects and counterforce. Missing sounds were also perceived as misalignments. The scent was not noticed by participants and didn't influence the experience. The visual appearance did however create the illusion of an actual material like paper, cardboard or foamboard. Realistic materials created an impression of real artifacts. Participants mentioned that the book looked like a real book and participants could also notice the age of the book through the illustration style and the aged colors. The misalignments made participants perceive the materials and objects as something virtual or not realistic. Participants mentioned objects feeling like a render or a VR texture of a physical object. This was perceived differently, some participants mentioned that objects like coins were confusing or incomplete due to the lack of collision sound. While others were excited about feeling like they had superpowers or hearing the sound of a real engine instead of a paper one.

Connections between material and interaction qualities

Figure 110 (next page) looks into how the materiality of specific object influenced the interactions and included all levels of the framework. It showed that sensorial qualities influenced the performative interaction style and how people feel about a material in an experience. It presents multiple interactions with objects. This created a link between the material experience and the interaction qualities. The material thickness drives the curiosity and exploratory behavior of the users by searching for interactions. The physics of the materials also created a different type of exploration in which the user actively experimented with the limits of the physics, comparing it to realistic physics and creating a new frame of reference. The interactions between interactable elements also created many surprising physics-based effects.

Other interactions

Figure 110: Material interactions



Material touchpoints

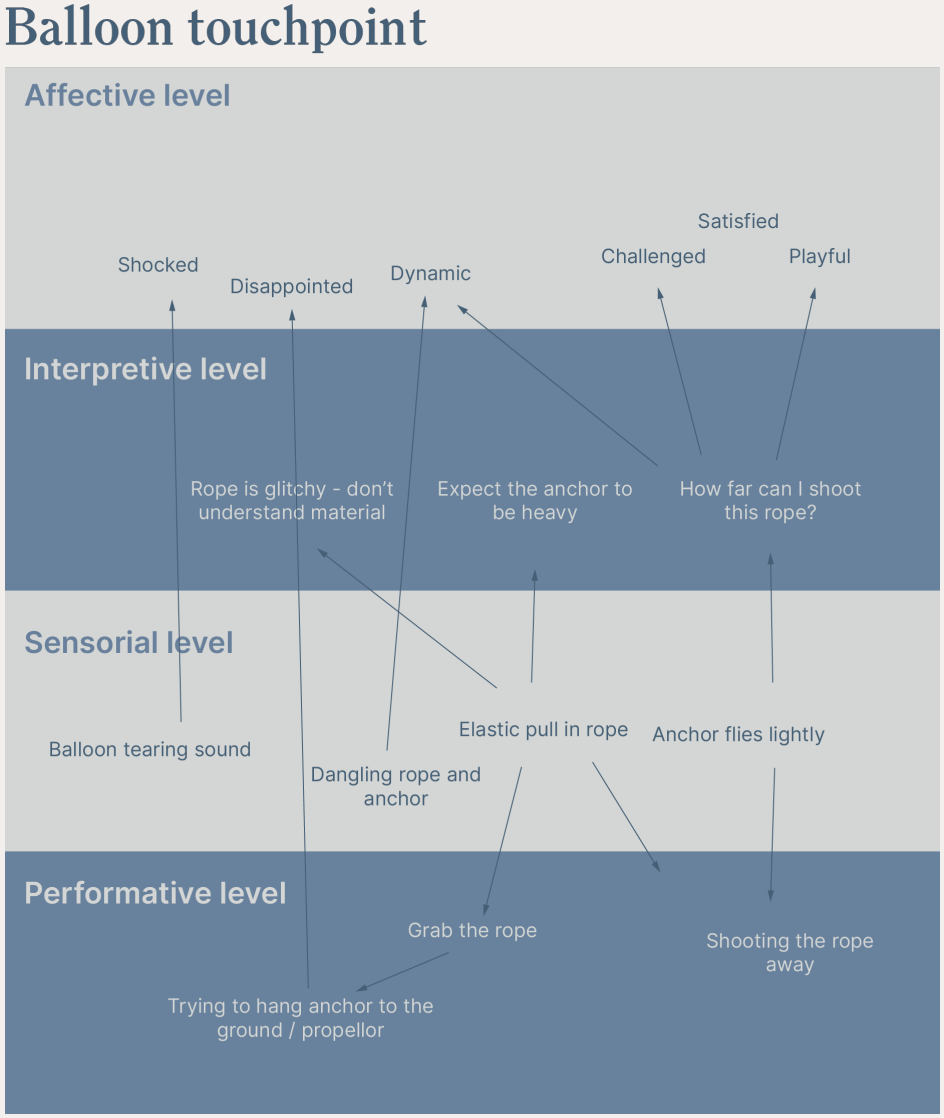


Figure 111: Balloon touchpoint

Balloon touchpoint

Figure 111 shows how the tearing sound and the balloon ripping from the page created a shock response in combination with the narration. This triggered the participants to take action urgently. After grabbing the rope the participants used their whole bodies to pull down the balloon and save Top. This physical interaction was intense for the user. A lot of dangling objects made the interaction dynamic. The rope shot off after release, enhancing the dynamic effect and satisfying the user. This also created a kind of challenge for the user, trying to shoot it off as far as possible. The material qualities also influenced the narrative engagement as the time pressure caused participants to focus and take action immediately. The illusion of agency created a feeling of responsibility in the user which were sad or disappointed after not being able to pull the balloon to the ground.

Propeller touchpoint

The biggest addition of this interaction was the haptic effect when touching the propeller (Figure 112). The intention was to create a feeling of adventure and shock when touching the rotating propellers. The haptics were interpreted differently with some participants claiming it did not add to the experience, while others associated it with feeling the motor rumble. The haptic was also perceived as a usecue with some participants associating it with doing the right thing while others felt like they were doing something wrong. It was seen as surprising because the interaction was new while also being cool! This lead to different actions like retracting their hands or repeating the interaction. The rotation itself was similar to the weight and speed of a physical propeller, however the rotation was not too smooth. The sound was too loud and not synchronised with the propeller. This distracted from the interaction and led to annoyance and misalignment. It did not have any significant effect on the narrative engagement.

Propeller touchpoint

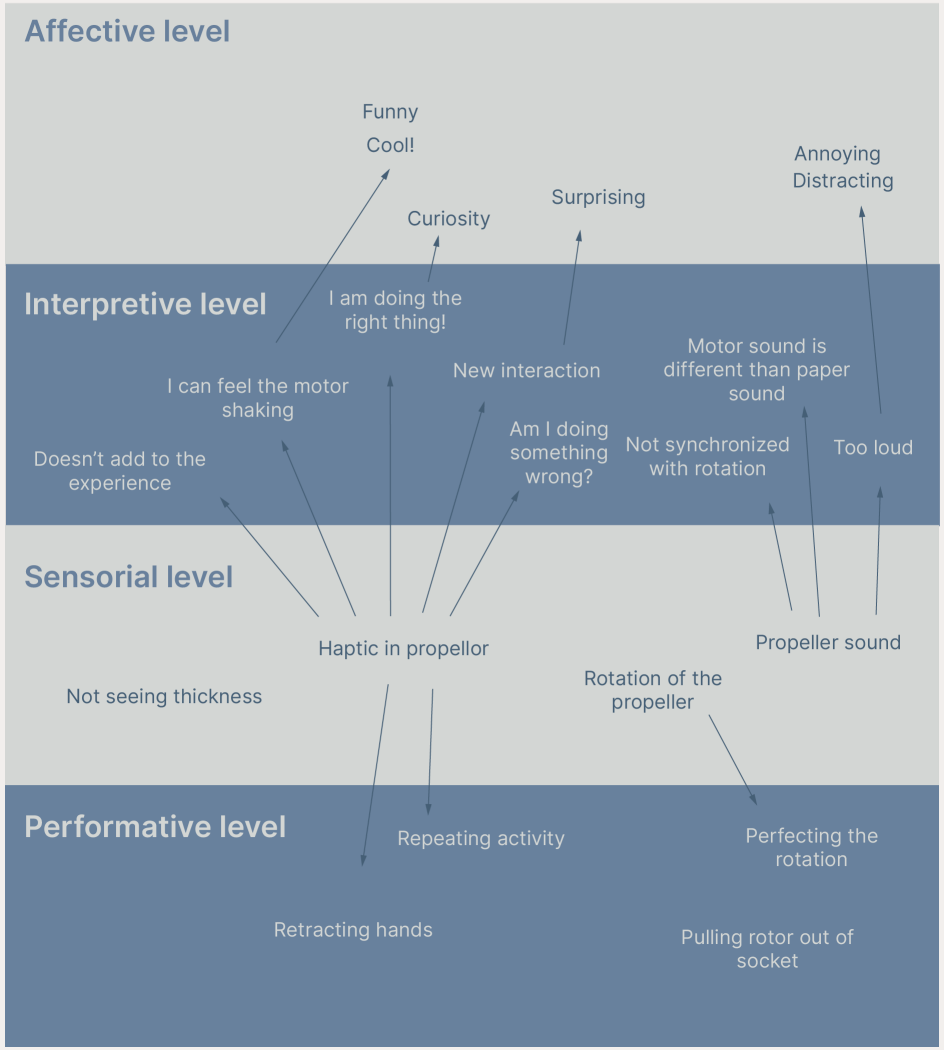
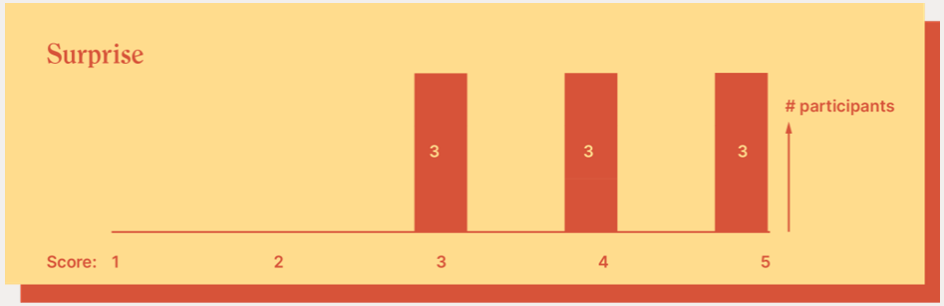
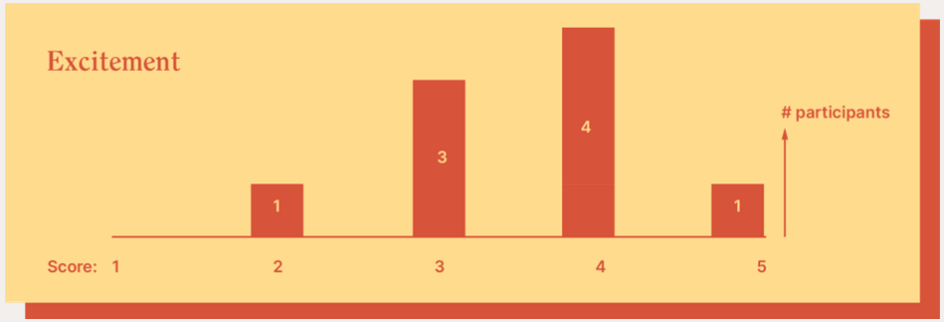


Figure 112: Balloon touchpoint

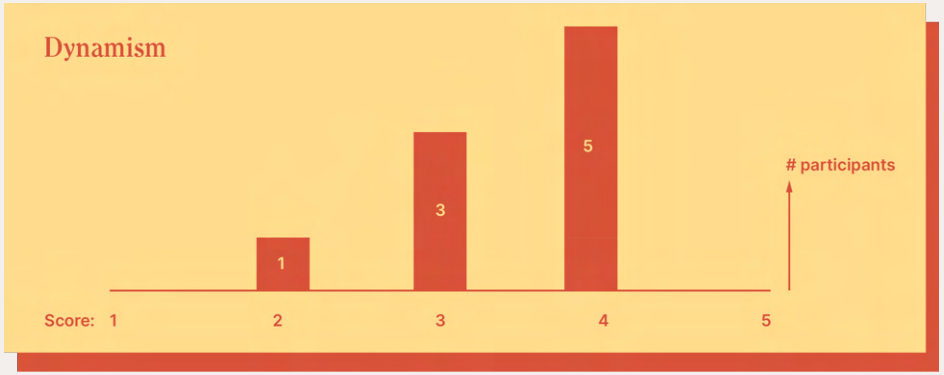
11.5 Interaction qualities



Surprise
The participants rated the interactions quite surprising with an average of four out of five. Many participants mentioned being surprised both in positive and negative ways. The interactions were negative when they didn't live up to their expectations. The interactions were surprising in the beginning but at the end became predictable. A lot of interactions were repeated like the narration which reduced the surprise. Curiosity and discovery were mentioned by multiple participants describing the experience, which are closely linked to surprise. Most surprising were the physics of the different objects and how they responded to the user and other interactable objects. It lead to creative interactions, in which the participants created their own games and experiments.



Excitement
The excitement was rated quite high. The excitement was mainly due to the anticipation of searching and starting new interactions. The urgency of the balloon interaction was really exciting due to the time constraint and agency. The interactions were quite basic in terms of effects and still have a lot of potential. The effects did not create the excitement participants are used to in games or videos. Again the physics of the objects were exciting.



Dynamism
The interactions were dynamic, especially the touchpoint interactions. The balloon leaving the page came towards the user and the different parts dangled around. The propeller and the sound created an intense effect. The physics of the objects were perceived as dynamic as they were free to move and throw around. The elasticity of the rope that shot into the air was mentioned most often. Not all interactions were dynamic, most were just sliding a figure around. A participant mentioned that this was alright because it fitted the style of a pop-up book.

Other interaction qualities
Participants also mentioned a lot of other qualities in different interactions. These are also really interesting and can be seen below in Figure 113:

Triggering multiple narrations at once

Impatience

Airplane falling through floor

Sadness

Searching for thickness

Anticipation

Top not responding to interaction

Disappointment

Throwing the coins

Playfulness

Flipping the coins

Creativity

Placing back wing

Disappointment

Tearing off wing

Funny Confusion

Figure 113: Extra interaction qualities

11.6 Conclusions evaluation

The evaluation was concluded by comparing the final concepts with the original book and the 2D interactive storyboards. The design goals were used as criteria. Figure 114 rates how the different concepts were perceived, using a +/- scale. The individual design goals are swiftly discussed. Design goal 1 is not included in the ratings as this is a scale which can difficulty be rated with plusses or minuses. The final design meets all the design goals to a certain degree. The design requirements were also checked, this can be found in Appendix F.

	Physical Tip & Top book	2D Interactive storyboards	Final concept
DG2: Narrative engagement	- +	+	+ +
DG3: Interactions connected to narrative	- +	+	+
DG4: Materiality	+ +	- +	+
DG5: Materiality connected to narrative	- -	- +	+

Figure 114 Comparison final concept

DG1: Adapting the story to fit the digital medium and a current day audience, while preserving the original storyline and a feeling of authenticity.

The original book was successfully adapted to the digital medium and the experience was perceived as quite modern and innovative. The technology made the experience better suited for a mature audience. The original storyline was respected; however, the sequence of events was made semi-exploratory. The balloon had a different outcome than in the original book. The feeling of authenticity remained due to the fact that the original pop-up structure was kept and all new elements were flat like paper. The experience created a better balance between novelty and authenticity than the 2D storyboards which were not recognized as a pop-up book due to the lack of depth and layers. The final concept adds a new layer of experience and novelty to the original book.

DG2: Increasing the engagement with the story compared to the original pop-up book and previous VR pop-up books.

The narrative engagement (except presence) was highest in the final concept. The original book was not read by half of the participants and they could not recall many events. The interactive storyboards had a lot of distracting usecues and the lack of depth made it difficult to distinguish the figures from the visuals. The final concept sequenced the narration and interactions in a non-guided way. This allowed for exploration of the non-linear story parts and a dedicated sequence for linear parts. The interactions and effects visualized the story better than the original book by breaking up the story into multiple interactions.

DG3: Creating an interactive storytelling experience of the book in VR in which the interactions support the story and vice versa.

The final concept created an illusion of interactive storytelling by creating the idea that the user has control over the outcome of Top on page 2. It also contained many interactions with story objects, some of which directly connected to the story and some of which were disconnected. Compared to the original book more interactions were added that visualized the story. The interactions also triggered the narration, forcing the user to interact in order to continue the story. The interaction qualities also helped synchronize the interactions with the core of the story. The connection between story and interactions was similar to the 2D storyboards.

DG4: Designing for a multisensory material experience with the book in VR.

The rating visualizes how well the materiality was perceived by participants. The final concept can never match the original book in recreating the materiality. Instead the hybrid materiality replaced and added material qualities in the final concept. Vision, hearing and touch were successfully simulated. The blend of materialities was recognized and added to the overall experience. Some mismatches did occur and these were perceived negatively. The final concept scores higher than the 2D storyboards as these only showed materiality through visuals. This was interpreted as something completely digital.

DG5: Integrating the material experience with the storytelling in VR to create a balanced and integrated experience.

The material experience was integrated with the narrative through the material touchpoints and the usecues. The material qualities were explored by participants and they felt like being part of the discovery story. In the original book there was one example of the bounciness of the fighter jets that created a dynamic feeling that supported the story. The 2D storyboards supported a range of material touchpoints, in lower levels of development than the final concept.

11.7 Recommendations

The project met all of the design goals; however, there are still a lot of things that could be improved. The project was limited in time and an extra round of concepting before the final concept or an extra iteration of the final concept could take the project to a next level. Extra VR knowledge and experience could also enhance a lot of the effects and create new interactions. The recommendations provide an overview of the steps that can still be taken.

Narrative engagement

Blending the virtual world with the narrative
The virtual world was not very well developed and was quite empty. The immersion scored lowest of the narrative engagement. This can be improved by designing the story world as a more integrated space with the narrative. Paper elements from the story could be added to the virtual world around the pages. It can bridge the gaps in the immersion and improve the transitions between pages. Participants were observed using the external objects to interact with the elements in the pages. The experience could be designed in a way that these objects are crucial for the story development. Another possibility could be moving the characters from one page to the next to create a more internal experience.

Materiality

Hybrid materiality
The concept of hybrid materiality was directly implemented into the final prototype. This could be developed a lot further by testing the limits of the materiality matrix and combining different senses. This could discover which balance has to be met to prevent undesired misalignments of senses. More senses can be tested as the current prototype only mixed physics, visual appearance and sounds. Some improvements could be variety in: thickness, texture, rigidity, reflectance and scent. Some direct improvements could be adding a sheen to the propeller or increasing the weight of the radios.

Paper interactions and interacting with the pages
The interactions included some paper properties like light-weight physics. However, many participants mentioned that the rigid structure of the pages felt very static. The rigidity of the paper could be made less stiff to mimic paper. This would add a lot of new interactions and surprising qualities. Some examples could be: bouncing objects against the balloons, wobbling the wing of the airplane or folding pieces of the page. If enough force is exerted, the pages could tear. It could also be possible to make the pages grabbable and interactable. Part of the magic of interacting with pop-up books is opening and closing the pages. This could increase the surprise effect. The rotation of the pages was already set up by the XR zone, however this was not directly related to the design goals so this interaction was skipped.

Interaction qualities

Diversity in interactions
Participants mentioned that the interactions became predictable after the first page. This could be improved by adding a unique interaction to every page. It can be combined with the material qualities to integrate the experience even more. Adding new senses, creating new triggers or mixing the material qualities can enhance the diversity. This would increase the anticipation, surprise and consequently the excitement for each new page. Another option could be to increase the freedom of interactions and let the participants be creative in their interaction style. This was already observed with a participant trying to tie down the balloon to the propeller. These interactions were perceived as most surprising.

Enhanced effects
The interactions of the experience worked but were quite basic in terms of effects. This was partially due to my limited VR experience. The effects were not as convincing as I had hoped for and were not perceived as very dynamic by participants. The impact of the effects is in the details and a lot more could be added. For example in page 1 the intention was to shoot out the exclamation marks as dynamic confetti with a burst to enhance the celebration. This however turned into somewhat sad images falling through the sky. Another example is the propeller, the effect would be much more realistic if the sounds were synchronized with the rotation. The propeller could also create wind that blows away dust and paper tears. This could make the experience more exciting and dynamic.

12. References

12.1 Literature references

Artemciukas., E. (2016). Augmented Reality Books: Safari Animals, World of Fairytales (Paparmali). Youtube.com. Retrieved March 20, 2023, from https://www.youtube.com/watch?v=jH4PmVLq3Xc.

Augmented Stories. (2011). World's First AR Pop-up Book for IPad and IPhone. Augmentedstories.com. Retrieved March 20, 2023, from https://www.augmentedstories.com/blog/2019/2/5/first-ar-pop-up-book-for-ipad-and-iphone-using-image-recognition.

Aniwaa. (2021). The Ultimate VR, AR, MR Guide. Aniwaa.com. Retrieved June 15, 2023, from https://www.aniwaa.com/guide/vr-ar/ultimate-vr-ar-mr-guide/.

Barreda-Ángeles, M., Aleix-Guillaume, S., & Pereda-Baños, A. (2021). Virtual reality storytelling as a double-edged sword: Immersive presentation of nonfiction 360°-video is associated with impaired cognitive information processing. Communication Monographs 88, nr. 2 (2021): 154–73. https://doi.org/10.1080/03637751.2020.1803496.

Barriault, C. & Pearson, D. (2010). Assessing Exhibits for Learning in Science Centers: A Practical Tool. Visitor Studies, 13:1, 90-106, DOI: 10.1080/10645571003618824

Barriault, C. (1998). The science centre learning experience: A visitor-based framework. Unpublished masters thesis, University of Glamorgan, Cardiff, Wales.

Bekele, M., Pierdicca, R., Frontoni, E., Savina Malinverni, E., & Gain, j. (2018). A Survey of Augmented, Virtual, and Mixed Reality for Cultural Heritage. Journal on Computing and Cultural Heritage 11, no. 2: 7:1-7:36. https://doi.org/10.1145/3145534.

Bujić, M., Salminen, M., Macey, J., & Hamari, J. (2020). "'Empathy machine": how virtual reality affects human rights attitudes. Internet Research 30, nr. 5 (August 2020): 1407–25. https://doi.org/10.1108/INTR-07-2019-0306.

Busselle, R., & Bilandzic, H. (2009). Measuring Narrative Engagement. Media Psychology 12, nr. 4 (November 2009): 321–47. https://doi.org/10.1080/15213260903287259

Camera, S., & Karana, E. (2018). Experiential Characterization of Materials: toward a toolkit. Design as a catalyst for change - DRS International Conference 2018, 25-28 June, Limerick, Ireland. https://doi.org/10.21606/drs.2018.508

Chu, J. H., Harley, D., Kwan, J., McBride, M., & Mazalek, A. (2016). Sensing history: Contextualizing artifacts with sensory interactions and narrative design. DIS 2016 - Proceedings of the 2016 ACM Conference on Designing Interactive Systems: Fuse, 1294–1302. Association for Computing Machinery, Inc, 2016. https://doi.org/10.1145/2901790.2901829.

Chu, J. H., & Mazalek, A. (2019). Embodied engagement with narrative: A design framework for presenting cultural heritage artifacts. Multimodal Technologies and Interaction 3, nr. 1 (March 2019). https://doi.org/10.3390/mti3010001.

KB. (n.d.). Collectie kinderboeken | KB. KB.nl. Retrieved April 20, 2023, from https://www.kb.nl/onderzoeken-vinden/bijzondere-collecties/collectie-kinderboeken.

Constine, J. (2015). Virtual reality, the empathy machine. http://techcrunch.com/2015/02/ 01/what-it-feels-like/

Dal Falco, F., & Vassos, S. (2017). Museum Experience Design: A Modern Storytelling Methodology. The Design Journal 20, no. sup1 (July 28, 2017): S3975–83. https://doi.org/10.1080/14606925.2017.1352900.

Damala, A., Ruthven, I. & Hornecker, E. (2019). The MUSETECH Model: A Comprehensive Evaluation Framework for Museum Technology. J. Comput. Cult. Herit. 12, 1, Article 7 (February 2019), 22 pages. https://doi.org/10.1145/3297717

Dong, Y. & Webb, M. & Harvey, C. & Debattista, K. & Chalmers, A. (2017). Multisensory Virtual Experience of Tanning in Medieval Coventry.

Falk, J. H. (2009). Identity and the Museum Visitor Experience. New York: Routledge, 2016. https://doi.org/10.4324/9781315427058.

Giaccardi, E., & Karana, E. (2015). Foundations of Materials Experience: An Approach for HCI. Conference on Human Factors in Computing Systems - Proceedings 2015-April (2015): 2447–56. https://doi.org/10.1145/2702123.2702337

Grimes, W. (2014). 'Wizard Who Made Art Jump Off the Page. The New York Times, 30 januari 2014, sec. Arts. https://www.nytimes.com/2014/01/31/arts/design/pop-ups-from-prague-celebrates-vojtech-kubasta.html.

Häkkilä, J., Hannula, P., Luiro, E., Launne, E., Mustonen, S., Westerlund, T., & Colley, A. (2019). Visiting a Virtual Graveyard: Designing Virtual Reality Cultural Heritage Experiences. In Proceedings of the 18th International Conference on Mobile and Ubiquitous Multimedia, 1–4. MUM '19. New York, NY, USA: Association for Computing Machinery, 2019. https://doi.org/10.1145/3365610.3368425.

Heijne, K., & Van der Meer, H. (2019). Road map for creative problem solving techniques. 2019. Boom Uitgevers Amsterdam.

Johnson, H. (2021). KB in Microsoft-podcast over VR-experiment met 4 kinderboeken. Retrieved April 16, 2023, from https://www.kb.nl/nieuws/kb-microsoft-podcast-over-vr-experiment-met-4-kinderboeken

Krumpen, S., Klein, R., & Weinmann, M. (2022). Towards Tangible Cultural Heritage Experiences—Enriching VR-based Object Inspection with Haptic Feedback. Journal on Computing and Cultural Heritage 15, nr. 1 (2022): 1–17. https://doi.org/10.1145/3470470.

Kenderdine, S., Leith K., Chan, Y., & Shaw, J. (2014). Pure Land: Futures for Embodied Museography. Journal on Computing and Cultural Heritage 7, no. 2 (July 2014): 1–15. https://doi.org/10.1145/2614567.

Loscos, C., Tecchia, F., Frisoli, A., Carrozzino, M., Widenfeld, H. R., Swapp, D., & Bergamasco, M. (2004). The Museum of Pure Form: touching real statues in an immersive virtual museum. In VAST (pp. 271-279).

Marto, A., Gonçalves, A., Melo, M. and Bessa, M. (2022). A Survey of Multisensory VR and AR Applications for Cultural Heritage. Computers & Graphics 102 (February 1, 2022): 426–40. https://doi.org/10.1016/j.cag.2021.10.001.

Milgram, P. (1994). A TAXONOMY OF MIXED REALITY VISUAL DISPLAYS. IEICE Transactions on Information Systems, 1994. http://vered.rose.utoronto.ca/people/paul_dir/IEICE94/ieice.html.

KB. (n.d.). Missie, visie en kernwaarden | KB, de nationale bibliotheek. Retrieved April 18, 2023, from https://www.kb.nl/over-ons/missie.

OpenCulture. (2014). Kurt Vonnegut Diagrams the Shape of All Stories. Openculture.com. Retrieved March 3, 2023, from https://www.openculture.com/2014/02/kurt-vonnegut-masters-thesis-rejected-by-u-chicago.html.

Petousi, D., Katifori, A., Servi, K., Roussou, M., & Ioannidis, Y. (2022). Interactive Digital Storytelling in Cultural Heritage: The Transformative Role of Agency. In: Vosmeer, M., Holloway-Attaway, L. (eds) Interactive Storytelling. ICIDS 2022. Lecture Notes in Computer Science, vol 13762. Springer, Cham. https://doi.org/10.1007/978-3-031-22298-6_3

Petrelli, D., Ciolfi, L., van Dijk, D., Hornecker, E., Not, E., & Schmidt, A. (2013). Integrating material and digital in CHI. ACM. July-August 2013

Qian, Y. (n.d.). Wonder-LAND. Qianyedan.com. Retrieved April 21, 2023, from http://www.qianyedan.com/wonderland.

Senseglove. (2023). Hold the virtual like it's real. Senseglove.com. Retrieved July 6, 2023, from https://www.senseglove.com/

Shin, D. (2018). Empathy and Embodied Experience in Virtual Environment: To What Extent Can Virtual Reality Stimulate Empathy and Embodied Experience? Computers in Human Behavior 78 (January 1, 2018): 64–73. https://doi.org/10.1016/j.chb.2017.09.012.

Silva, M., & Teixeira, L. (2022). eXtended Reality (XR) Experiences in Museums for Cultural Heritage: A Systematic Review. In: Lv, Z., Song, H. (eds) Intelligent Technologies for Interactive Entertainment. INTETAIN 2021. Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering, vol 429. Springer, Cham. https://doi.org/10.1007/978-3-030-99188-3_5

Spence, Charles. (2020). The Multisensory Experience of Handling and Reading Books. Multisensory Research 33, no. 8 (September 15, 2020): 902–28. https://doi.org/10.1163/22134808-bja10015.

The FWA. The Boy and the Lemon. Thefwa.com. Retrieved April 25, 2023, from https://thefwa.com/cases/the-boy-and-the-lemon.

Tschmits. (2008). The application of a texture in the UV space related to the effect in 3D. Wikipedia.org. Retrieved June 28, 2023, from https://en.wikipedia.org/wiki/UV_mapping#/media/File:UVMapping.png

UploadVR. (2016). “Peronio” Brings A Children’s Pop-Up Book To Life With VR And AR. Uploadvr.com. Retrieved November 25, from https://www.uploadvr.com/peronio-pop-up-book-vr-ar/.

Vingerhoets, K. Tip en Top op de maan. KB.nl. Retrieved April 28, 2023, from https://www.kb.nl/ontdekken-bewonderen/blogs/tip-en-top-op-de-maan

Weart. (2023). What is TouchDIVER?. Weart.it. Retrieved July 6, 2023, from https://www.weart.it/

12.2 VR model and image references

Radio model
CemCreative. (2023). 3D Radio Model Low Poly Free low-poly 3D model. Cgtrader.com. Retrieved June 28, 2023 from https://www.cgtrader.com/free-3d-models/architectural/decoration/3d-radio-model-low-poly

Coin images
Museum of Applied Arts & Sciences. (2022). One Czechoslovak Twenty Haleru coin. Collection.maas.museum, Retrieved June 28, 2023 from https://collection.maas.museum/object/315334

Stamp
Wilson, M. (2011). Postage stamp library. Cpslib.org. Retrieved June 28, 2023 from https://www.cpslib.org/pages-large/1960-1137.htm

Poster
Pinterest. (n.d.) Czechoslovak Airlines. Pinterest.nl. Retrieved June 28, 2023, from https://nl.pinterest.com/pin/362117626279367674/

Appendix A: Case study table

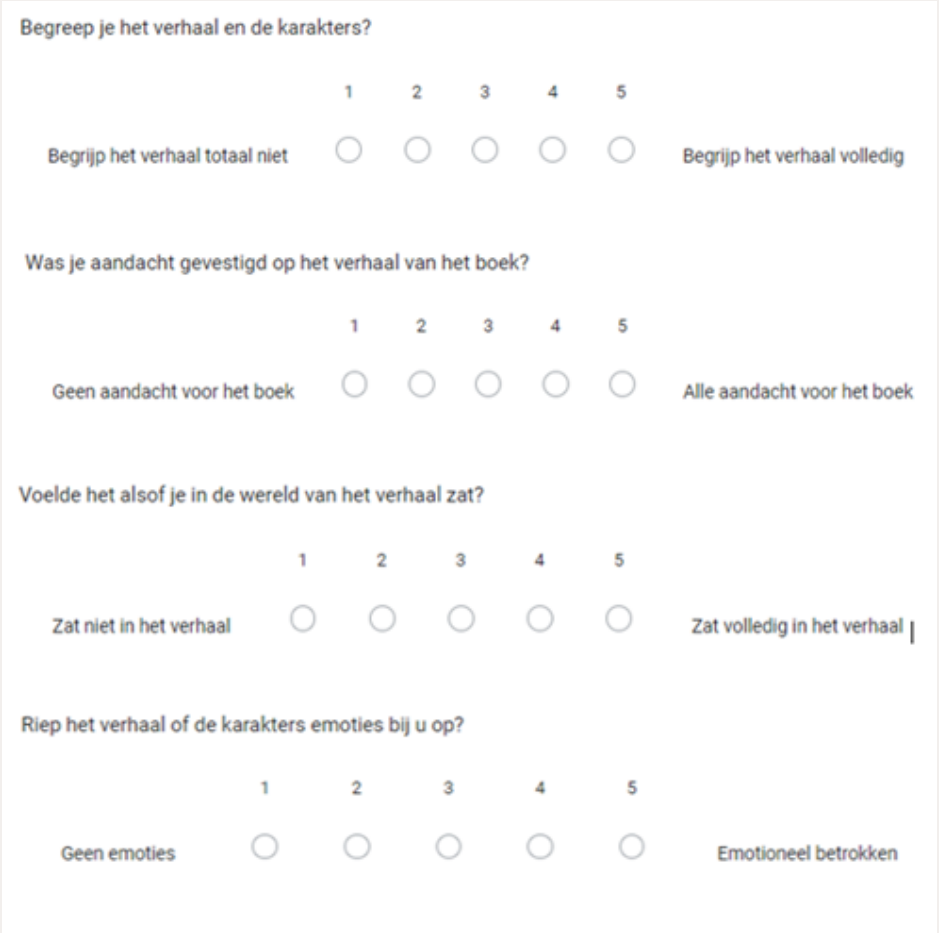
Existing VR/AR pop up books

Icon:	Name of project:	Image:	Topic & goal:	Technology:	Reference:
	Wonderland		• Children education science book • Experimenting and learning in mixed reality • Learning through play • Revealing secret stuff • Interactive storytelling	• Mixed reality • AR/VR technology • Physical triggers • paper-based mechanisms from pop-up books, cardboard toys, movable cards, board games and origami • move in physical space • touch the tangible elements • Influence characters with physical movement	
	Peronio		• Childrens pop up book • Augmented reality book	• AR pop up book • Mobile devices or HMD • Interactive elements • Games • 3D and 2D • Interactive storylines • Sound • Virtual text	
	The Boy and the Lemon		• A 3D children's book about Jack, a boy whose house is crushed by a giant lemon from outer space. • Storybook • Audio narrative	• VR • AR • HMD • hand-painted pop-up style illustration • Flat paper figures & 3D figures	
	Who's Afraid of Bugs?		• Discovering different creepy crawlies in 3D that interact with the user. • Kids • Playful method for exposure to bugs • learning through story and technology • Storybook • Reading • Playful rhyming text	• Physical pop up book • AR • Mobile devices • Image recognition • 3D modelled bugs • Interactive 3D modelled bugs • Links to educational content with images and diagrams	
	World Fairytales (Pasaulio pasakos)		• Fairytale book • Fairytales • Reading the story	• Physical book • AR • Mobile devices • 3D figures • Figures are acting the scene • Music & environmental sounds	
	KB VR book: De garage		• Historical pop up book • Carroussel book • Spatial scene	• VR • Wheel interaction • Life size book • Audio story • Sound effects	

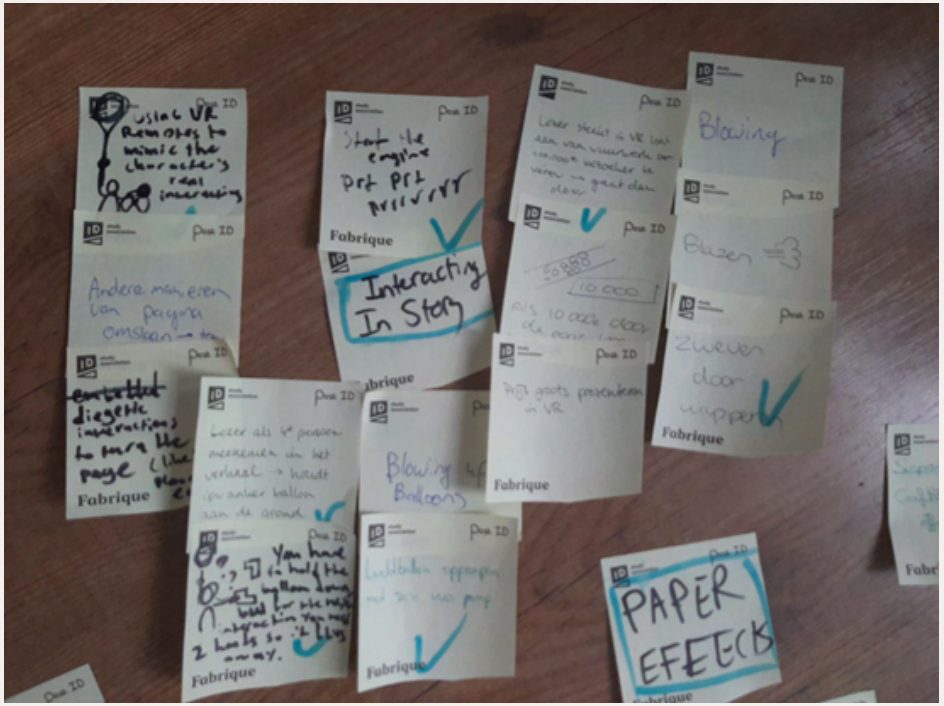
Appendix B: Questionnaire and interview questions

Interview questions

- Wat vond je van het boek?
- Las je de tekst / Keek je naar de afbeeldingen / interacteerde je met beweegbare delen? Waarom wel of niet?
- Waar ging het verhaal van het boek over? Wat vond je van het verhaal?
- Welke elementen van het boek waren belangrijk voor de ervaring? Is het verhaal een essentieel onderdeel van de ervaring?
- Zijn de illustraties / pop ups / interacties verbonden met het verhaal van het boek?
- Wat zou je willen kunnen doen in een VR ervaring van dit boek?
- Wat is uw leeftijd?



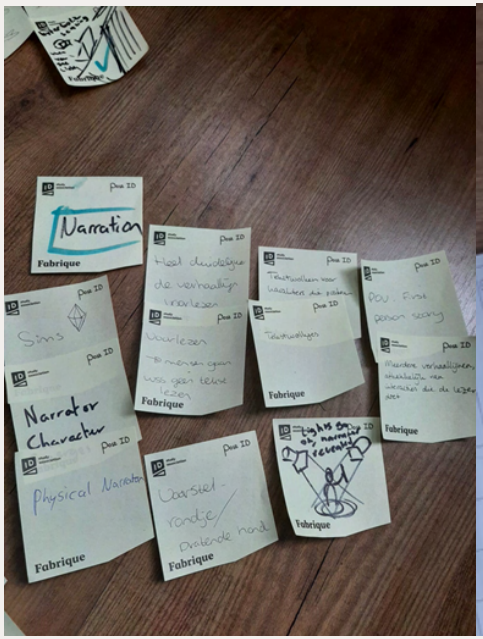
Appendix C: Creative session - Clusters & Ideas

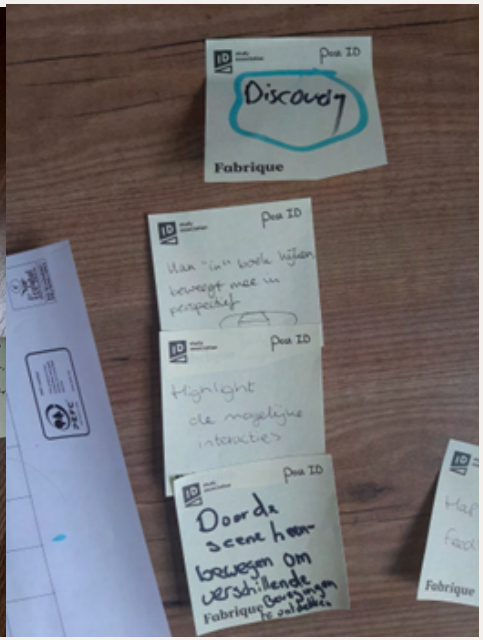



GAME TASKS
Gamify


SCENE Background


PAPER EFFECTS
3D - uitvouw
origami dingen


Narration
Sims
Narrator Character
Physical Narrator


Discovery
Highlight de mogelijke interacties

Appendix D: Interview questions and Criteria 2D Interactive storyboards

General prototype questions

- What did you think of the experience in general?
- How suitable is the experience for a modern/mature audience? Why so or not?
- How original or authentic does the experience feel?
- Is the level of control over and interactivity with the story suitable? Why so or not?
- (How) Are the story, and the interactions/effects connected? Which are and which aren't? Why?

Design goal questions

- Was the story engaging?
- Were the story and the characters understandable? What made it (un) clear?
- Which elements of the experience grabbed your attention? Why?
- Did you feel any empathy or sympathy for the characters during the story? Why or why not?
- Name 3 emotions or associations that the experience evoked, what caused them?
- How immersed did you feel in the story world? What made you feel immersed or not?

Criteria:

- The experience is suitable for a mature audience without being childish.
- The experience and story should be engaging and interesting for a modern audience used to interactive media.
- The story remains original and the experience keeps its historical authentic feeling.
- The user feels like he/she has the right amount of control and interactivity over the experience. The interactivity doesn't hinder the experience and is engaging.
- The interactions and effects are connected to or support the narrative. The interactions and effects don't distract from the narrative.
- The characters are clear and the storyline is understandable in detail
- The characters or the plot evoke emotions, sympathy or empathy.
- The user feels present in the story world as a character or observer and forgets the outside world.
- The user is focussed on the story elements like the narration, the visuals or the interactions.
- The interactions and effects are surprising and makes people feel curious to explore.
- The interactions and effects are exciting and engage the user emotionally.
- The interactions and effects create a dynamic effect that is not possible with regular books.

Appendix E: Overview of usecues

Tip klom in een oude dubbeldekker,
Top klom met veel moeite in een luchtballon.

Dames en heren, hier volgt een belangrijke mededeling!
Het hondje Tap is de 100 000ste bezoeker.

Kennen jullie Tip en Top?
Dat zijn heel dikke vrienden!

Maar dat gebeurde gelukkig niet...
Want een paar mannen trokken hem naar beneden.

Op een dag gingen Tip en Top op weg naar het vliegveld!
Al dadelijk merkten ze dat er een tentoonstelling was.

Alles liep gelukkig goed af!

Grijp het touw!

Sleep Tap om hem te laten blaffen

Beweeg de hendel

Til de radio op om de omroeper te starten

Teleporteer op de prul om het luchtschip te laten vliegen

Appendix F: Meeting the design requirements

The design requirements serve as a list of criteria to guide different prototypes and the final concept. They were used during designing and prototyping or when taking decisions. Not all requirements can be met at the same time and some requirements are contradictory. They were clustered per topic and are hierarchical, the higher on the list, the more important they are. The list was compiled by me, based on conversations with users, designers and my supervisors.

Materiality

- The VR book should convey the materiality of the physical book.
- The materiality should take advantage of the extra affordances and interactions in VR.
- The materiality should blend qualities from the narrative and the artifact in VR.

Narrative engagement

- Users should understand the plot of the story.
- Users should be able to distinguish the characters.
- Users should have some kind of emotional response to the story and/or characters.
- The story should draw the attention of the user.
- Users should feel present in the story.

Story authenticity and enhancement

- The original plot and the characters should remain the same.
- The physical structure of the book should remain the same, and new elements can be added.
- The historical sensation from the 1960's should be preserved and respected.

Interactions

- The interactions should engage the full body and be largely mimetic.
- The interactions should evoke the interaction qualities: surprise, excitement, and dynamism.

VR technology

- The experience should be self-explanatory.
- The experience should be playable without external instructions.
- The experience should be engaging for first-time and experienced VR users.
- The VR experience should minimize the risk of nausea.

Requirement met

Requirement partially met

Requirement not met

Appendix G: Approved Project Brief

DESIGN FOR our future

TU Delft

IDE Master Graduation

Project team, Procedural checks and personal Project brief

This document contains the agreements made between student and supervisory team about the student's IDE Master Graduation Project. This document can also include the involvement of an external organisation, however, it does not cover any legal employment relationship that the student and the client (might) agree upon. Next to that, this document facilitates the required procedural checks. In this document:

- The student defines the team, what he/she is going to do/deliver and how that will come about.
- SSC E&SA (Shared Service Center, Education & Student Affairs) reports on the student's registration and study progress.
- IDE's Board of Examiners confirms if the student is allowed to start the Graduation Project.

USE ADOBE ACROBAT READER TO OPEN, EDIT AND SAVE THIS DOCUMENT
Download again and reopen in case you tried other software, such as Preview (Mac) or a webbrowser.

STUDENT DATA & MASTER PROGRAMME

Save this form according the format "IDE Master Graduation Project Brief_familyname_firstname_studentnumber_dd-mm-yyyy".
Complete all blue parts of the form and include the approved Project Brief in your Graduation Report as Appendix 1 !

family name
initials
student number
street & no.
zipcode & city
country
phone
email

Your master programme (only select the options that apply to you):
IDE master(s): ( ) IPD (★) DfI ( ) SPD
2nd non-IDE master:
individual programme: - - (give date of approval)
honours programme: ( ) Honours Programme Master
specialisation / annotation: ( ) Medisign ( ) Tech. in Sustainable Design ( ) Entrepeneurship

SUPERVISORY TEAM **

Fill in the required data for the supervisory team members. Please check the instructions on the right !

** chair Willemijn Elkhuizen dept. / section: SDE / MD
** mentor Jeff Love dept. / section: SDE / KIND
2nd mentor
organisation:
city: country:
comments (optional)

Chair should request the IDE Board of Examiners for approval of a non-IDE mentor, including a motivation letter and c.v..

Second mentor only applies in case the assignment is hosted by an external organisation.

Ensure a heterogeneous team. In case you wish to include two team members from the same section, please explain why.

TU Delft

Procedural Checks - IDE Master Graduation

APPROVAL PROJECT BRIEF

To be filled in by the chair of the supervisory team.

chair Willemijn Elkhuizen date 17 - 02 - 2023 signature

Digitally signed by tudelft.protect Jamf Protect CSR Identity Date: 2023.06.30 13:59:50 +02'00'

CHECK STUDY PROGRESS

To be filled in by the SSC E&SA (Shared Service Center, Education & Student Affairs), after approval of the project brief by the Chair.
The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total: EC
Of which, taking the conditional requirements into account, can be part of the exam programme EC
List of electives obtained before the third semester without approval of the BoE

( ) YES all 1st year master courses passed
( ) NO missing 1st year master courses are:

name date - - signature

FORMAL APPROVAL GRADUATION PROJECT

To be filled in by the Board of Examiners of IDE TU Delft. Please check the supervisory team and study the parts of the brief marked **.
Next, please assess, (dis)approve and sign this Project Brief, by using the criteria below.

- Does the project fit within the (MSc)-programme of the student (taking into account, if described, the activities done next to the obligatory MSc specific courses)?
- Is the level of the project challenging enough for a MSc IDE graduating student?
- Is the project expected to be doable within 100 working days/20 weeks ?
- Does the composition of the supervisory team comply with the regulations and fit the assignment ?

Content: ( ) APPROVED ( ) NOT APPROVED
Procedure: ( ) APPROVED ( ) NOT APPROVED
comments

name date - - signature

Initials & Name M.H. van Geene Student number 4665333
Title of Project Designing a VR/AR storytelling experience of a historical pop up book.

Personal Project Brief - IDE Master Graduation

TU Delft

Designing a VR/AR storytelling experience of a historical pop up book. project title

Please state the title of your graduation project (above) and the start date and end date (below). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

start date 13 - 02 - 2023 14 - 07 - 2023 end date

INTRODUCTION **

Please describe, the context of your project, and address the main stakeholders (interests) within this context in a concise yet complete manner. Who are involved, what do they value and how do they currently operate within the given context? What are the main opportunities and limitations you are currently aware of (cultural- and social norms, resources (time, money,...), technology, ...).

The Nationale Bibliotheek (KB) is an institution in the Netherlands responsible for the archive of Dutch and international literature. This collection includes historical artefacts but also more contemporary styles of books, in this case: pop-up and movable children's books. The pop up books are part of their special collection and have cultural historical value. The KB is moving their collections to a remote archive, this means that their collections can't be accessed by the public anymore. The specific book chosen for this project is: Tip en Top boven de wolken (figure 1). New technology like VR/AR can make these books accessible again by creating a virtual interactive copy.

These technologies are being implemented in new contexts like cultural heritage. They offer immersive ways of experiencing heritage and can be used to augment historical artefacts without damaging the originals. Pop up books contain many movable and interactive elements and are three dimensional. However they are also very fragile, this makes them very suitable for VR/AR applications. One of the problems with VR/AR is that these technologies are virtual which creates a disconnect with the tangible heritage artefacts. Part of the historical sensation of these artefacts is their materiality which gets lost in VR/AR. This project explores how the materiality of these artefacts can be implemented in a VR/AR experience. VR technology is complex so the VR zone of the TU Delft library will be involved for prototyping and testing VR/AR concepts.

This project is facilitated by Willemijn Elkhuizen, researcher in residence at the KB. She is researching the materiality of (historical) pop-up and movable books.

space available for images / figures on next page

Personal Project Brief - IDE Master Graduation

TU Delft

introduction (continued): space for images

image / figure 1: Tip en Top boven de wolken

TO PLACE YOUR IMAGE IN THIS AREA:

- **SAVE THIS DOCUMENT TO YOUR COMPUTER AND OPEN IT IN ADOBE READER**
- **CLICK AREA TO PLACE IMAGE / FIGURE**

PLEASE NOTE:

- **IMAGE WILL SCALE TO FIT AUTOMATICALLY**
- **NATIVE IMAGE RATIO IS 16:10**
- **IF YOU EXPERIENCE PROBLEMS IN UPLOADING, COVERT IMAGE TO PDF AND TRY AGAIN**

image / figure 2:

Personal Project Brief - IDE Master Graduation

TU Delft

PROBLEM DEFINITION **

Limit and define the scope and solution space of your project to one that is manageable within one Master Graduation Project of 30 EC (= 20 full time weeks or 100 working days) and clearly indicate what issue(s) should be addressed in this project.

The aim of this graduation project will be looking into how heritage can be made accessible and exciting through AR/VR technology. VR offers new ways of reading and interacting with pop up books which might conflict with the qualities and the intentions of reading a physical book. In a VR experience people are often distracted by the immersiveness and interactiveness and don't focus on the content of the story. This project will look into different methods of storytelling, navigating and interacting with a virtual pop up book. It should combine the qualities of reading a physical books and the extra possibilities the VR technology can offer. The materiality of the physical books is an important part of the experience, this project will look into how this materiality can be implemented in new ways to support the story and to create the feeling of interacting with a piece of heritage. The project will also look into how this experience fits the needs of the KB and how it can be implemented to make their heritage accessible again.

ASSIGNMENT **

State in 2 or 3 sentences what you are going to research, design, create and / or generate, that will solve (part of) the issue(s) pointed out in "problem definition". Then illustrate this assignment by indicating what kind of solution you expect and / or aim to deliver, for instance: a product, a product-service combination, a strategy illustrated through product or product-service combination ideas, ... In case of a Specialisation and/or Annotation, make sure the assignment reflects this/these.

During this graduation project I will design a VR/AR experience of a historical pop up book that focusses on storytelling in a virtual world. It will specifically look into how the materiality can be translated in order to support the story.

- I will research the story of the pop up book (figure 1) to see how the story progresses, what the goal of the story is and which emotions and associations the book aims to evoke. This will be core of the VR experience.
- I will research the material qualities of the physical pop up book in order to translate them to the VR in both digital and physical ways. Examples of material qualities could be: the fragility of the pages, the scent of the book, the fading of the colours, the resistance in the mechanisms or the texture of the pages.
- I will prototype different types of storytelling and interactions in VR that serve the purpose of the physical book.
- The end goal is an experiential storytelling experience through a virtual pop up book that conveys the emotions and the goal of the original book in a novel way.

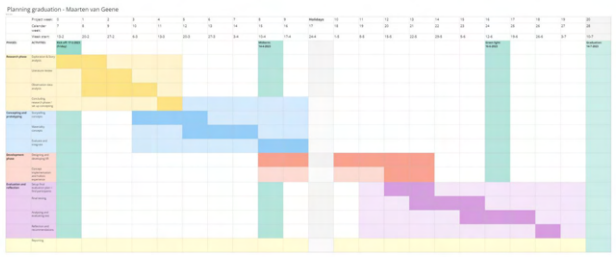
Personal Project Brief - IDE Master Graduation

TU Delft

PLANNING AND APPROACH **

Include a Gantt Chart (replace the example below - more examples can be found in Manual 2) that shows the different phases of your project, deliverables you have in mind, meetings, and how you plan to spend your time. Please note that all activities should fit within the given net time of 30 EC = 20 full time weeks or 100 working days, and your planning should include a kick-off meeting, mid-term meeting, green light meeting and graduation ceremony. Illustrate your Gantt Chart by, for instance, explaining your approach, and please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any, for instance because of holidays or parallel activities.

start date 13 - 2 - 2023 14 - 7 - 2023 end date



I plan to do four phases in my graduation project and I will work full time on the project. I will take one week of holidays halfway through the project. The four phases are:
Research: I will do a combination of literature research and analysis of observation study data. This phase will take 3 or 4 weeks.
Concepting: Based on the research I want do some rapid cycles of low fidelity prototyping. These will focus on different storytelling methods and different ways of implementing the materiality. These will be evaluated and integrated into a final concept.
Development: The development will focus on designing the final concept which will be a VR experience of the pop up book. Certain aspects will be highlighted and prototyped in more detail. The final design will be evaluated through a user test.
Reflection and recommendations: The insights and conclusions will be gathered. Recommendations will be made. The project will be reflected upon. The graduation will be prepared.

Personal Project Brief - IDE Master Graduation

TU Delft

MOTIVATION AND PERSONAL AMBITIONS

Explain why you set up this project, what competences you want to prove and learn. For example: acquired competences from your MSc programme, the elective semester, extra-curricular activities (etc.) and point out the competences you have yet developed. Optionally, describe which personal learning ambitions you explicitly want to address in this project, on top of the learning objectives of the Graduation Project, such as: in depth knowledge a on specific subject, broadening your competences or experimenting with a specific tool and/or methodology, ... Stick to no more than five ambitions.

I have always been interested in history and cultural heritage. I like visiting museums, using historic artefacts and reading old stories because they have the magic to transport you to different times and places. I think design could be used to enhance this effect using digital tools and modern technology. Pop-up books also contain a story which is something I am also interested in. I have chosen this topic for my graduation because I want to learn how to use digital tools for cultural heritage in a meaningful way.

During my studies I have done multiple design projects around cultural heritage and (museum) experiences. In the bachelor elective 'design for cultural impact', I redesigned the zoo experience in a more ethical and educational way. I looked into the current values and interactions at the zoo and designed an experience which fitted my personal view of how a zoo should be. During C&C I wrote my paper for the Museum Futures Lab, it focused on AR applications in natural history museums. It studied three different cases and listed some limitations and best practices when using AR for natural history.

In this project I want to use the interactive design skills that I have developed during the courses Exploring Interactions and Interactive Technology Design. This involves ideation, rapid prototyping, digital prototyping and user testing. This can be combined with the knowledge and the methods I have developed during the block course Design for Emotion. I want to design meaningful interactions for a VR environment.

I will have to develop my VR design skills as this is something I have almost no experience with. I have always seen the technology more as a tool to create a certain experience than the final design. For my future career I need to develop my technological skills as they will be very useful as an interaction designer. For this project I will be mainly learning 3D modelling using Blender and animation using Unity.

FINAL COMMENTS

In case your project brief needs final comments, please add any information you think is relevant.

Initials & Name M.H. van Geene Student number 4665333

Title of Project Designing a VR/AR storytelling experience of a historical pop up book.