Design VR Pop-up book experience

From the principles of creating immersive user experience

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Executive summary

The National Library of the Netherlands boasts an extensive collection of Pop-up books. However, due to their age, some of these Pop-up books have deteriorated over time, making it impossible to display them to the public. Nonetheless, emerging VR/AR technologies offer a solution to this issue. By recreating these Pop-up books within the VR/AR realm, users can once again engage with these embodiments of human wisdom. Hence, the core of my graduation project lies in designing a VR/AR Pop-up book experience. With the aim of fostering a greater appreciation and understanding of Pop-up books, I envision my experience to meet the following criteria: 1. It should provide users with a profound sense of immersion. 2. It should be easy to navigate and operate. 3. It should offer users a novel perspective for appreciating Pop-up books.

Analysis

Through my research into the histories of "Pop-up books" and "VR/AR books," coupled with an analysis of their features, I have uncovered a shared core concept: the transformation of imagination into tangible form. This underlying principle resonates with people's desire for immersion. Furthermore, my investigation into the literature surrounding "immersion" has led me to identify seven factors that influence the sense of immersion in an experience: Sensory, Curiosity, Concentration, Comprehension, Control, Challenge, and Empathy. These factors exert varying degrees of influence on immersion at different stages of the experience.

Design

After careful consideration, I decided to utilize VR to present a Pop-up book titled "TIP+TOP Boven De Wolken." Building upon my previous conclusion of immersion and insights gained from user study, I particular emphasis on the environment and interactions part. I decided to craft the environment as a "Wizard's attic" and will introduce two pivotal interactions: "Scalable Pop-up book size" and "Exploration-triggered story-telling." These components collectively encompass all the factors influencing immersion. I believe that their synergistic integration will effectively enhance the sense of immersion within the experience.

Conclusion

Ultimately, upon completing the experience, I invited 24 participants to engage with it and provide feedback. Through the analysis of both ratings and feedback, I have concluded that my VR Pop-up book experience has successfully enhanced user immersion and introduced a novel perspective on Pop-up books for some users. However, it also revealed several areas that require further improvement.

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Chapter 1：
Introduction

In this chapter, you will gain insight into the content of my graduation project, along with the motivations driving my choice of this particular project. I will also briefly outline my design objectives and the strategies I intend to employ in achieving them.

1.1 Introduction

In recent years, virtual reality (VR) and augmented reality (AR) have been steadily gaining prominence. From the release of the movie "Ready Player One" in 2018 [1] to the well-received VR game "Beat Saber" in 2019 [2], and more recently, the unveiling of Apple's latest VR/AR eyewear, the Apple Vision Pro [3], it becomes evident that this emerging VR/AR technology is making significant inroads across various industries, while also gradually reshaping our individual lifestyles. It is conceivable that our future might be intricately intertwined with the profound influence of this technology.

Figure 1: The VR exhibition "Mona Lisa: Beyond the Glass" launched by the Louvre in 2019 [4]

Figure 2: The VR exhibition "Curious Alice" launched at the V&A museum in London in 2021 [5]

Public educational institutions such as museums and exhibition halls have also been impacted by VR/AR technology, with some museums and exhibition venues establishing dedicated VR experience zones. Although the current number of museums/exhibition spaces adopting these new technologies remains relatively limited, these innovative

experiences have left a profound impact on visitors, garnering much acclaim. For instance, in October 2019, the Louvre in Paris introduced 'Mona Lisa: Beyond the Glass,' a VR experience that delves into the intricacies of the Renaissance painting. Through interactive design, audio, and animated imagery, users can explore intricate details of the artwork [4]. Similarly, in 2021, London's renowned V&A museum unveiled the "Curious Alice" exhibition, providing visitors with a playful VR experience that immerses them in the enchanting world of Lewis Carroll's classic [5].

VR/AR harnesses its immersive nature, unparalleled entertainment value, and meticulous attention to detail to forge a novel viewing experience, thereby drawing diverse user demographics to museums and exhibition halls. In fact, numerous of them have ventured into creating virtual versions of their exhibits, enabling individuals to explore these institutions from the comfort of their homes by donning VR glasses. Undoubtedly, VR/AR technology has revolutionized the design of experiences, service processes, and promotional strategies employed by museums and exhibition halls. Its influence extends even to the creative expressions of artists, underscoring the profound impact of virtual reality on the industry as a whole.

1.2 Motivation

As public educational institutions, some libraries have also begun to take an interest in VR/AR technology. The National Library of the Netherlands, situated in The Hague, is one such institution. For brevity, I will refer to it as "KB" from now on.

Founded in 1798. The KB collects everything that is published in and concerning the Netherlands, from medieval literature to today's publications. About 7 million publications are stored in the stockrooms. The KB also offers many digital services, such as the national online Library, Delpher and The Memory. Since 2015, the KB has played a coordinating role for the network of the public library. It is the first web collection in the world that has been granted this status [6].

Currently, KB houses an extensive collection of Pop-up books, many of which date back to the 1950s and 1960s. However, the deteriorating paper quality of these books raises concerns, making them unsuitable for direct use as exhibits for library visitors. Fortunately, VR/AR technology has offered a transformative solution to this challenge.

By leveraging VR/AR, KB can recreate these Pop-up books within a virtual environment, thereby overcoming the limitations imposed by their physical condition. This not only preserves the historical significance of these books but also expands the experience for visitors. Through VR/AR, readers can now appreciate the wealth of knowledge and ingenuity

contained within these Pop-up books, while also gaining a more immersive experience and new methods of engagement.

Figure 3：Users are experiencing the current VR Pop-up book 'Garage' [7]

Recently, KB has entered into a collaboration with other two VR developers to develop a VR experience [7]. This immersive experience allows users to explore a virtual library where they can engage with four distinct Pop-up books. Users have the freedom to open and close the Pop-up books in various ways and read their contents. Moreover, within these Pop-up books, there are interactive elements awaiting discovery. For instance, consider the 'Garage' Pop-up book depicted in the accompanying figure 3. If a user activates it by turning the steering wheel and enters the virtual garage, they will be greeted by the authentic sounds associated with a real garage.

The current version of the VR experience is undeniably innovative, engaging, and significantly important, as it lays a solid foundation for my graduation project. More

importantly, it has dawned upon me the unparalleled level of immersion that can be achieved through the fusion of VR/AR technology with Pop-up books. This level of immersion has personally intensified my interest in Pop-up books during my experience, and I firmly believe that this sense of immersion coming from current experience holds significant untapped potential for further development. Thus, I aspire to design the environment and interaction of the experience in my own way, aiming to craft a immersive Pop-up book VR/AR experience for KB.

1.3 Project aim

In order to locate my project more clearly. I sorted out the core goals I hope to achieve in the final VR/AR Pop-up book experience. Within this context, there exists a main goal, accompanied by two sub goals:

- **Main goal: I aim to bring users an immersive Pop-up book experience.**
  Immersion holds profound significance in enhancing any form of experience. Research has indicated that heightened levels of immersion contribute to increased user loyalty and satisfaction in experiences [7]. Additionally, it aids in fostering long-term memory retention and short-term divergent thinking. Therefore, my aspiration is that the VR/AR Pop-up book experience I design will evoke a profound sense of immersion among users, thus enticing a broader audience to take interest in and deepen their comprehension of Pop-up books.

- **Sub goal: I aim to make the experience easy to operate.**
  Given that the project's target audience includes individuals who may have limited prior experience with VR/AR technologies, I aim to design the experience with a reduced learning curve and operational complexity. Even with minimal explanations, individuals new to VR or AR could be able to swiftly grasp how to navigate and fully appreciate the experience.

- **Sub goal: I aim to bring user new perspective to look at Pop-up book.**
  I hope Pop-up books to garner increased attention and appreciation from a broader audience. Hence, I aim to utilize the innovative technologies of VR/AR to present Pop-up books in a novel manner that offers users a distinctive experience. Ultimately, I hope this approach will encourage them to view Pop-up books in a new perspective within reality.

1.4 Project approach

Designing a VR experience from the ground up indeed entails a significant investment of production time, and it differs from conventional design projects due to its unique workflow. Balancing the time schedule and ensuring that the design remains at the forefront, rather than being overshadowed by the technological aspects, poses a primary challenge. To address this issue, I divided the project process into four distinct phases: "Analysis," "Creation," and "Making + Testing."

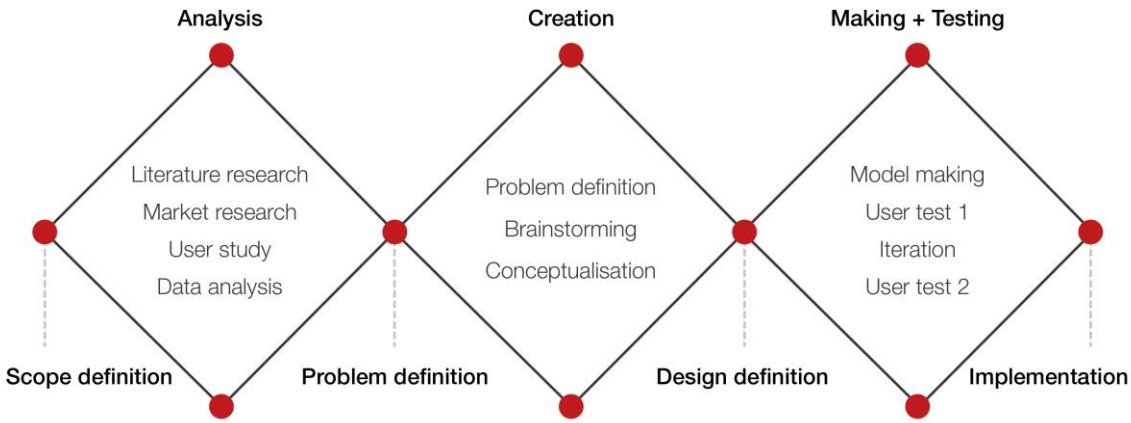

Figure 4: A visual representation of the approach used during this project

- **Analysis**

  In preparation for exploring the realms of VR/AR, and Pop-up books, it is essential to acquire a comprehensive understanding of these domains. This can be accomplished by immersing oneself in relevant literature and gaining insights into the existing works available in the market. Primarily, it is imperative to succinctly summarize the history, inherent features, and advantages associated with VR/AR and Pop-up books.

  Following this preliminary phase, my chair will undertake a user study with the objective of evaluating the existing VR experience of KB. Both a fellow graduate student and I have been granted the opportunity to participate. The central focus for me of this research is to determine whether the current VR experience lacks immersion. If that immersion is lacking, my research will strive to identify the means by which user engagement can be enhanced. Conversely, if the VR experience is deemed immersive, my attention will shift towards discerning the factors that influence user engagement. Moreover, I aim to ascertain the user expectations regarding VR/AR experiences.

  Drawing upon the data derived from user study and the outcomes of my desktop inquiries, this study will delineate the fundamental issues concerning immersion in the present VR experience. Furthermore, it will identify the key considerations for designing immersive VR/AR experiences that cater to user expectations.

- **Creation**

  Upon defining the core problem, it becomes necessary to devise a solution. In the creative phase, leveraging the insights acquired through research, I will refine my design objectives and undertake an in-depth exploration of the concept of immersion through an extensive review of relevant literature. The ultimate aim is to address the central question: "What factors influence user immersion in the Pop-up book VR/AR experience?"

  By synthesizing the information gleaned from the literature, I will formulate my own conclusion. Subsequently, I will compare this conclusion with the data obtained from field research to establish its credibility. Building upon this foundation, I will engage in a brainstorming process to generate multiple interactive solutions aimed at augmenting immersion.

- **Making + Testing**

  Moving forward, I will commence the realization of my ideas by employing various tools and techniques. Utilizing 3D design software (i.e., Blender [8] and Rhinoceros 3D [9]) for modeling and 3D painting software (i.e., Adobe Substance 3D Painter [10]) for texture creation, I will bring my envisioned designs to life. Subsequently, I will translate these designs into a functional interactive experience within the Unreal game engine. I will first develop a simplified version of the VR/AR experience, incorporating the newly designed interaction methods. Through rigorous user testing, I will ascertain whether these interactions effectively enhance user immersion as envisioned. Valuable user feedback will be gathered and organized to facilitate an iterative process.

  I will then make a full Pop-up book VR/AR experience based on the feedback, and conduct end-user testing after completion. In this test, I will comprehensively measure whether this VR/AR experience meets the design goals I set at the beginning. And do some reflection based on the final feedback results.

Chapter 2：

Desktop research

In this chapter, I will conduct research on two pivotal elements: "Pop-up books" and "VR/AR books." Through an examination of their historical evolution and an analysis of their respective advantages, I aim to delve into the interplay between these two elements and their connection to immersion.

2.1 Pop-up books

At the outset of my project, I directed my focus towards delving into the historical evolution of Pop-up books. By gaining insights into the inception and developmental trajectory of Pop-up books, I could readily apprehend the motivations behind the invention of this distinctive reading mode and discern the pivotal factors contributing to the widespread appeal and fondness for Pop-up books.

2.1.1 History of Pop-up books

It is imperative to establish a precise definition for the concept of Pop-up books first. A Pop-up book is any book with three-dimensional pages, often with features that "pop up" as the page is turned. The terminology serves as an umbrella term for movable book, pop-ups, tunnel books, transformations, pull-tabs, and other features each performing in a different manner. [11]

When contemplating Pop-up books in contemporary times, one might associate them primarily with children's book. However, Pop-up books were initially crafted for an adult audience, finding their early application within the realms of religion, astronomy, and medicine.

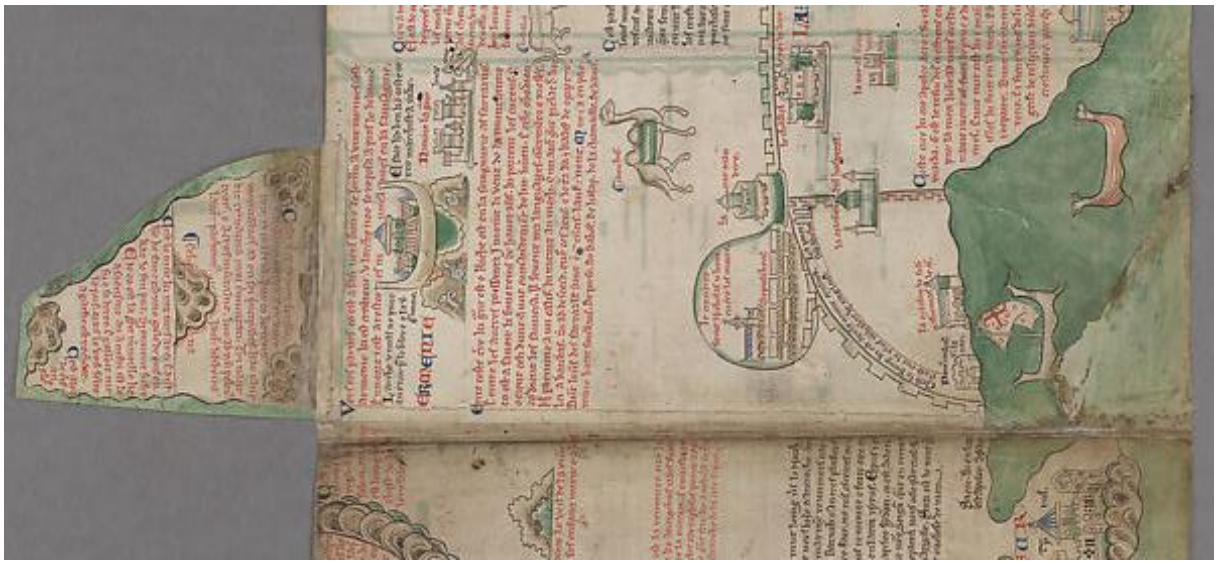

Figure 5: Movable books: Matthew Paris, Chronica Majora, 1240 [12]

- **1240**

  Most historians agree that the first known Pop-up book was created by a Benedictine monk named Matthew Paris. He crafted the "Chronica Majora" in year 1240. Similar to "Liber Floridus," this book aimed to serve as a comprehensive history of the world. What sets it apart are the rotating and pivoting wheels ingeniously integrated into the book's design, which aided monks in calculating lunar seasons and determining holy days [12].

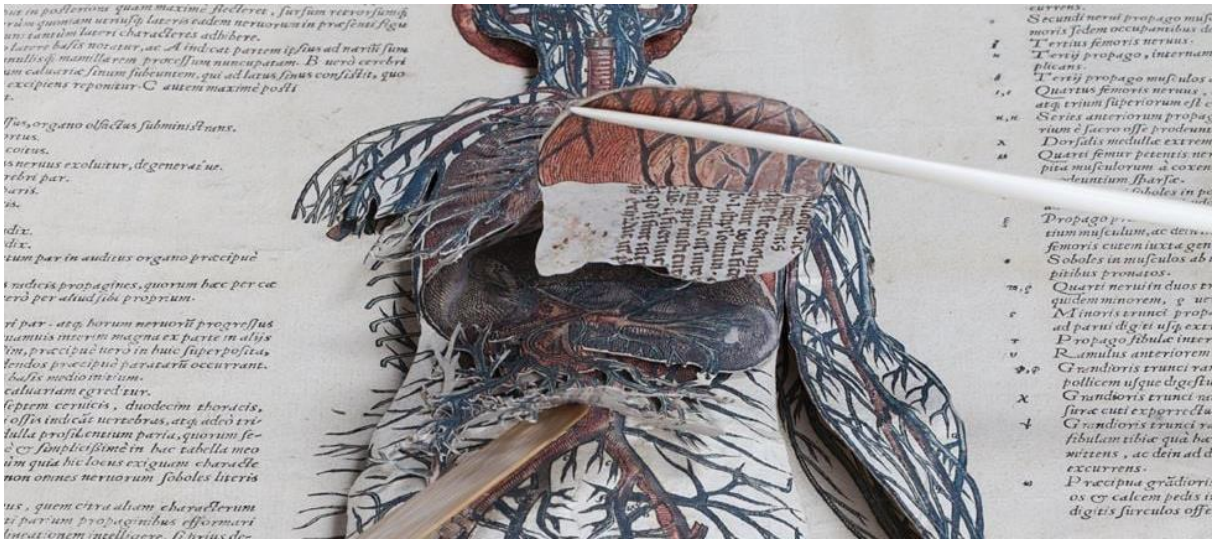

Figure 6： Movable books: Andreas Vesalius, De Humani Corporis Fabrica Librorum, 1543 [12]

- **1543**

  As scientific knowledge continued to advance, the subject matter of Pop-up books transitioned from theology and occultism to the field of medicine. Medical professionals began creating anatomical books featuring intricate layers and flaps that illustrated the human body. One of the most renowned works in this genre, printed in 1543, was "De Humani Corporis Fabrica" (On the Fabric of the Human Body), authored by Andreas Vesalius. This groundbreaking book depicted the anatomy of the human body through seven superimposed layers[12].

Figure 7： Tunnel books: Lanes Telescopic View of the Ceremony of Her Majesty Opening the Great Exhibition, 1751 [12]

- **1750s**

  As the 18th century dawned, Pop-up books became increasingly widespread and enjoyed popularity. Tunnel books, sometimes referred to as peep show books, gained prominence during this period. These books featured a lengthy tunnel-like structure

made of folded paper, arranged in a concertina shape and viewed through a hole in the cover. Drawing inspiration from theatrical stage sets, tunnel books were frequently created to commemorate special occasions and events [12].

Figure 8： Pop-up books: Thomas Dean and Son, The History of Little Fanny, 1864 [12]

- **1860s**

  As the technology for creating Pop-up books became more refined, they transitioned into the realm of mass production. Previously, Pop-up books had been somewhat akin to toys for the middle class, but now they were gaining broader public appeal. Thomas Dean and Son emerged as pioneers in this regard, becoming the first publishers to produce Pop-up books on a large scale. Throughout the 1860s, they introduced a diverse range of Pop-up books [12].

Figure 9： Pop-up books: Stephen Louis Girard, The Apples of Iduna, 1948 [13]

- **1940s/1960s**

  During the First and Second World Wars, there was a notable reduction in the production of Pop-up books owing to heightened labor demands. However, following the post-war economic recovery, Pop-up books experienced two significant revivals. The period between 1940 and 1960 witnessed the birth of numerous Pop-up books, many of which are now found in libraries as historical artifacts. During this time, there was an unprecedented demand for Pop-up books. The reasons behind this phenomenon are multifaceted. Firstly, Pop-up books began to incorporate children's stories, thus tapping into the children's market. Additionally, collaborations with prominent animation IPs such as Disney and Sesame Street provided Pop-up books with the advantage of leveraging the existing brand value of these IPs. [13]

Figure 10: Pop-up books: Matthew Reinhart, Harry Potter: A Pop-Up Guide to Hogwarts, 2019 [13]

- **Now**

  In the present day, despite the advancements in digital technologies, Pop-up books continue to maintain their popularity among both children and adults. They are appreciated for their innovative techniques, exquisite craftsmanship, and their ability to serve as educational resources. Pop-up books have become more accessible than ever before, but their significance as a primary form of entertainment has undoubtedly diminished in light of the digital age. [13]

2.1.2 Feature of Pop-up books

Surveying the entire developmental history of Pop-up books, I am inclined to believe that it was the pursuit of these distinct attributes that led to the invention of Pop-up books. Moreover, it is these very attributes that have fortified the endurance of Pop-up books over a span of over 800 years, gradually fostering their widespread acceptance and endearment

among the masses:

- **Immersion beyond ordinary books**
  Pop-up books offer a heightened sense of immersion by presenting the storyline through three-dimensional scenes or interactive elements that bring the content to life. This captivating presentation captivates readers, enhances their understanding of the plot, and piques their curiosity about what will unfold next. The combined effects of increased attention, comprehension, and curiosity result in an enduring sense of immersion.

- **Understandability beyond words**
  As previously mentioned, Pop-up books were originally used as teaching tools to elucidate complex subjects such as anatomy and theology. This illustrates that Pop-up books possess an expressive tension that surpasses ordinary texts, enabling clearer explanations. The opening and closing of three-dimensional elements further amplify the visual impact of Pop-up books, allowing for almost exaggerated expressions.

- **Sophisticated structure**
  The intricate structural design of Pop-up books leaves a lasting impression, showcasing the ingenuity and artistic brilliance of human craftsmanship. The thoughtful construction of Pop-up books becomes a captivating point of attraction for readers, often prompting them to ponder, "How did they do that?"

- **Core of educating with entertaining**
  In its initial emergence, the primary function of the Pop-up book was educational. However, as time progressed and production costs diminished, the central role of Pop-up books gradually shifted towards entertainment. Nevertheless, throughout its evolution, the Pop-up book has consistently epitomized a harmonious equilibrium between education and entertainment.

In his article titled "Why Pop-Up Books Are the Original VR," Matt Peters eloquently captures the essence of Pop-up books, stating that they are synonymous with decorative covers and surprising objects that spring to life from the pages. Pop-up books hold a special place in the hearts of people as they evoke a sense of magic and ignite creativity [14]. I wholeheartedly agree with Peters' sentiment.

Eight centuries ago, the inception of Pop-up books was driven by the intention to provide readers with an enhanced platform for illustrating intricate concepts. This initial impetus bestowed upon Pop-up books the capability to vividly materialize imaginative ideas. Over

time, through successive generations' efforts, the process of concretely rendering imagery onto paper became increasingly refined, and concurrently, the thematic scope of Pop-up books expanded substantially.

Within this progression, I discern the quintessential allure that has garnered widespread appreciation for Pop-up books: they inherently address a fundamental human expectation—to transform imagination into reality in order to generate more immersiveness, to some extent. This sentiment is akin to reading J.R.R. Tolkien's original "The Lord of the Rings" and subsequently anticipating the cinematic adaptation to bring to life the imaginative landscapes conceived during reading. It's an intrinsic aspect of human comprehension. Pop-up books ingeniously achieve this by means of paper engineering, a method that not only embodies their conceptualization but also introduces newfound artistic value and aesthetic appeal.

This core essence imbues Pop-up books with several "innate impressions." For instance, when individuals engage with Pop-up books, even before opening the covers, they are naturally predisposed to anticipate the ingenious means by which the narrative will be dynamically unfolded. People attend to interactive components, take note of the mechanisms facilitating movement, and evaluate the symbiotic relationship between the storyline and interactivity. These constitute the innate expectations individuals hold toward the medium of Pop-up books.

2.2 VR/AR books

As societal progress unfolds, novel technologies have emerged, including virtual reality (VR) and augmented reality (AR). However, what prompts the integration of these technologies into the realm of books? How has the amalgamation of these new technologies with books undergone transformation? Centered upon these inquiries, I embarked on another investigation into the domain of VR/AR books. Based on the findings from this inquiry, I have also distilled the advantages of employing VR/AR to present literary content, along with the reasons behind the invention and acceptance of this innovative mode. By contrasting these outcomes with those of Pop-up books, I have unearthed significant connections between the two domains.

2.2.1 History of VR/AR books

Figure 11：Students are experiencing VR project in a library of New Delhi [17]

- **Early period: Derived from VR/AR education**

  VR/AR technology have been introduced into education in the 1990's [15]. The initial inception of VR/AR books stemmed from this intervention, primarily driven by the demand for text-based content within VR educational materials.

  At that time, students comprise the primary user group for this kind of experiences, with projects heavily reliant on educational institutions such as schools and libraries. The primary focus in this domain revolves around enhancing students' reading speed and cultivating their interest in learning within the VR environment. Research conducted during this period demonstrated that students exhibit faster reading speeds in virtual reality compared to traditional book reading [15]. Furthermore, it was observed that students' learning motivation experienced a notable increase in the immersive VR environment [16].

  This initial focus on VR/AR books with children's education has led to the attribution of certain inherent characteristics, such as being associated with childlike elements and possessing educational significance. Veronica S. Pantelidis discusses several similar cases in her article titled "Virtual Reality in the Classroom " [17]. For instance, school teachers have experimented with utilizing VR to guide students in reading animal picture books, thereby aiming to foster their interest in biology through an engaging and immersive experience.

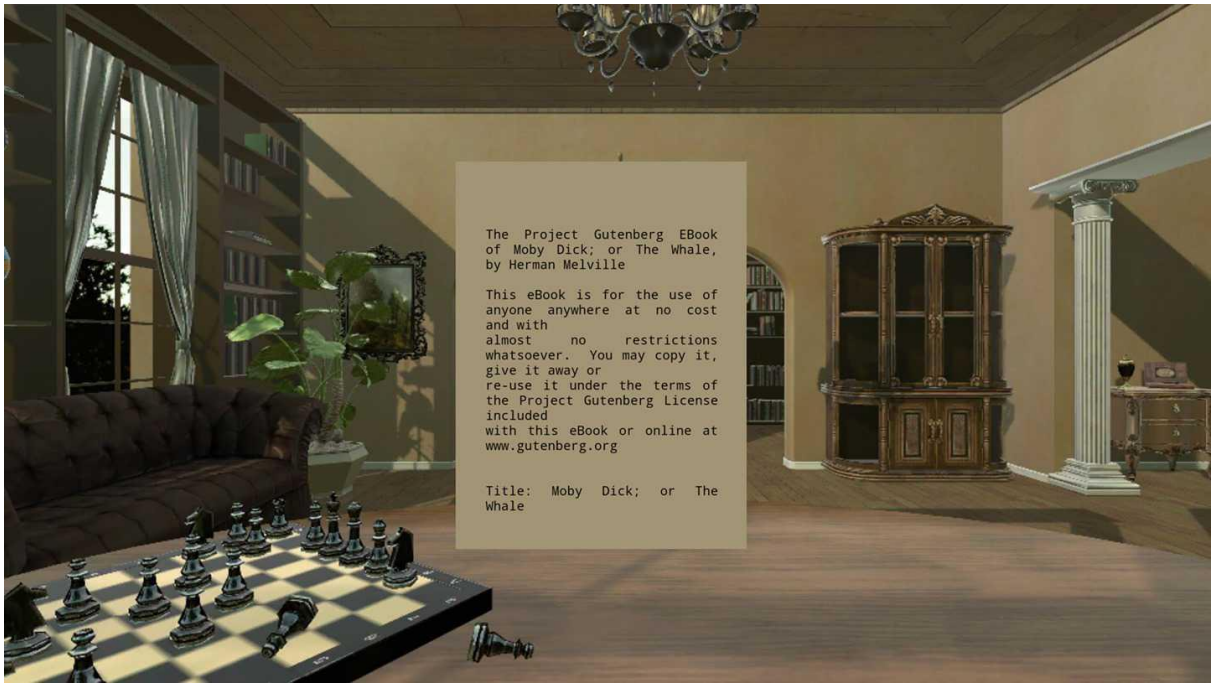

Figure 12：People can choose the reading environment in Chimera Reader [18]

- **Transitional period: Back to reading a book itself**

  As technology continues to advance, an increasing number of researchers are recognizing the sense of immersion and heightened reading motivation that VR/AR technology can provide. Furthermore, it is becoming evident that VR/AR books are not limited solely to children or student education. The field of VR/AR books has returned to reading itself and ventured into the mass market with a simpler form.

  Between 2010 and 2020, more and more adults are embracing the immersive qualities of VR/AR to enhance their reading experiences within a comfortable and personalized space. Platforms like Chimera Reader [18] and Virtual Book Viewer [19] have emerged as VR reading tools catering to the general public. These platforms offer a library of books, allowing users to choose their desired reads and select a preferred virtual environment to engage in their reading activities. Although due to technical limitations, the functions of these software are very simple or even rough, but Their appearance indicates people's new attempt to read a book in VR/AR environment.

Figure 13：“Lincoln in the Bardo” Nominated for Emmy [20]

- **Latest period: Redefinition the way of story-telling**

  In recent years, VR/AR books has expanded beyond traditional "visual reading" and evolved into a multi-sensory experience. Some VR/AR books incorporate animations that bring text content to life, blending the experiences of reading books and watching movies. For example, in 2017, George Saunders' novel "Lincoln in the Bardo" received a ten-minute VR adaptation funded by the New York Times. This adaptation allowed users to interact with the ghosts from the novel [20]. In other instances, user behavior is integrated with the story content, where the progression of the narrative depends on the user's interactions, resembling a fusion of reading books and playing games. These developments in VR/AR books have blurred the boundaries of traditional story-telling, utilizing reading material as a foundation while employing various experiential methods for creative enhancement.

  However, VR/AR books still remains a relatively niche approach due to the limited ownership of personal VR headsets. Despite an increasing trend in personal VR headset ownership, it still represents a relatively small percentage of the population. In 2018, NESTA research indicated that less than 1% of the population owned a high-end VR headset, and less than 6% owned a mobile-based VR headset [21]. With such a limited user base, relying solely on commercialization to promote the entire VR/AR books industry is challenging. Currently, a significant portion of VR/AR books relies on the support of educational and large cultural institutions. These institutions provide the necessary financial backing for the projects to conduct non-profit experiments and initiatives.

In summary, the emergence of VR/AR books initially aimed to combine children's education with the immersive and entertaining aspects of VR/AR. However, With the progression of

time, VR/AR books has gained popularity and attracted the interest of a broader audience seeking highly personalized and immersive reading experiences. Now in recent years, VR/AR books has expanded its horizons and ventured into new avenues of story-telling exploration. However, due to the limited adoption of VR/AR hardware, large-scale commercialization of VR/AR books methods remains challenging. Currently, the survival and growth of VR/AR books largely rely on educational initiatives and public welfare efforts. But it is crucial not to overlook the rapid advancements in VR/AR technology that underlie the rise of VR/AR books. Despite the current limitations, the future of VR/AR books holds great promise and potential.

2.2.2 Feature of VR/AR books

Upon conducting an analysis of the historical development of VR/AR books, I have arrived at preliminary conclusions regarding the advantages of this innovative technology in the realm of book. Combining insights from relevant scholarly literature, the following are the advantages I have gleaned, differentiating VR/AR books from other conventional modes:

- **Immersive**

  VR/AR technology provides an exceptional sense of immersion. As Mestre states in his paper "Immersion and Presence" entry, VR immersion refers to the perception of being physically present in a non-physical world. This perception is created by surrounding users with captivating visual, auditory, and other stimuli that engross them in a comprehensive environment [22]. This immersion is also a fundamental aspect of the VR/AR books. By enhancing visual and auditory stimulation, VR/AR books enables users to momentarily escape the real world, immersing themselves in a focused virtual world, facilitating emotional empathy with the story.

Measure	Group				Sig	d
	HMD		2D Video			
	M	SD	M	SD		
Presence	4.18 (.74)		2.91 (1.01)		$p < .001$	1.43
Enjoyment	4.65 (.63)		3.58 (1.22)		$p < .001$	1.10
Interest	4.06 (.76)		3.45 (1.31)		$p = .003$	.57
Immediate posttest	18.29 (4.04)		15.57 (4.83)		$p = .001$	.61
Delayed posttest	18.90 (4.35)		15.64 (4.97)		$p < .001$	.70

Table 1： The score two groups of students gave at the end of the experiment [23]

- **Entertaining + Motivating**

  In his paper “Benefits of Taking a Virtual Field Trip in Immersive Virtual Reality: Evidence for the Immersion Principle in Multimedia Learning”, Makransky conducted an experiment in which a sample of 102 middle school students embarked on a virtual field trip to Greenland using a head-mounted display (HMD) or a 2D video. This virtual field trip served as an introductory lesson within a six-lesson inquiry-based climate change

intervention. The experimental results revealed that students who conducted their research through VR scored significantly higher in terms of "Enjoyment" and "Interest" compared to those who conducted their research using 2D videos [23]. Although reading a VR book was just a part of this experiment, I believe these results have valuable implications for it.

VR/AR books offers various ways to break free from the confines of traditional reading experiences. Whether by incorporating videos or introducing game interactions, it transforms the book into an experience that goes beyond mere reading. Additionally, the novel experiences encountered in VR/AR books can increase users' interest in the stories within the book or the book itself to a certain extent. This newfound interest then drives users to seek out more knowledge, creating the motivation of "I want to know more."

- **Thinking helping + Memory helping**

  One University of Maryland study found that median recall accuracy rates with VR headsets hit 90 percent compared to 78 percent for learning with desktop computers. This is because VR gives our brain a more complete experience from which to learn, explained Jazmine Betz, a research analysis at G2 Crowd [24]. Therefore, in the long run, VR/AR books is easier for people to remember the content, and in the short term, VR/AR books helps users understand the content and sort out the logic and promote the divergence of thinking. According to Kenshiro Ichimura's view in his paper “Effects of virtual reality's viewing medium and the environment's spatial openness on divergent thinking”, the VR environment can significantly enhance the divergent thinking of the experiencers, thereby enhancing their creativity [25].

- **Convenient**

  Users can enjoy VR/AR books at their convenience in a comfortable environment, provided they possess the necessary devices. With internet connectivity, a vast array of books is accessible within the experience. In comparison to physically visiting libraries to borrow and read books, VR/AR books offers greater convenience.

- **Customizable**

  Within the VR/AR realm, users have the freedom to customize their reading space, posture, and perspective. Many related software applications grant users the ability to define these parameters according to their preferences, ensuring a more personalized and satisfying experience.

2.2.3 Relationship between VR/AR books and Pop-up books

When I compared the developmental history and advantages of Pop-up books and VR/AR books, I made a striking discovery: there exist numerous parallels between the two. The genesis of both innovations stems from the innate human desire to immersively comprehend the world around them. They are both made for immersion！ Moreover, both achieve this objective through the utilization of contemporary technologies — paper engineering and VR/AR. Initially, both found their application in education and gradually gravitated towards the realm of entertainment, ultimately striking a delicate balance between education and amusement. One could posit that Pop-up books serve as the earliest incarnation of VR/AR books, while VR/AR books stands as the contemporary counterpart to traditional Pop-up books.

While their core essence aligns closely, the means of achieving "immersion" are distinct, resulting in marked differences in their forms of expression. The wisdom embedded within paper engineering contributes to a distinct artisanal aesthetic, enhancing the visual appeal of Pop-up books. On the other hand, the limitless possibilities of the virtual realm within VR/AR amplify the curiosity and entertainment value of VR/AR books.

In my assessment, Pop-up books are indeed well-suited for presentation through the medium of VR/AR. The strengths of both platforms mutually complement each other in their shared objective of enhancing immersion. The exquisite structure and visuals of Pop-up books deliver aesthetic appeal and serve as focal points for attention. Simultaneously, the stories they contain offer VR/AR boundless creative potential. Moreover, the limitless possibilities within VR/AR align seamlessly with the imaginative essence of Pop-up books and can be enhanced through more interaction.

Also, both platforms offer immersive experiences, leveraging spatial design to provide vivid visual impacts and catering seamlessly to both educational and entertainment purposes. Given the substantial commonalities shared by both, they significantly converge in their influence on users and have a considerable overlapping audience.

Beyond the subjective advantages discussed above, utilizing VR/AR to present Pop-up books carries several objective benefits. It inherits the entire array of advantages associated with VR/AR, including customization. Additionally, since many Pop-up books are delicate and rare, employing VR/AR to showcase them not only preserves the original texts but also facilitates wider accessibility to the masses.

2.3 Case study

Following a comprehensive desktop exploration of Pop-up books, as well as VR/AR books, I proceeded with an in-depth investigation of existing relevant experience within the current market landscape. Initially, I distilled several pivotal keywords: "VR," "AR," and "Paper engineering." These keywords, along with the domains they conjoin in pairs, delineate the crux of my primary research direction.

My intention is to use these case studies to gain insights into how mature experiences in the market enhance immersion through the utilization of VR/AR technologies and paper engineering techniques. I researched nearly 30 projects in total. Here I only present a curated selection of particularly illustrative exemplars.

You can find the complete summary of related projects in Appendix A.

Figure 14: In Wonder-LAND, a child is exploring the structure of a volcano [26]

- **Wonder-LAND**

  Corresponding field: "AR" + "Paper engineering"

  Wonder-LAND [26] is mixed reality Pop-up book platform that provides an imaginative and safe environment for kids to develop scientific mindset. It combines AR/VR technology with various traditional paper-based mechanisms from Pop-up books, cardboard toys, movable cards, board games and origami. Kids can directly move in physical space and touch the tangible elements to see direct feedback magically, leading to learning through playing.

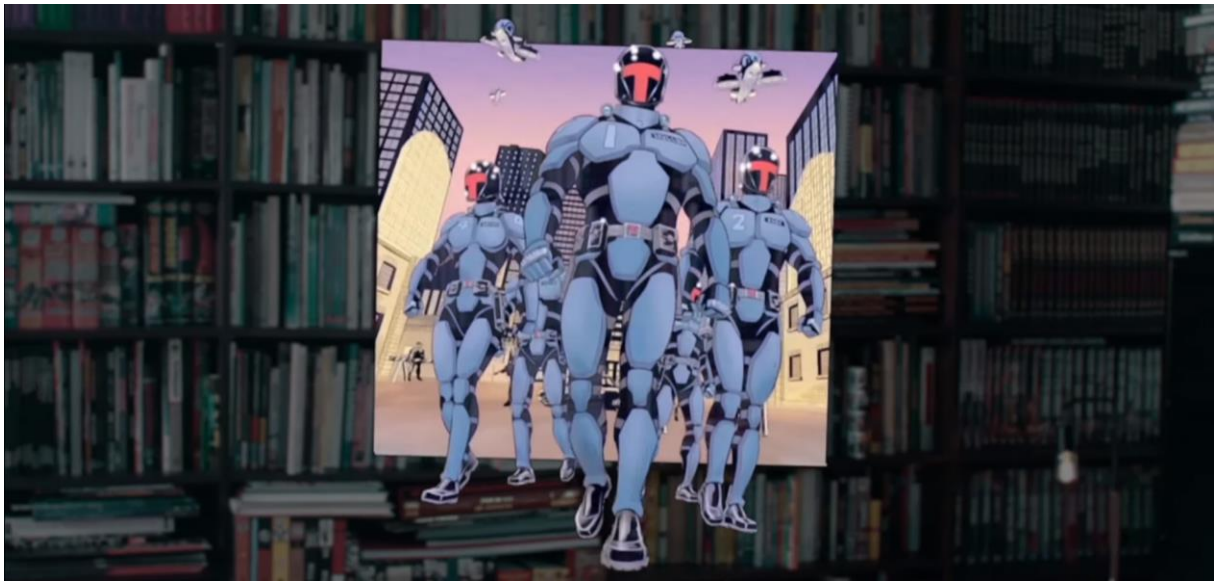

Figure 15：The AR version of "Robocop" produced by cartoonists through Madefire [27]

- **Madefire**

  Corresponding field: "AR"

  Madefire [27] is a digital comics publisher. Comic writers can convert their comics into electronic three-dimensional versions through the Madefire platform. Users only need to wear AR glasses to enjoy the 3D animations made by cartoonists for comics presented in real space, thus making them more comfortable. Good to feel the emotions of the characters in the plot.

Figure 16：VR experience The Raven's entry page [28]

- **The Raven**

  Corresponding field: "VR"

  The Raven VR [28] is an audio-visual experience for Oculus Rift based on Edgar Allan Poe's poem "The Raven". The user will be in an attic that appears in a story, and listen to the storyteller—a crow—to tell the story that happened here. Users can explore the

virtual environment, or just sit back and listen to the narrative poem.

Figure 17: Giant Pop-up book designed by Scottish artist John Byrne for the play [29]

- **John Byrne's giant Pop-up book**

  Corresponding field: "Paper engineering"

  Scottish artist John Byrne undertook the design and illustration of an expansive Pop-up book for a local theater [29]. This voluminous Pop-up book extends over four meters in length and exceeds two meters in height when unfurled. Within its pages, it intricately portrays select scenes from the local production "The Cheviot, the Stag and the Black, Black Oil." As the play progresses to specific scenes, actors have the opportunity to deftly flip the pages to the corresponding sections.

Figure 18: Visitor is taking a tour of the "infinite library" with a VR headset [30]

- **The infinite library**

  Corresponding field: "VR" + "AR"

The artistic installation titled "The Infinite Library" [30] was collaboratively crafted by the Goethe-Institute Bangladesh in conjunction with The Tech Academy (TTA). By amalgamating a virtual library with a tangible counterpart, visitors are afforded the liberty to chart their own exploratory trajectories across both the physical and virtual realms. Within this installation, attendees have the opportunity to read books about Polynesian Navigation, South Indian Puppetry, and European Alchemy.

Evidently, the domains encompassed by VR/AR books have attained remarkable breadth, catering to a diverse spectrum of individuals. Whether it be children, enthusiasts of comic art, connoisseurs of classic literature, or museum-goers, VR/AR technology has the capacity to elevate the immersiveness of experience for various demographic groups. Moreover, the means through which enhancement is achieved are multifarious. Madefire [27], for instance, orchestrates a transformation of two-dimensional visuals into dynamic three-dimensional imagery, thereby amplifying the visual impact experienced. In the case of Wonder-LAND [26], augmented reality engenders interactive object feedback, fostering a heightened sense of exploration in children. The immersive ambiances meticulously crafted by "The Raven" [28] and "The Infinite Library" [30] contribute to a more deeply immersive engagement.

Nevertheless, within the realm of Pop-up books with immersion, pertinent projects remain relatively scarce. While recognition exists regarding their potential to augment amusement—illustrated, for instance, by Wonder-LAND's utilization of Pop-up book presentation [26]—and to offer aesthetic appeal—evident through John Byrne's monumental stage-designed "giant Pop-up book" [29]—related endeavors are indeed limited. Presently, the development of Pop-up books has largely centered around artisanal craftsmanship. This void underscore the promising synergy between Pop-up books and VR/AR technology again.

Chapter 3：

User study

My chair has decided to initiate a user study for Pop-up books as well as the existing VR Pop-up book experiences within KB. I am fortunate to be actively involved. In this chapter, I will elucidate the process of the user study and share the insights I have gained from participating in it.

3.1 Purpose

While doing desktop research, my chair has made the decision to conduct a user study session for her project. Fortunately, both a fellow graduate student and I (hereinafter referred to as "we") have been granted the opportunity to participate. The subjects of this study are physical Pop-up books, along with KB's current VR Pop-up book experience.

Prior to the commencement of the user study, I also set goals for my project:
Regarding physical Pop-up books, the central aim of me is to discern: what specific attributes of Pop-up books attract individuals to engage in exploring them? Conversely, what are the aspects that people find unappealing? Do individuals experience a sense of immersion while exploring physical Pop-up books in reality? If so, what contributes to this sensation and is it profound?
Concerning the current VR Pop-up book experience available through KB, I am eager to gather participants' feedback. Particularly noteworthy are insights related to immersion and attractiveness. Do participants experience a sense of immersion during the VR experience? What factors contribute to this immersion, and what elements tend to disrupt their experiential journey? How do participants envision the act of exploring a Pop-up book within a virtual reality context?
Lastly, I aim to draw a comparative analysis between the two paradigms. What are the distinct advantages and disadvantages of virtual reality technology in cultivating a sense of immersion? Will participants embrace this virtual sense of immersion? How do participants perceive the connections and disparities between virtual reality and physical Pop-up books?

3.2 Theory

Given that this user study initiative is under the research of my chair, it is only fitting that I have seamlessly integrated the "material experience" model that constitutes the focal point of chair's research.

'Materials experience' is a phrase that acknowledges the experience people have with and through materials. Originally, the expression was coined to acknowledge the active role of materials in shaping our internal dialogues with artifacts. “To facilitate this understanding, we suggest that in the situational whole in which encounters, performances, and collaborations come about and transitions from one another occur, materials are experienced at four experimental levels: sensorial, interpretive, affective and performative. These levels affect each other in a non-sequent manner.” Giaccardi and Karana wrote in

their paper "Foundations of Materials Experience: An Approach for HCI" [31].
The concept of "materials experience" delineates the interaction between individuals and materials into four distinct layers. The first layer is the Sensorial level, which is the sensory stimulation triggered when the subject touches things. The second level is Interpretive level, which is the subject's subjective interpretation of these sensory stimuli. The third layer is the Affective level, that is, after the explanation, the emotional changes of the subjects. The fourth level is Performative level, that is, the feedback made by the subjects. We will explain subjects' behavior through these four-level models, while extending their logic as design interview questions.

The framework of "materials experience" primarily steers our approach in designing interview questions for the research and in structuring the analysis of the data obtained from the surveys. This alignment ensures a strong correlation between the research findings and the principles of "materials experience."

3.3 Preparation

We meticulously planned three study to be conducted at both the TU Delft library and KB. The study at TU Delft primarily targets students with a keen interest in VR/AR technology. The initial study at KB focuses on book-related experts employed by KB, while the second study caters to children visiting the facility.

Figure 19: We prepared a total of 8 books for the study

The following books were ultimately chosen for the study:

- Alice in wonderland: Pop-up. [32]
- Blue 2: A pop-up book for Children of all ages. [33]
- *De Boerdery.* (Made by the other graduate student)
- Gute Reise = bon voyage = goede reis. [34]

- Het circus komt!. [35]
- Het Wonder Van De Appel. [36]
- Noodles. [37]
- Pop Vibbe. [38]

To ensure comprehensive documentation, we employed 2-3 GoPro cameras during the setup, the entire interview process will be recorded.

Building upon the "materials experience" model, we have formulated a set of interview questions. These questions have been divided into three sets, allocated for participants after engaging with physical Pop-up book, virtual reality Pop-up book, and following completion of both experiences for comparative analysis. At their core, these questions are segmented into four layers: Sensorial, Interpretive, Affective, and Performative. Our intention is to comprehensively capture the multifaceted contemplations arising from the interaction between participants and the books, examined through these distinct perspectives.
Additionally, recognizing the varying degrees of familiarity that participants might have with Pop-up books and virtual reality, we have incorporated pertinent inquiries. These queries enable us to gauge individual familiarity with the terminologies associated with these mediums, as well as gather demographic information such as age and gender, acting as control variables.
You can find the complete set of questions in Appendix B.

3.4 Process

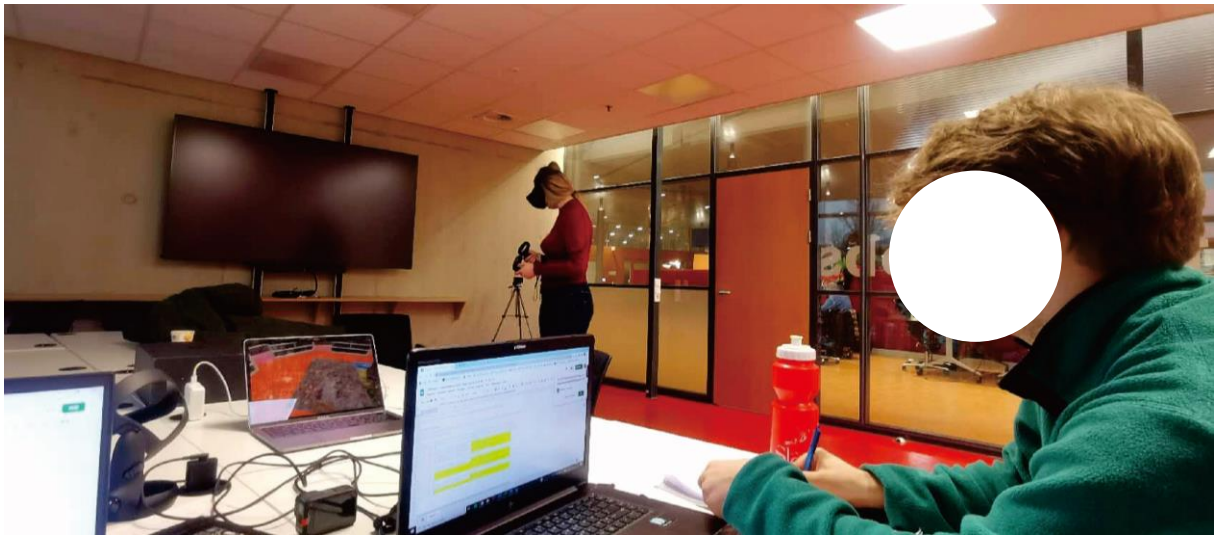

Figure 20: User study at the TU Delft library on the first day

Figure 21: User study at KB on the second day

Figure 22: User study at KB on the third day

To facilitate a comparative analysis between VR and physical books, we organized the subjects to experience both formats in a specific order. To mitigate any potential influence of consecutive experiencing on the overall experience, we divided the subjects into two groups. The first group start on the physical book, followed by experiencing virtual Pop-up books with the aid of VR glasses. The second group followed the reverse order.

Let's consider the first group as an example. We commenced the process by providing a brief introduction of the study content to the subjects and obtaining their informed consent by signing the consent form. Subsequently, we guided the subjects to the area dedicated to physical books. Here, we explained the purpose of the study and allowed the subjects to engage in independent experiencing. We endeavored to minimize any disruption to the subjects' experience and encouraged them to vocalize their thoughts. The entire process was recorded using a video recorder, and both areas were soundproofed to the best of our ability. Following the completion of the physical books, we conducted interviews using pre-

prepared questions.

After the interview, we guided the subjects to the virtual reality area. We assisted the subjects in donning the VR glasses and provided a brief explanation of the VR operation method. Once the subject's VR experience was complete, we helped them remove the VR glasses and conducted another interview. At the conclusion of the interview, given that the subjects had experienced both formats, we included the comparative question. Finally, we conclude the study process by posing questions related to variable control to the participants.

You can find the complete user study flow chart in Appendix C.

3.5 Analysis

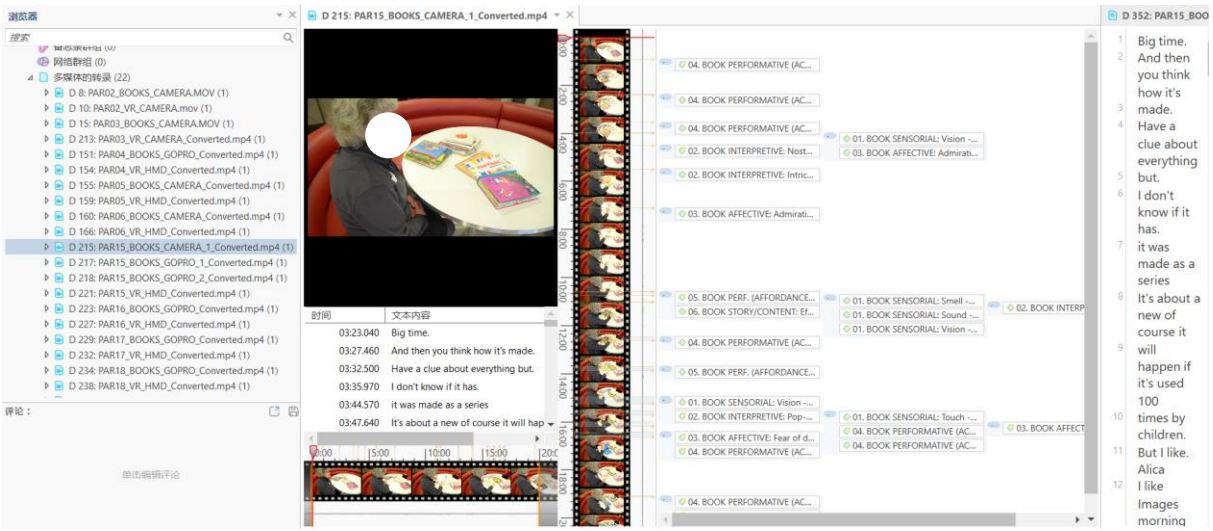

Figure 23: We analyze video and audio recordings in ATLAS.ti

After the completion of the three study, we obtained a significant amount of high-quality data. We interviewed 14, 13, and 7 individuals in the first, second, and third rounds, respectively, resulting in a total of 34 participants. Each participant had a video recording of experiencing physical book, an audio interview capturing their tactile experience with the physical book, a video recording of experiencing the VR book, an audio interview capturing their tactile experience with the virtual book, and an audio interview comparing the two different experiences.

We organized and imported the extensive dataset into ATLAS.ti [39] for further coding. To facilitate better data organization, we defined numerous tags. When we identified corresponding behaviors or expressed thoughts from the subjects in the video recordings or interviews, we marked those segments with the respective tags in the software. For instance, during the experiment, we observed that many subjects enjoyed repeatedly flipping a specific page of the Pop-up book to explore the intricacies of its structure. Consequently, we created a category named "Book Performative (Actions)" and added a

tag called "Open and close pages (repeatedly)" within it.

These tags can be roughly categorized into three groups:

- **Control variable tags**
  During the interviews, we gathered information such as the subjects' age, gender, and their familiarity with VR or Pop-up books. These details are marked as control variable tags. They pertain to subject information and are unrelated to the experiment itself. This information helps us better control for differences between subjects.

- **Performance observation tags:**
  Based on the "material experience" model, we divided the observation process into four components: the Sensorial level, which describes the sensory stimulation experienced by the subjects when engaging with the book; the Interpretive level, which captures the subjects' subjective interpretation of the book; the Affective level, which represents the emotional responses of the subjects; and the Performative level, which denotes the behavioral aspects of the subjects. We assigned distinct tags for each of these components to analyze the subjects' performance during the experience.

- **Experience feedback tags:**
  This set of tags is primarily used for data obtained during the interviews. After experiencing both formats, the subjects express their perspectives in the interviews. We further categorized their subjective views into tags related to Affordance, Limitation, Content, Environment, and Usability. This allows for quantitative analysis of the subjects' somatosensory perception of the two experiences.

By organizing the data using these tags, we can utilize the statistical functions provided by ATLAS.ti for analysis. Additionally, we can explore the connections between tags that occur more frequently to identify associations and patterns within the data.
You can find the complete tag collection in Appendix D.

3.6 Result

After conducting statistical analysis on the data using the three categories of tags, several conclusions were derived. These conclusions are as follows:

- **Control variable tags**
  - **The average age of the subjects on Day 1 was 29.7 years. While they did not read books frequently, the majority of them had previous exposure to VR/AR.**

- **The average age of the subjects on Day 2 was 44.2 years. Most of these participants had a habit of reading books, but only a small number of them had previous exposure to VR/AR.**

- **Performance observation tags**
  - **Sensorial level: Subjects expressed a desire for more realistic sensory feedback in VR.**
    Out of the 27 subjects, 14 indicated that the current VR experience lacked certain sensory feedback compared to the physical book, such as the texture of the paper, the sound of page turning, and the tactile and olfactory sensations associated with physical books. While some subjects understood the limitations of current VR technology, they still hoped for a familiar physical experience in the virtual world.

  - **Interpretive level: Subjects made more associations during the VR experience.**
    When experiencing Pop-up books in the virtual world, many subjects had associations with their childhood experiences of reading Pop-up books or even with video games. For example, when experiencing a Pop-up book about garages, one subject thought of her childhood garage. Interestingly, when experiencing the physical Pop-up book, subjects primarily perceived it as a straightforward reading experience without many associations.

  - **Affective level: The emotions experienced by subjects in the VR experience were more complex.**
    When engaged in physical book, participants tended to exhibit relatively straightforward emotional responses, such as "Excitement," "Curiosity," and " Anticipation." However, within the context of VR experiences, due to the presence of a broader range of influencing factors, participants' emotional states became notably more intricate. Alongside the emotions typically associated with experiencing physical books, many participants also expressed mixed feelings of "Confusion," "Awe," and "Boredom" while engaging with VR content.

  - **Affective level: Subjects become "bolder" in VR.**
    Among the 27 participants, 6 individuals specifically mentioned that the intricate structure of Pop-up books could lead to apprehension about potentially damaging the book due to improper handling. However, within the VR context, this concern was substantially alleviated, as they felt more at ease interacting boldly with the virtual Pop-up books.

  - **Performative level: Subjects demonstrated a strong interest in the structure of the Pop-up book.**

Throughout the study, all subjects engaged in the repetitive action of "turning back and forth" pages. They exhibited a desire to thoroughly understand the mechanics and internal structure of the Pop-up books through repeated interactions, whether in physical or virtual form.

- **Performative level: Subjects expected more and clearer interactions.**
  Among the 27 subjects, 15 clearly attempted to find new interactions within the Pop-up book. However, due to the limited number of VR Pop-up book interactions and the complexity of some interactions, many subjects expressed feelings of "loss" when their expected interactions were not present or when they struggled to understand how to interact with the virtual elements.

- **Performative level: Few subjects read the stories from Pop-up books.**
  Out of the 27 subjects, 20 did not read the Pop-up book. Their attention was drawn to other aspects, or they simply did not prioritize reading the story from a children's book in both virtual and real environment.

- **Experience feedback tags:**
  - **The majority of subjects expressed a liking for the enlarged Pop-up books in the virtual world.**
    Among the 27 subjects, 11 expressed a positive affinity towards the sensation of exploration within the magnified Pop-up book. Notably, when presented with a virtual Pop-up book featuring an arch, 4 participants attempted to physically traverse the arch in order to explore its depths. These individuals reported that the enlarged Pop-up book offered them unforeseen delights that captured their interest. The immersive experience of standing within the book or freely moving around it was described as "cool" by these participants.

  - **Many subjects expressed a desire to experience interaction methods in VR that cannot be replicated in reality.**
    "The experience in VR does not necessarily have to restore the Pop-up books in reality. What I expect is what something that I cannot experience in reality." Said by one subject. "In reality, I am afraid of breaking the book, but in VR I can even throw the book away." Similarly, "People like enlarged Pop-up books in VR experience" is actually also an example for this.

  - **Many subjects expressed a wish to share their Pop-up book experiences with others.**
    Whether it was their children or friends, 8 out of the 27 subjects expressed a desire to experience Pop-up books together and share their discoveries. They valued the

social aspect of experiencing and passing on the joy of Pop-up books to others, drawing from their own memories of experiencing with family members.

- **Subjects disliked highly coercive interactions in the VR experience.**
  "The red ball used to remind me to turn the book is very conspicuous, but whether this is really the optimal solution, I am skeptical." There are some mandatory interactions in the current VR experience. For example, you can only hold a specific position to turn a book, and you cannot turn the next page without turning the previous page. Several users have commented on these interactions.

- **The environment was seen as important by a subset of subjects.**
  Out of the 27 subjects, 10 mentioned that the virtual environment had an impact on their overall experience. Some subjects appreciated the quietness of the current virtual environment, which allowed them to focus on the experience. However, others felt that the virtual environment felt too deserted. Never the less, this highlights the significance of creating an appropriate and engaging virtual environment for the experience.

- **Operating VR, especially for older individuals, was seen as challenging.**
  Out of the 27 subjects, 19 encountered difficulties with VR controller operations during the study. The 8 subjects who did not face these issues had prior exposure to VR/AR. This suggests that operating VR can be difficult, particularly for those with less experience, and older individuals may find it more challenging to become proficient in VR interactions.

Chapter 4：

Literature guidance

In this chapter, I will comprehensively expound upon the concept of "immersion" and elve into the various factors that influence the emergence of it based on knowledge gleaned from literature. Furthermore, I will provide a theoretical framework that has the potential to enhance the immersive qualities of VR/AR Pop-up book experiences.

4.1 Literature review

According to the user study data, I can already summarize some experiences that need to be paid attention to when designing a VR/AR Pop-up book. But these experiences are relatively trivial. I need core theories to guide me to improve the immersion of the experience.

The theory needs to answer the following core questions:

- **What is immersion?**
- **Does the sensation elicited while experiencing Pop-up books in VR/AR constitute a feeling of immersion?**
- **How can I create immersion in the Pop-up book VR/AR experience?**

Consequently, following the conclusion of the user study, I embarked on an extensive literature review in an endeavor to address these three inquiries and to identify appropriate theoretical underpinnings to substantiate my design.

4.1.1 What is immersion?

In order to comprehend the concept of immersion, it is important for me to examine three closely related terms used in academic discourse: "Flow", "Cognitive absorption" and " Immersion". These terms encapsulate similar subjective experiences, each offering its own perspective on the phenomenon of immersion.

Hua Qin's paper, titled "Measuring Player Immersion in the Computer Game Narrative," provides a comprehensive overview of existing models that describe these three experiences [40]. The paper presents a table that lists the proposed models, their authors, time of publication, and the perspectives and keywords used to measure the respective feelings. For instance, Brown and Cairns proposed in 2004 that, from a gaming perspective, immersion is determined by factors such as emotional involvement, transportation to different settings, attention, control, and autonomy [40].

Analyzing the keywords mentioned in these models reveals striking similarities among "Flow", " Cognitive absorption" and " Immersion" while also acknowledging the subtle differences between them.

You can find the complete table of existing models in Appendix E.

Charlene Jennett also gave the definitions of "Flow", " Cognitive absorption" and " Immersion" in her paper "Measuring and defining the experience of immersion in games" [41].

- "Flow" is described as the process of optimal experience, "the state in which individuals are so involved in an activity that nothing else seems to matter" when in the flow state

people become so absorbed in their activities that irrelevant thoughts and perceptions are screened out [41].

- "Cognitive absorption" (CA) is described as a state of deep involvement with software. The main goal of CA research is to enrich understanding of user reactions to information technology [41].
- "Immersion"is described as a form of spatio-temporal belonging in the world that is characterized by deep involvement in the present moment. It implies getting away from everyday experience, playing a different role or taking on a new identity [41].

4.1.2 Does VR/AR experience generate immersion?

Charlene Jennett also gives the relationship between the three:

- **Flow is a sense of immersion in extreme situations**
  Immersion is evidently a pre-cursor for flow because that sense of being so involved that nothing else matters is practically a colloquial definition of immersion. However, flow is a particular sort of experience, specifically an optimal and therefore extreme experience. Immersion is not always so extreme. A person can be highly engaged in playing a videogame but still be aware of things like needing to leave the game soon in order to catch a bus or go to a lecture. The player is still immersed in the game to some extent but they are not immersed to the exclusion of all else and therefore not in flow [41].

- **CA theory studies the immersion when people facing information technology**
  A clear distinction between CA and immersion is that CA is an attitude towards information technology in general whereas immersion is the actual experience of a particular occasion of playing a videogame. That is, where immersion asks about similar factors to CA, it does so in regard to a specific instance of playing and unlike CA is not concerned with motivations for playing such as curiosity [41].

Therefore, I can be sure that in VR/AR experience, especially in the VR/AR game, the player's feeling is more inclined to "Immersion". The article sums it up like this: "Immersion clearly has links to the notion of flow and CA and all three use things like temporal dissociation and awareness of surroundings as indicators of high engagement. However, immersion is concerned with the specific, psychological experience of engaging with a computer game." [41]

4.1.3 How to create immersion in VR/AR Pop-up book experience?

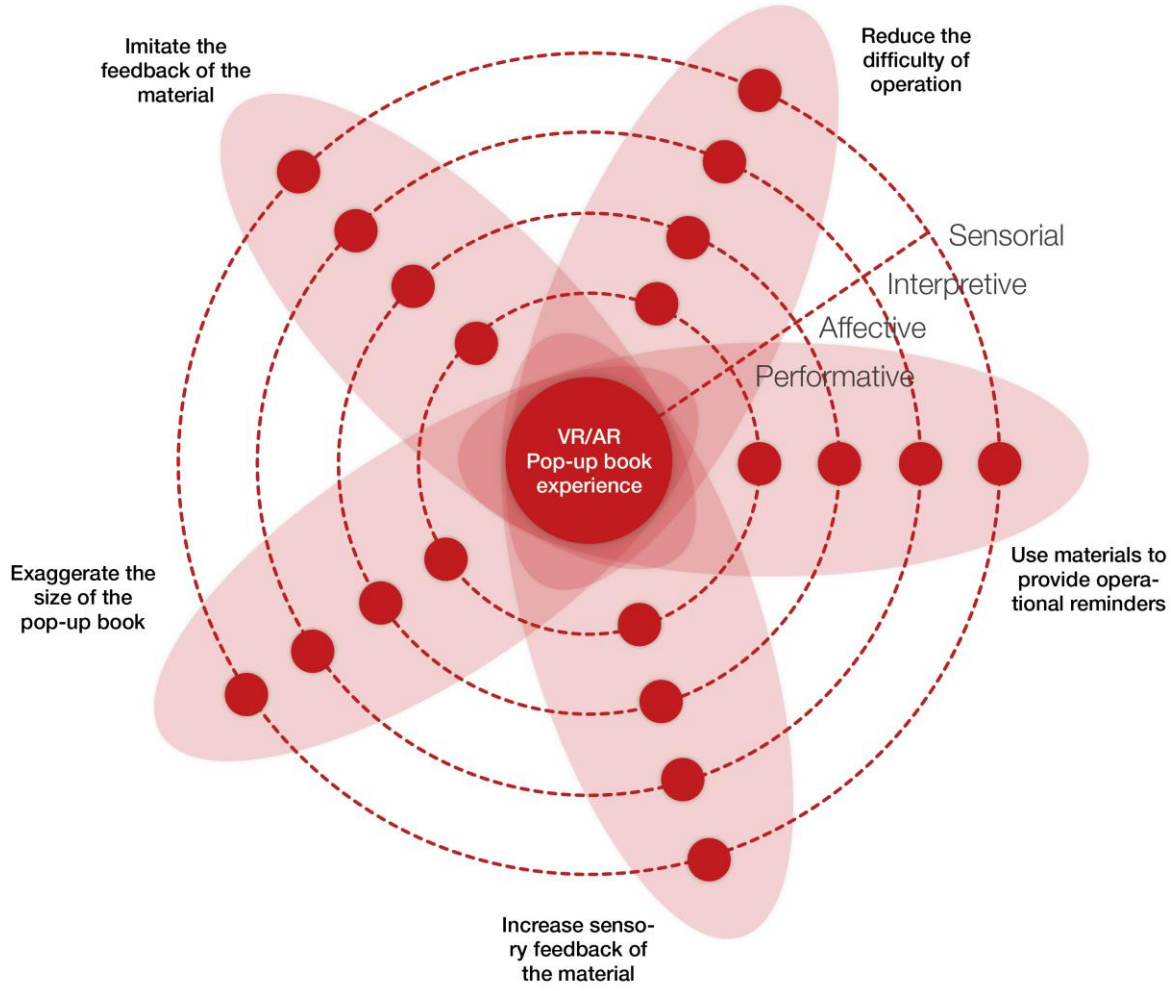

Figure 24：I want to use "Material experience" to measure whether my interaction can bring immersion

PHASE 1: "Material experience" theory

Initially, I intended to incorporate the concept of "Material experience" [31] as a supportive measure for my design. "Material experience" effectively assesses the impact of materials on individuals within the realm of human-computer interaction. I had aspired to extend this notion to encompass the process of human-virtual object interaction, thereby gauging the appeal and advantages associated with such interactions in terms of immersion.

Referring to the model, I have categorized the interaction process into four distinct stages: the Sensorial level, Interpretive level, Affective level, and Performative level (represented by four layers of circles in figure 24). My intention was to devise several interactions that can influence individuals across these four stages, consequently enhancing their sense of immersion (represented by five ovals of different colors in figure 24). For instance, when a user engages with a VR Pop-up book component, they may perceive the vibrations emanating from the handle, thus recognizing the distinct material quality of that specific part. This sensory experience may evoke curiosity, surprise, and a desire to explore other sections offering diverse material characteristics.

However, I soon realized that "Material experience" cannot be fully extrapolated to encompass the realm of virtual reality interaction. For instance, through interviews, it became evident that many users encountered difficulties when initially engaging with VR controllers, which significantly impacted their overall experience. Surprisingly, this effect did not correlate with the Sensorial level or Interpretive level. Furthermore, "Material experience" does not classify experiences as inherently good or bad; rather, it solely describes the degree of impact. Consequently, it fails to discern whether such effects evoke feelings of happiness or disgust. This distinction becomes crucial when considering immersion. If an interaction elicits negative emotions and prompts rejection, it would undoubtedly hinder the user's ability to effectively substitute reality. Consequently, I have relinquished the idea of employing "Material experience" as an explanatory framework for immersion.

PHASE 2: Two related theories of immersion

Subsequently, I started an extensive reading of papers pertaining to immersion. Fortunately, I encountered two highly insightful papers that proved to be immensely beneficial to my project. These two papers further elucidated the essence of "immersion" and provided quantitative methodologies for assessing immersion:

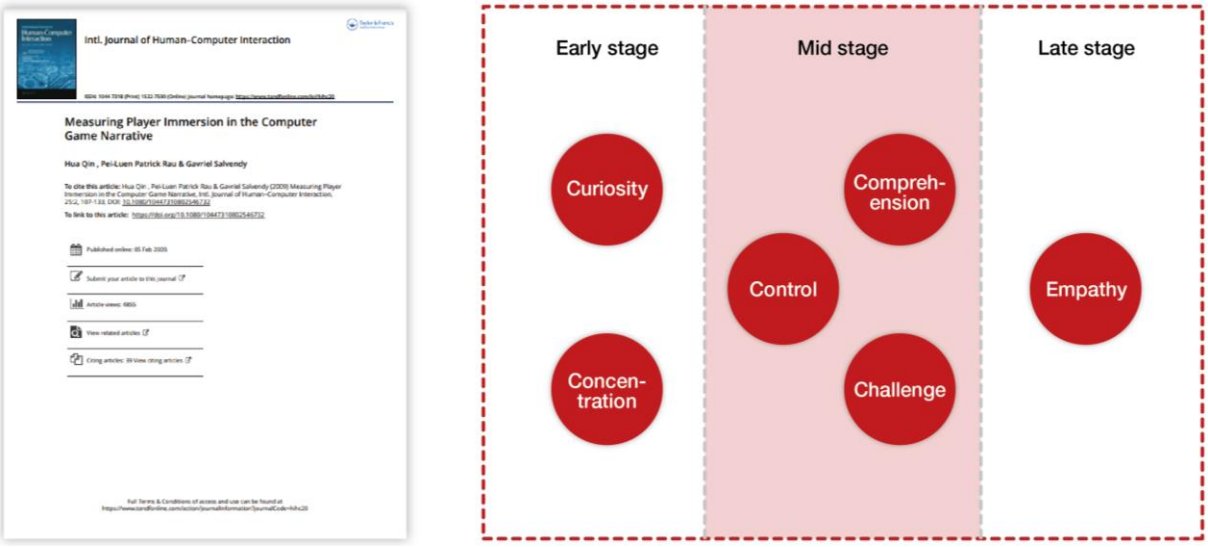

Figure 25：Factors affecting immersion in game narrative proposed by Hua Qin in his paper. [40]

- **Measuring Player Immersion in the Computer Game Narrative**

  In this thesis [40], Hua presents a methodology for enhancing player immersion within the narrative of computer games. Qin proposes that immersion brought about by game narratives can be divided into three distinct stages.

  In the Early stage, immersion is primarily driven by "Curiosity" and "Concentration." By introducing extraordinary events that capture the player's attention and pique their curiosity, the initial sense of immersion is established.

Moving into the Mid stage, players seek to "Comprehend" the game's plot in order to gain "Control" over their in-game avatar. However, to prevent players from easily attaining these two elements, a level of "Challenge" is introduced. Players engage in challenges to acquire a deeper understanding and a sense of control, thereby forming a mid-term immersion experience.

Finally, in the Late stage, players begin to emotionally connect with the plot, with the key factor being their ability to establish "Empathy" with the narrative. This emotional connection and the subsequent thought-provoking experiences are crucial in creating a sense of immersion in the later stage.

Consequently, Hua Qin proposes that the seven variables of "Curiosity," "Concentration," "Comprehension," "Control," "Challenge," and "Empathy" serve as pivotal elements in creating a sense of immersion.

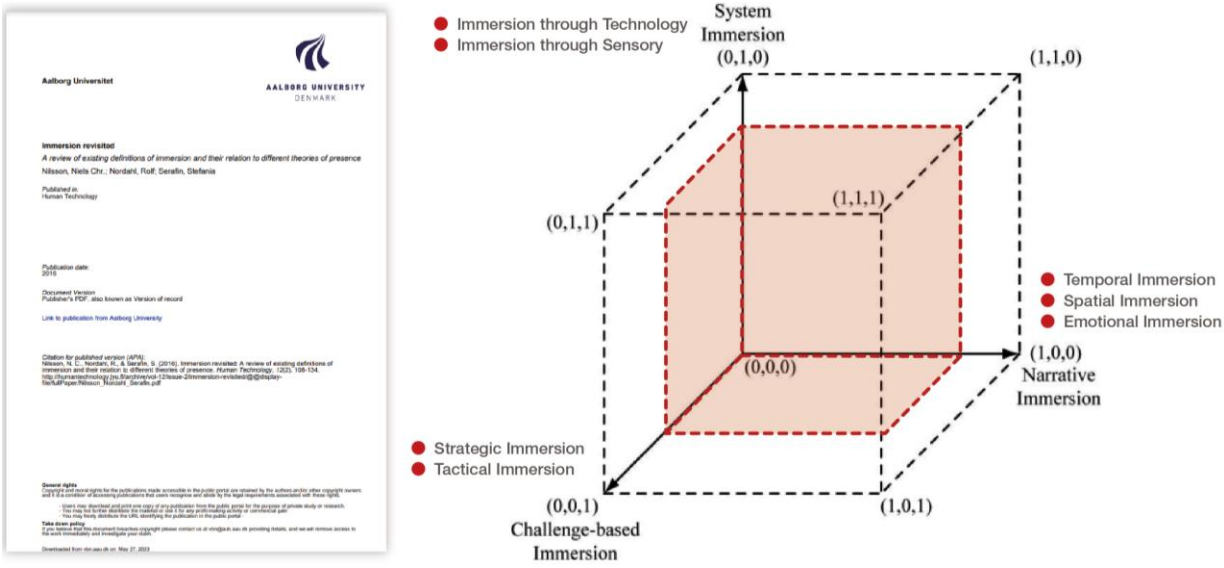

Figure 26: Niels Christian Nilsson summed up the factors that affect immersion with a spatial coordinate. [42]

- **A review of existing definitions of immersion**

  In his paper [42], Niels introduces a classification of immersion into three categories:

  System Immersion:

  This category pertains to the sense of immersion derived from the system itself. It comprises two subcategories: *"Immersion through Technology"* and *"Immersion through Sensory."* The former refers to the immersive experience brought about by the hardware equipped with intelligent systems, such as the visual and auditory impact of a 4K screen. The latter subcategory emphasizes the sensory stimulation offered by the content within a virtual reality experience. For example, the dynamic rhythm and special effects experienced when slicing blocks with lasers in the virtual reality music game "Beat saber" [42].

  Narrative Immersion:

This category encompasses the immersion derived from the content of the experience itself and is further divided into three subcategories. *"Temporal Immersion"* captures the immersion engendered by the narrative progression, prompting questions such as what will transpire next. For instance, the opening of the survival game "Don't starve" [43] in which the player-controlled protagonist is mysteriously transported to a forest in another world elicits curiosity regarding the reason behind it. *"Spatial Immersion"* pertains to the immersion evoked by the environment, as players wonder about hidden elements or areas ahead. Using " Don't starve " as an example again, players can only observe the immediate surroundings from a top-down perspective, with the rest of the area concealed, thus inciting a desire for exploration. Lastly, *"Emotional Immersion"* describes the emotional fluctuations within the experience that resonate with the player, fostering a deep sense of immersion. In " Don't starve," the long winter nights and heavy snowfall can create a feeling of solitude and loneliness near the solitary light source.

Challenge-based Immersion:

This category revolves around the immersion derived from gameplay challenges and is divided into two subcategories: *"Strategic Immersion"* and *"Tactical Immersion."* These subcategories represent the immersive experiences associated with gameplay focusing on intelligence and physical dexterity, respectively. For example, the challenge of finding objects in the book "Where's Waldo" [44] leans toward strategic immersion, while the experience of a fighting game like "Street Fighter" [45] leans more toward tactical immersion.

Nilsson conceptualizes these three types of immersion as axes on a coordinate system, with *"Narrative Immersion"* representing the X-axis, *"System Immersion"* representing the Y-axis, and *"Challenge-based Immersion"* representing the Z-axis. The resulting cube formed by these axes represents the immersive space. Nilsson argues that any given experience corresponds to a specific point within this cube. For instance, the game "Tetris" [46] primarily tests reflexes and spatial imagination, utilizes an electronic screen for presentation, and provides auditory stimulation upon block elimination. However, it lacks narrative, setting, and emotional resonance. Hence, its coordinates within the immersive space can be considered as (0, 1, 1). On the other hand, Fantasy roleplaying games, such as Dungeons and Dragons [47], may be used to illustrate the experience corresponding to the coordinate set (1, 0, 1). Such games need not involve explicit use of technology; players may experience narrative immersion when they assume the role of a character in an unfolding story or in challenge-based immersion due to the mental skills required to tackle the fictional challenges. Therefore, an optimal positioning for the sense of immersion in a virtual experience should be located proximate to the coordinates (1, 1, 1), as illustrated in Figure 26 by the highlighted red section.

These two papers have proven to be invaluable resources in my research endeavors. They effectively address the question of "how to enhance the level of immersion in virtual reality experiences?" and offer a quantitative analysis of the various factors influencing immersion. Furthermore, these papers mutually support one another, as they share several overlapping perspectives. Notably, both works acknowledge the significant impact of "Curiosity" regarding the narrative or environment on the overall sense of immersion, while emphasizing the crucial role of attention guidance in fostering immersion. The introduction of "Challenges" is also highlighted as a means to engage players for prolonged periods and heighten the sense of immersion. However, subtle disparities do exist between the two papers, mainly due to their differing focal points. For instance, the former theoretical model primarily emphasizes narrative elements and overlooks the influence of hardware on immersion. It is my intention to leverage these two models synergistically, capitalizing on their respective strengths, and ultimately consolidate them into a comprehensive theoretical framework.

4.2 Conclusion

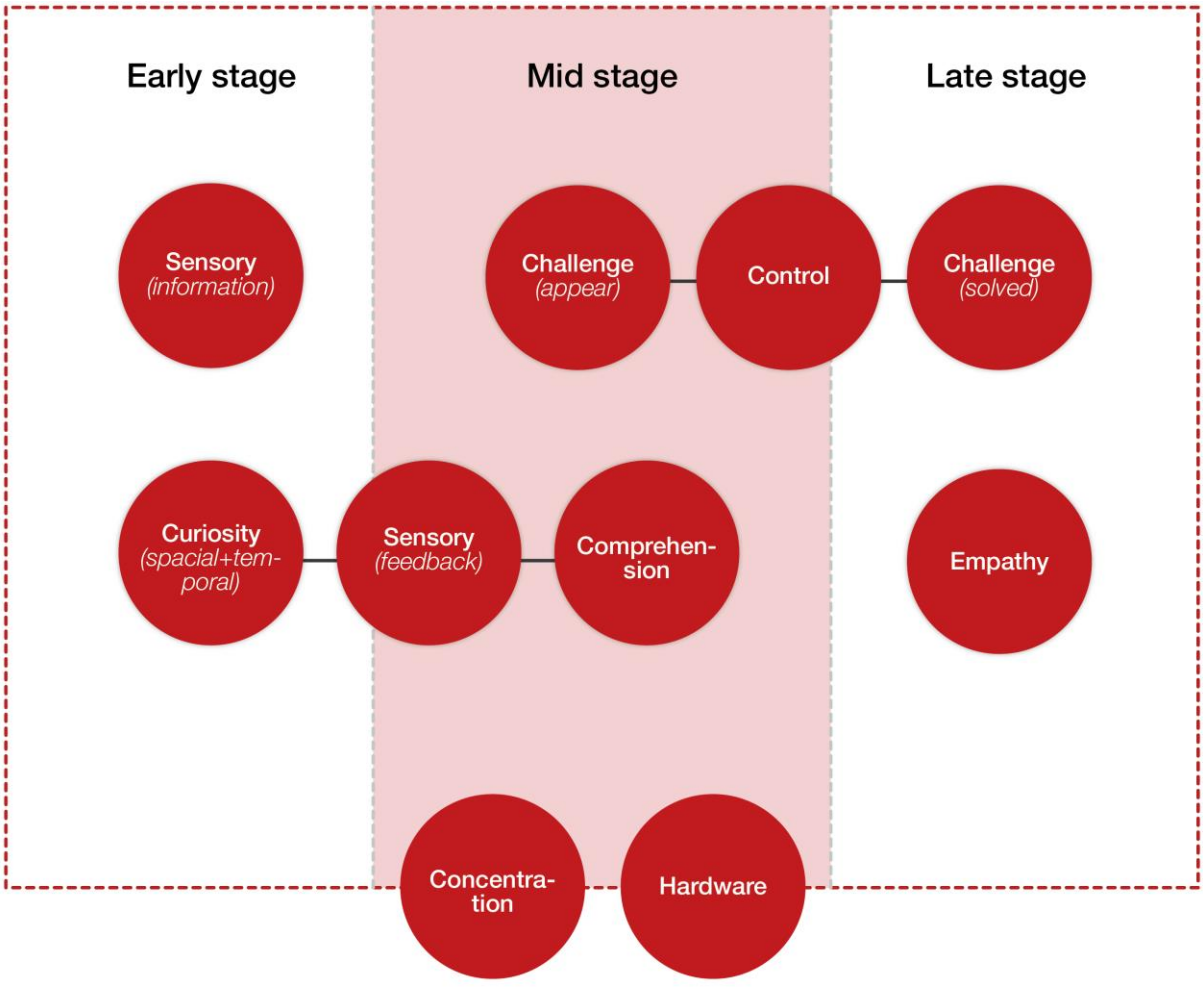

Figure 27: The method I summed up to improve the immersion of the experience

Drawing from the lucidly defined variables and multi-stage factors presented in the initial paper [40], and in conjunction with insights gleaned from the second paper [42], I have synthesized a comprehensive theoretical framework that I believe exerts influence on the immersion of the Pop-up book VR/AR experience:

I also categorized the overall experience into three distinct stages.
During the Early stage, when users initially enter a new virtual environment, they are exposed to "Sensory" stimuli encompassing visual, auditory, and tactile elements. These stimuli evoke a sense of "Curiosity" regarding what will happen next and what is in the surrounding environment.
Consequently, the experience transitions into the Mid stage. Users feel compelled to explore and engage with the new surroundings, gradually acquiring a "Comprehension" through the "Sensory" feedback obtained from their interactions. At this point, a central "Challenge" emerges, which may test the users' cognitive abilities or physical prowess. Drawing upon their existing "Comprehension", users strive to "Control" the situation and successfully overcome the presented challenge.
With the completion of the challenge, the experience proceeds to the Late stage. During this reflective phase, users experience emotional fluctuations and establish a sense of "Empathy" towards particular aspects of the experience, culminating in a lasting impression.

Throughout the entire process, whether it be the elements that pique the user's "Curiosity", the stimulation provided by the "Sensory" aspects, or the "Challenge" encountered, the core objective remains consistent: to "Concentrate" the user's undivided attention throughout the entirety of the experience. Even the subsequent "Empathy" serves the purpose of maintaining the user's focused attention after the experience concludes. This prolonged attention span, in conjunction with the aforementioned factors, collectively engenders a profound sense of immersion for the user throughout the entirety of the experience.
It is worth noting that the influence of "Hardware" on immersion exists within the overall process. However, as it is unrelated to the design aspects under discussion, I will refrain from delving into further details.

4.3 Validation

To validate my theory, I revisited the findings from previous user testing to examine whether they align with my proposed framework. The following conclusions emerged from the analysis:

- **“Subjects expressed a desire for more realistic sensory feedback in VR.”**
  While this expectation may not directly enhance the sense of immersion, it does indicate that the level of “Sensory” realism impacts participants' experiences. It is reasonable to speculate that unrealistic sensory experiences can create inconsistency and diminish the sense of immersion, thereby influencing the overall user experience.

- **“Subjects expected more and clearer interactions.”**
  This observation can be interpreted from two perspectives: "Curiosity" and "Comprehension". Participants sought more interactive elements, driven by their curiosity to receive immediate feedback during exploration. Additionally, they desired clearer interactions to quickly comprehend how the interactions functioned, enabling them to trigger responses accurately.

- **“The majority of subjects expressed a liking for the enlarged Pop-up books in the virtual world.”**
  This finding likely relates to factors such as "Curiosity" and "Concentration". Novel interaction methods, unique experiences, and visually captivating effects attract participants' attention and stimulate their curiosity. If a VR experience perfectly replicated reality, its appeal may diminish as it lacks distinctive features.

- **“Subjects disliked highly coercive interactions in the VR experience.”**
  It appears that most participants desired a sense of "Control" throughout the experience after gaining a certain level of understanding. Imposing mandatory interactions disrupts this desired relationship, forcing users to follow a predetermined path and relinquishing their sense of "Control" over the experience.

- **“The environment was seen as important by a subset of subjects.”**
  As the current VR experiences lack a background story, the impact of *"Temporal immersion"* on the overall experience cannot be ascertained. However, participants' emphasis on the environment provides evidence that *"Spatial immersion"* consistently affects their perception and engagement.

- **“Operating VR, especially for older individuals, was seen as challenging.”**
  The difficulty of VR operations had a direct impact on the user experience, this example highlights how "Hardware" can impact the user experience.

Chapter 5:

Creation

Building upon the conclusions drawn previously, in this chapter, I will engage in a brainstorming session on how to design my VR pop-up book experience. I will approach this from two key dimensions: interaction and environment.

5.1 Book selection

Figure 28：Dutch version of " TIP + TOP Jdi Létat " bookmarked in KB

Having concluded my literature review on "immersion," I am now equipped with the knowledge to start designing my own experience. The foremost question that lies before me is: which Pop-up book should I choose to present?

After careful consideration, I have ultimately chosen the Pop-up book for my project. It is the Dutch version of the Pop-up book "TIP+TOP Jdi Létat," originally designed by Czech artist Vojtěch Kubašta and published in 1964. In Dutch, it is titled "TIP+TOP Boven De Wolken" [48]. "TIP+TOP Boven De Wolken" is a children's Pop-up book that employs humorously engaging language to narrate the adventurous journey of two brothers, TIP and TOP, and their beloved dog, TAP. The story takes them to an aircraft exhibition, where they get to experience piloting various airplanes, culminating in an exciting visit to witness a space shuttle launch.

It is important to note that "TIP+TOP Boven De Wolken" is just one installment in the "TIP+TOP" series of Pop-up books created by Vojtěch Kubašta during the 1960s and 1970s. This series revolves around the adventures of the brothers, presenting a collection of their various escapades. The ingeniously designed Pop-up mechanisms in this series have been translated into numerous languages and have enchanted millions of children worldwide [49].

I selected the book "TIP+TOP Boven De Wolken" for the following reasons:

- The book's structure is relatively simple, with only six pages that can be transformed into a plane when turned 180°. This simplicity makes it convenient to create a virtual version of the book.

- Due to previous consultations with the current rights holder of the "TIP + TOP" series of Pop-up books, KB are allowed to use "TIP + TOP Boven De Wolken" for the project.
- The art style of "TIP + TOP Boven De Wolken" represents the distinctive Pop-up book designs of the 1970s. The color scheme, the Pop-up structures employed, and the content tailored for children effectively capture the essence of older-generation Pop-up book design.
- The copy of "TIP + TOP Boven De Wolken" in KB's collection can no longer be publicly displayed. Therefore, there is an urgent need to create a virtual version of the book to ensure its accessibility to the wider audience.

5.2 Ideation

Having confirmed the selection of the pop-up book, the next step will be to commence the design of my VR/AR pop-up book experience. Building upon the conclusions I have drawn regarding the creation of immersion, I have delineated precise requirements for the design of the experience:

- The experience should immerse users in three distinct stages, corresponding to the Early, Mid, and Late stages identified earlier.
- The experience should positively impact users in various aspects, including "Curiosity", "Sensory", "Comprehension", "Concentration", "Control", "Challenge" and "Empathy".
- The experience should be designed to be completed within a timeframe of 1-2 months, aligning with the available development schedule.

First, I ruled out the possibility of developing an experience with AR. On the one hand, the technical threshold of AR is higher than that of VR, which cannot meet my schedule for completing development within 1-2 months.

In order to better meet these requirements, I divided my design by three stages: "Early stage", "Middle stage" and "Late stage". At the same time, there are two parts to the design points that I need to especially focus on: "Interaction" and "Environment". I will introduce my ideation for the experience from three stages:

5.2.1 Early stage--Interaction

Figure 29：Concept image: Users can zoom out into a pop-up book to explore

- **Scalable Pop-up book size**

  During the initial user study, it was evident that many subjects expressed a strong interest in larger-than-life Pop-up books. They found that these enlarged Pop-up books provided a unique experience and even influenced their behavior. Interestingly, the book used for the test included a Pop-up book adaptation of "Alice in Wonderland." In the story, Alice's shrinking and subsequent exploration of a different perspective transformed the previously mundane world into something strange and captivating. This led me to wonder if the subjects experienced a similar fascination when encountering the enlarged Pop-up book in virtual reality.

  This line of thought prompted me to consider the idea of scaling the size of virtual Pop-up book. In my opinion, this can offer several benefits in terms of immersion. Firstly, an enlarged Pop-up book delivers a powerful visual "Sensory" impact to the user. Secondly, the enlarged size better showcases the intricate structure of the Pop-up book, aiding users' "Comprehension" of its mechanisms. Additionally, an enlarged Pop-up book provides users with a fresh perspective and an expanded space to explore, stimulating their "Curiosity". Lastly, navigating the enlarged Pop-up book may require users to climb for different areas, introducing some "Challenge" to the experience. All of these factors will continuously "Concentrate" user's attention.

  It is apparent that enlarging the Pop-up book enhances five key aspects: "Sensory" "Comprehension" "Curiosity" "Challenge" and "Concentration". All of these aspects contribute to immersion. Therefore, I infer that scaling into Pop-up books can significantly heighten immersion in the virtual reality experience.

My objective is to allow users to experience the sensation of being Alice in Wonderland during VR experience. In the early stage, as users first enter the virtual reality environment, the Pop-up book will initially appear in its regular size. Users will have the option to experience it in the standard manner, but they can also shrink themselves into the Pop-up book to assume a new perspective. This reduced perspective will enable them to navigate through the Pop-up book, jumping among its three-dimensional paper maze.

- **The pop-up process**

  The essence of a Pop-up book, distinguishing it from ordinary books, lies in its ability to unfold into a captivating three-dimensional scene upon opening. This process of unfolding and its intricate structural design are key reasons why many people are drawn to Pop-up books. Therefore, in the VR experience, I aim to faithfully recreate the entire pop-up process of Pop-up book.

  Restoring the opening process of the Pop-up book offers users a significant degree of "Control" over its action. During user study, I frequently observed subjects expressing a desire to understand the structure of specific pages in the Pop-up book. by diligently flipping one page back and forth. In my experience, I want to enable users to have the same level of controlment. They will have the freedom to determine whether each page of the Pop-up book is opened and to what extent. This interactive control complements the scaling interaction mentioned earlier. By combining these two interactions, users can freely explore the Pop-up book from almost any perspective they desire.

5.2.2 Early stage--Environment

Figure 30: Concept image from Art station: wizard in an attic [50]

- **Wizard's attic**

  When creating a virtual reality environment for books, it is crucial to consider an environment that not only provides a suitable atmosphere but also ensures that all interactions make sense within the context of the experience. Merely being in a virtual library where one can freely zoom in and out of their own body and witness three-dimensional forms opening and closing automatically would seem strange and disrupt immersion. Therefore, it is important to establish coherence and rationale in the interactions within the environment.

  In this regard, I find the wizard's attic to be an excellent choice. The attic offers a comfortable and inviting atmosphere, and the existence of magic provides a plausible explanation for the unique interactions that occur, further piquing the "Curiosity" of users to explore this place. Within this setting, users can also better immerse themselves by assuming the role of a wizard and establishing a sense of "Empathy" with the virtual characters they control.

  Therefore, I decide to build the environment as a captivating wizard's attic, with the user assuming the role of the wizard themselves. As the wizards explores the attic, they stumble upon a Pop-up book from the future that captivates their attention with its exquisite craftsmanship. Utilizing their magical abilities, they decide to shrink themselves and delve into the book to uncover its secrets.

- **Comfortable lighting and sound effects**

  An appropriate background narrative is essential; nevertheless, the creation of a comfortable space for users equally demands meticulous design. In this regard, careful consideration must be given to elements such as lighting, shadows, and background sounds within the environment. For instance, the cultivation of a soothing and serene atmosphere may be realized through the introduction of a warm and welcoming stove, accompanied by the light and crackling sound of roasting firewood emanating from within. All these details serve to enrich user's "Sensory" experiences.

- **Realistic material**

  During user study, I received extensive feedback concerning the material aspects of the VR experience. Many participants expressed their perception that the materials within the experience appeared somewhat fake, thereby impeding their sense of immersion. Consequently, I hope to enhance the fidelity of replicating both the materials within the Pop-up book and the overall environment, with the goal of affording users' "Sensory" feedback that closely approximates real-world experiences.

5.2.3 Middle stage—Interaction

Figure 31：Concept image: Users trigger story-telling during exploration and interaction

- **Exploration-triggered story-telling**

  Once the initial excitement of entering the virtual environment subsides, users will naturally attempt to engage with the virtual Pop-up book for interacting purposes. In my perspective, the process of enlarging the Pop-up book transforms the experience into an exhibition-like sightseeing. This scaling process accentuates the three-dimensional space created by the Pop-up book, effectively converting it into an expansive exhibition hall. Within this vast area, users navigate as if strolling through an exhibition hall adorned with captivating displays. These "exhibits" that users encounter while exploring can manifest as paragraphs of the story.

  As users venture into Pop-up book pages in miniature state, specific areas or interactive objects trigger corresponding audio prompts. Through these audio prompts, a narrator recounts a segment of the story relevant to the trigger event. For instance, rotating a propeller may prompt the narrator to describe the protagonist's journey with their siblings aboard a glider. However, the narration only unveils a portion of the overall narrative. To hear the complete story, users must seek out all the hidden interactive elements within the Pop-up book. This presents users with a "Challenge" in the middle stage, fueled by their "Curiosity" about the interaction and the story. The challenge lies in comprehending the entire space and discovering appropriate means of accessing various locations. The reward is the sense of accomplishment derived from experiencing the complete storyline. This persistent challenge effectively maintains users' unwavering "Concentration" and empowers them with greater "Control" over the entire scene.

Of course, users also have the option to experience the Pop-up book at a normal scale, without the accompanying interactions and narration. This design choice recognizes that individuals who choose to experience the Pop-up book conventionally may not be driven by curiosity alone, but instead seek a tranquil environment to quietly enjoy the Pop-up book.

- **Exploration-triggered interaction**

  In addition to incorporating story fragments as "exhibits" within the Pop-up book "exhibition hall," it is also possible to introduce engaging interactions. In reality, the interactive elements in "TIP + TOP Boven De Wolken" extend beyond mere opening and closing, featuring tabs and carousels that users can manipulate. Preserving and enhancing these interactions in the VR is also a worthwhile endeavor.

  Consider this scenario: as the player roams through the giant Pop-up book, they suddenly ponder, "Hmm, maybe I can pull this character." Driven by curiosity, they give it a try and are pleasantly surprised to witness the moving, accompanied by a change in the character's expression. The character appears somewhat startled, as if questioning, "Why are you pulling me?" This immediate feedback significantly enhances the user's sense of embodiment and serves as an instant reward for their exploration.

5.2.4 Late stage—Interaction

- **Pop-up book recommendation in reality**

  As the user progresses through the virtual Pop-up book experience, they eventually reach the late stage. At this juncture, creating a sense of immersion can be best achieved by establishing a connection between the virtual world and the real-world experience, thereby evoking a powerful sense of "Empathy."

  Imagine this scenario: after exploring the Pop-up book in a miniature virtual reality setting, the user removes their VR glasses and gazes upon the physical book from a normal perspective. In that moment, they may experience a profound feeling of revisiting a familiar place. Consequently, this shift in perspective prompts them to develop a deeper understanding and appreciation of the Pop-up book, viewing it through a fresh lens.

  Therefore, I decide to incorporate a recommendation at the end of the VR experience, encouraging users to explore the physical version of the Pop-up book (provided the paper quality allows). This recommendation serves as an invitation for users to re-examine the Pop-up book from this newfound perspective. Furthermore, it may even inspire users to revisit the VR version, with their newfound knowledge and perspective.

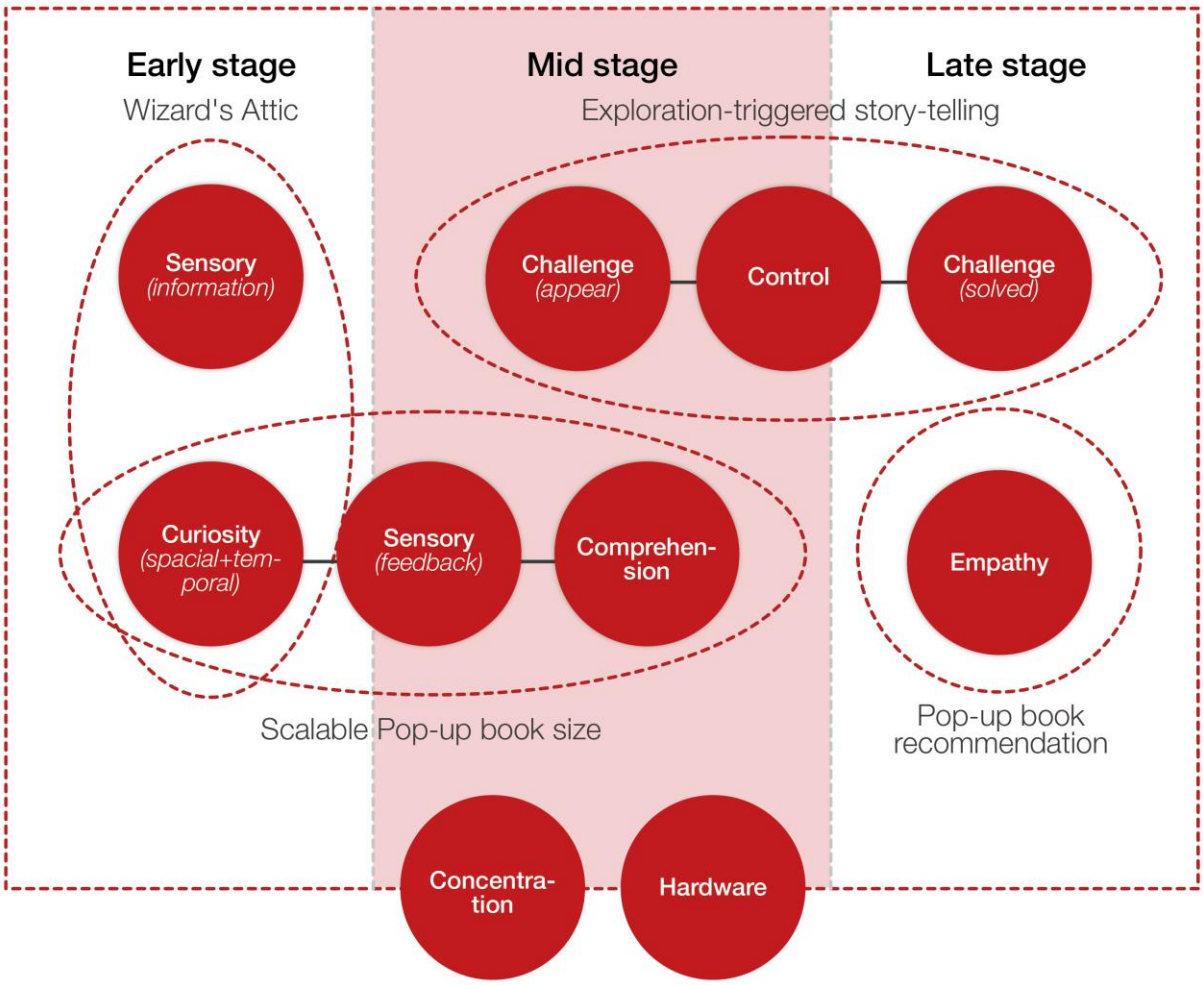

Figure 32: Relationship between interaction/environment and factors affecting immersion

Based on the previous conclusions, I believe that different factors influence immersion at different stages of the experience. Enhancing immersion necessitates the coordinated interaction of multiple factors at different stages. Consequently, immersion requires a harmonious cooperation between the environment and various interactions at different stages.

In an ideal scenario, the "Wizard's Attic environment " would impact users' "Sensory" perception in the early stage. Also, "Scalable Pop-up book size" would pique users' "Curiosity" and encourage exploration in this stage. "Exploration-triggered story-telling" would pose the primary "Challenge" for users during the middle stage. Lastly, "Pop-up book recommendation in reality" would extend the experience into reality during the final stage through "Empathy." These elements effectively span the entire experience, continually "Concentrating" the user's attention to enhance immersion.

Chapter 6:

Embodiment

After finalizing the design concept, in this chapter, I will provide a detailed exposition of how I proceeded to create the VR pop-up book experience.

6.1 Texture acquisition

Figure 33: Taking pictures of the front of "TIP+TOP Boven De Wolken"

With the ideation part finished, the focal point of my work now shifts to the realization of these conceptual ideas.

I began by obtaining the pattern of the selected Pop-up book. Me and another student, accompanied by my chair, visited KB where we had the opportunity to examine the "TIP+TOP Boven De Wolken". Initially, our plan involved placing the book in a professional studio and capturing photographs of each page from three angles: front view, top view, and side view against a white background. Once we determined the camera focal length, the photos were imported into Adobe Photoshop [51] for post-processing.

In Photoshop, I utilized the keying function to extract the unobstructed portions of the Pop-up book, and for occluded parts, I employed the deformation function along with images from alternate perspectives to restore their appearance. This meticulous process allowed me to obtain the pattern of each section of "TIP+TOP Boven De Wolken". Given the unique structure of the book, most sections could be flattened to form a plane, with only a few parts remaining three-dimensional. As a result, I assembled the pattern like a jigsaw puzzle, ultimately obtaining a flat image of the first page of "TIP+TOP Boven De Wolken".

However, several issues arose with this method. Firstly, the post-processing in Photoshop was time-consuming, particularly when it came to deforming and restoring occluded parts using images from other perspectives. Flattening the entire first page alone took approximately 25-30 hours. Secondly, the completed flat image did not exhibit optimal Pop-up functionality. The use of deformation tools during the production process resulted in size alterations in various structures, which caused the Pop-up book to fail to open properly. Additionally, despite using a white background, there remained a noticeable color discrepancy between the photographed Pop-up book and the real-life version due to

exposure variations. Collectively, these challenges compelled me to seek alternative and more effective approaches.

Figure 34: The difference between the patterns obtained by the two methods

Fortunately, my chair acquired another copy of "TIP+TOP Boven De Wolken" online. This time, I attempted to obtain the image through scanning. I flattened the Pop-up book, removed any excess parts, and placed it in a printer for scanning. The results were significantly improved, with only slight distortion in the image, which could be rectified through simple adjustments in Photoshop. The color difference between the scanned image and the actual three-dimensional book was minimal, and the production time was reduced from 25 hours per page to 2 hours per page.

However, this solution also had a significant drawback. Placing the Pop-up book flat into the printer caused irreversible damage to the newly acquired "TIP+TOP Boven De Wolken". Furthermore, not all Pop-up books can be flattened into a two-dimensional plane, especially those designed to be fully open at a 180° angle. Consequently, this approach is unsuitable for certain Pop-up books and may cause irreparable harm to them, contradicting our initial intention of preserving and protecting these books.

In conclusion, although I ultimately resorted to the faster scanning solution, it is not universally applicable. If we intend to create more virtual Pop-up books in the future, we should opt for the initial, more time-consuming method that preserves the integrity of the Pop-up books without causing any harm.

6.2 Modeling

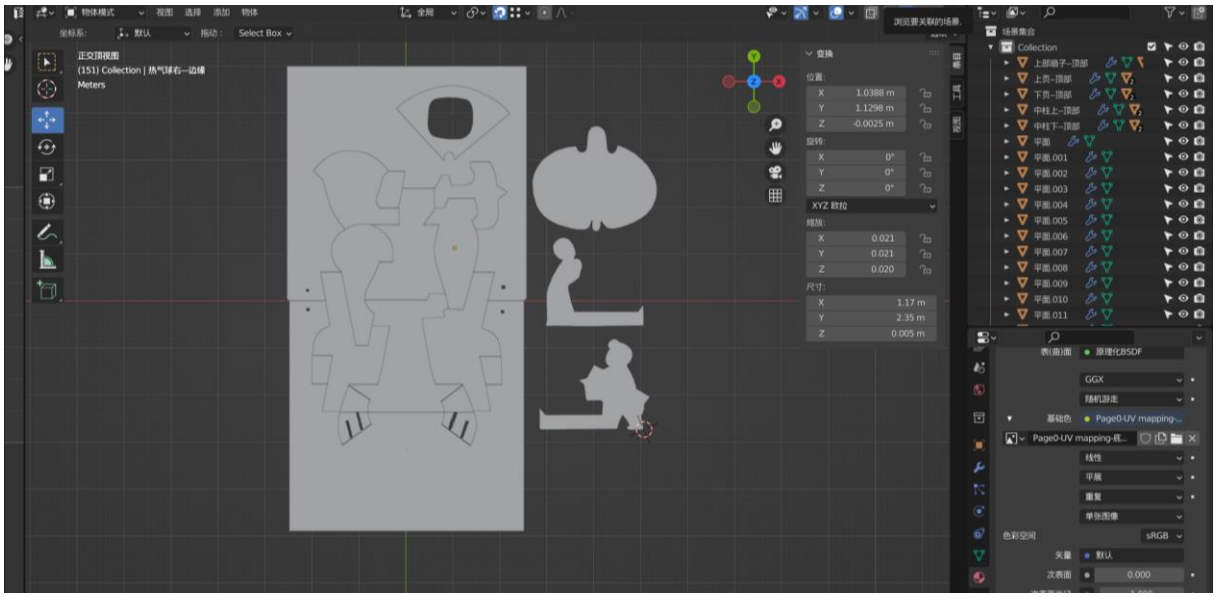

Figure 35: Outline the shape of each part according to the Pop-up book

After obtaining the pattern for the Pop-up book, I start to model it using Blender. Based on the structure of the Pop-up book's components, I initially outlined each part in Blender. To facilitate future material assignment, I separated each part into surface, bottom, and edge components. Additionally, I incorporated short links between all the parts to emulate the paper folds that occur when the book is folded.

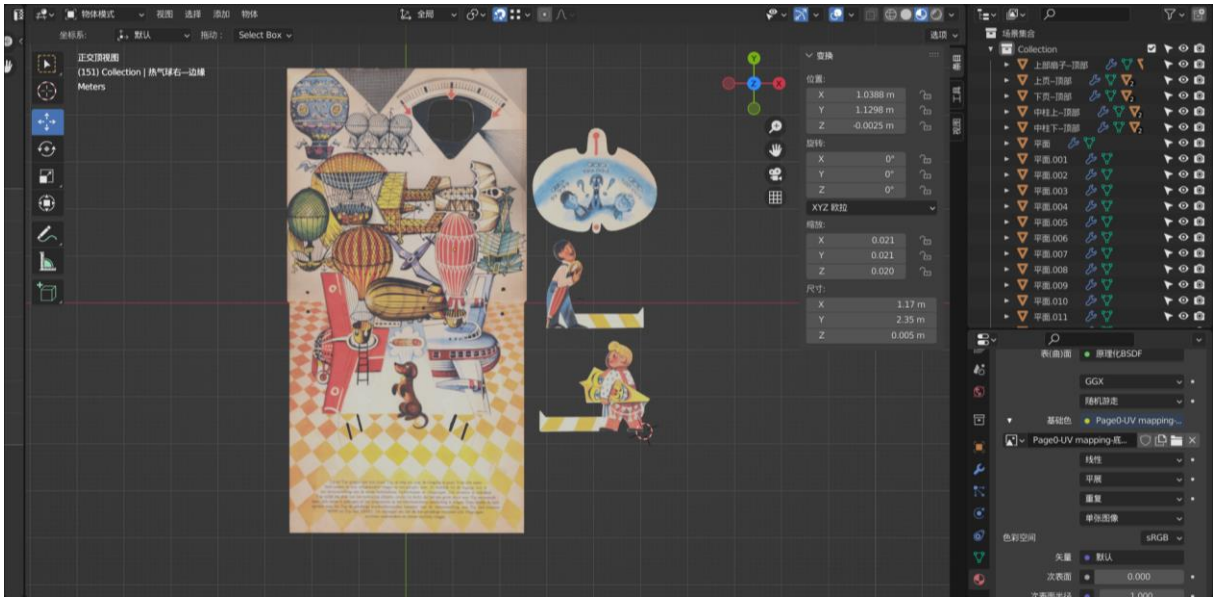

Figure 36: Organize the model UV and make the textures

Once the model was constructed, I proceeded to assign textures to the surfaces. The image obtained from the previous scan was used as the color texture for the surface of each part. Then I assign light-colored paper to the "Color" channel of the texture for the edges, and assign dark-colored paper for the bottom. Subsequently, I apply an image with a paper-

like texture to the "Bump" and "Height" channels. In this manner, the material for the Pop-up book model has been successfully created.

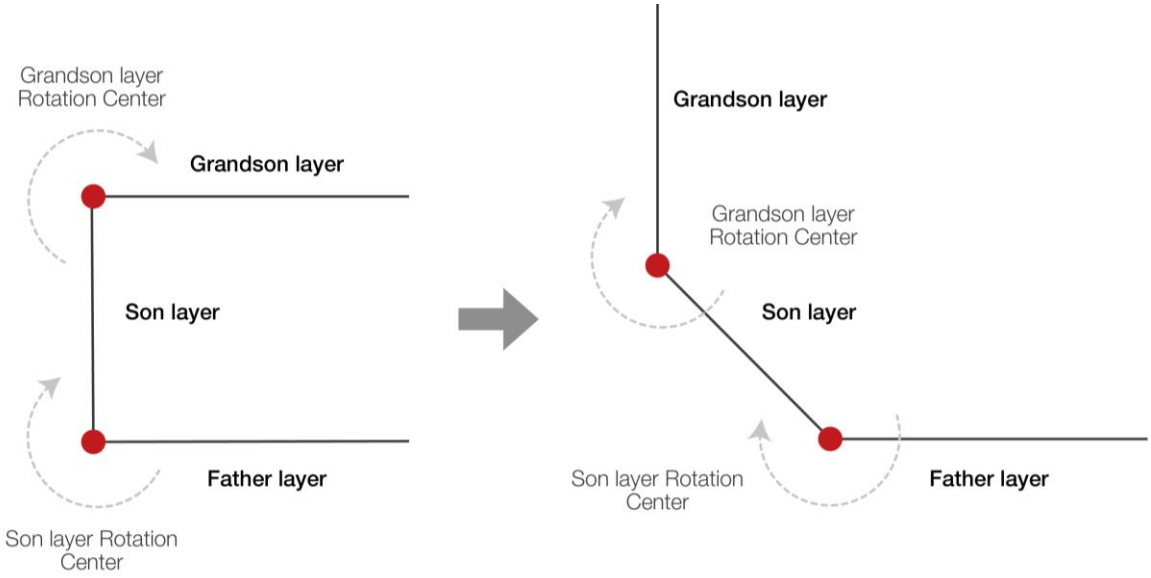

Figure 37: What is the parent layer relationship?

Lastly, I needed to address the "skeleton" to enable the opening and closing movements of the Pop-up book. This involved determining the rotation points of each component and their parent layers. By defining these rotation points and establishing parent-child relationships, I could control the axis of rotation for each part, its parent axis, and the angle of rotation. This, in turn, determined the path of rotation for all the components.

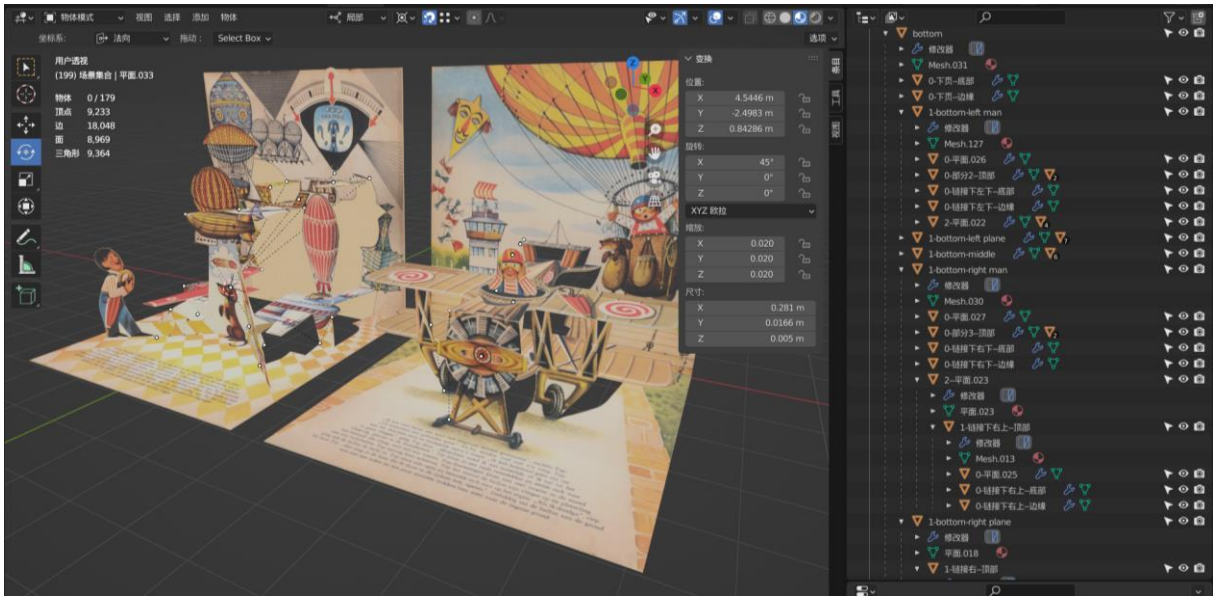

Figure 38: Determine the "skeleton" of the Pop-up book through the parent layer relationship

Following the logic of the opening and closing movements, I organized the relationships between all the rotation points and parent layers. During this process, I encountered two noteworthy observations:

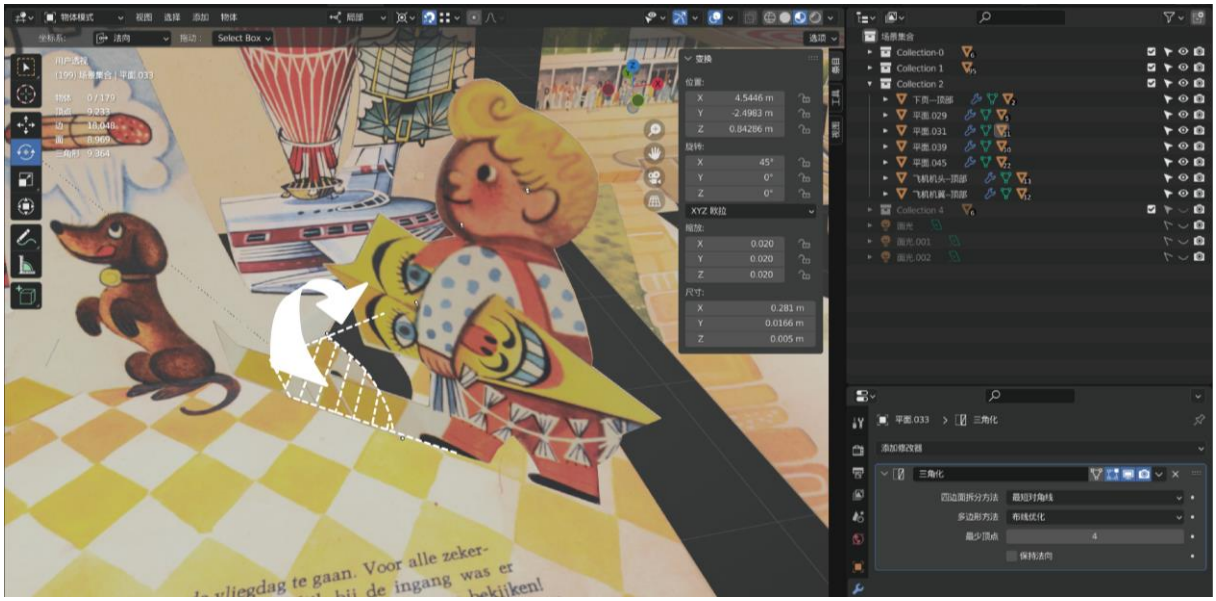

Figure 39: The parts marked in the figure do not rotate in the normal X circle.

- Some structures did not rotate around the normal X-axis. In such cases, it was crucial to determine both the rotation point and the rotation axis within Blender.
- Each subset of objects consisted of three types: one that moves with the parent layer, one that rotates X degrees further than the parent layer's direction, and one that rotates X degrees in the opposite direction of the parent layer. I denoted them with 0, 1, and 2 in their names. This naming convention simplified subsequent interactive production.

6.3 Environment building

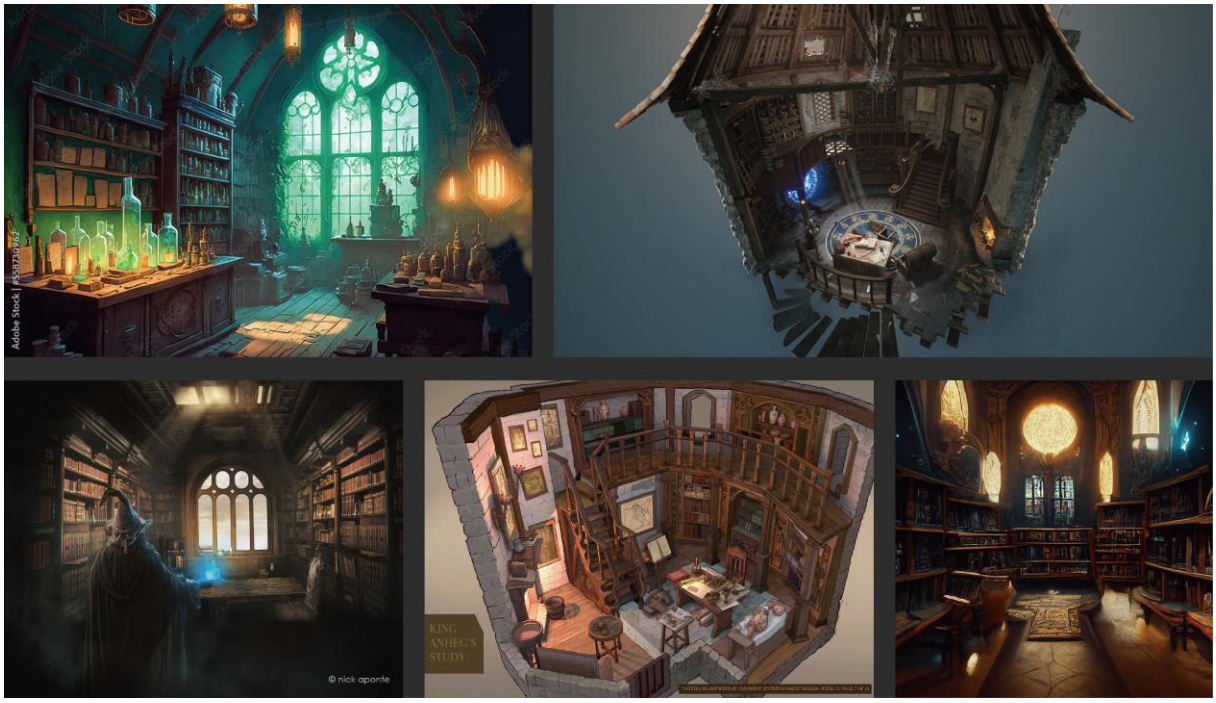

Figure 40: My reference when designing an experiential environment

After completing the model, I then began to create the environment. I conducted online research to gather references for "Wizard's Attic." By collecting and analyzing these pictures, I gained a general understanding of the attic's layout and the style of the interior.

Given that the image of wizards originated from Celtic mythology in 8th century and was later popularized through the character of Merlin in the legends of King Arthur in Wales during the 12th century [52], I set the location of the attic in the British Isles during the 9th centuries. During this period, the architectural style of the British Isles was significantly influenced by the Vikings, resulting in a rustic pragmatism while still showcasing recognizable features such as "stone wall towers" and "wooden carving decorations." [53]

Figure 41: The attic is in octagonal shape

In Rhinoceros, I modeled the attic as an octagon, with brick walls reinforced by wooden pilings at the corners. Most of the furniture was crafted from wood, including bookcases, ladders, and chairs, while a few pieces incorporated metal elements. The primary light sources were candles and torches. Additionally, I added magical decorations such as crystals, decanters, hourglasses, and wizard hats. The combination of these elements established the overall ambiance of the attic.

On the southern side of the attic, I included an abundance of bookcases and books to contribute to the reading atmosphere. In the center of the room, I placed a table where users could peruse the Pop-up books. This area served as the core of the entire loft and required special attention during the modeling and texturing process.

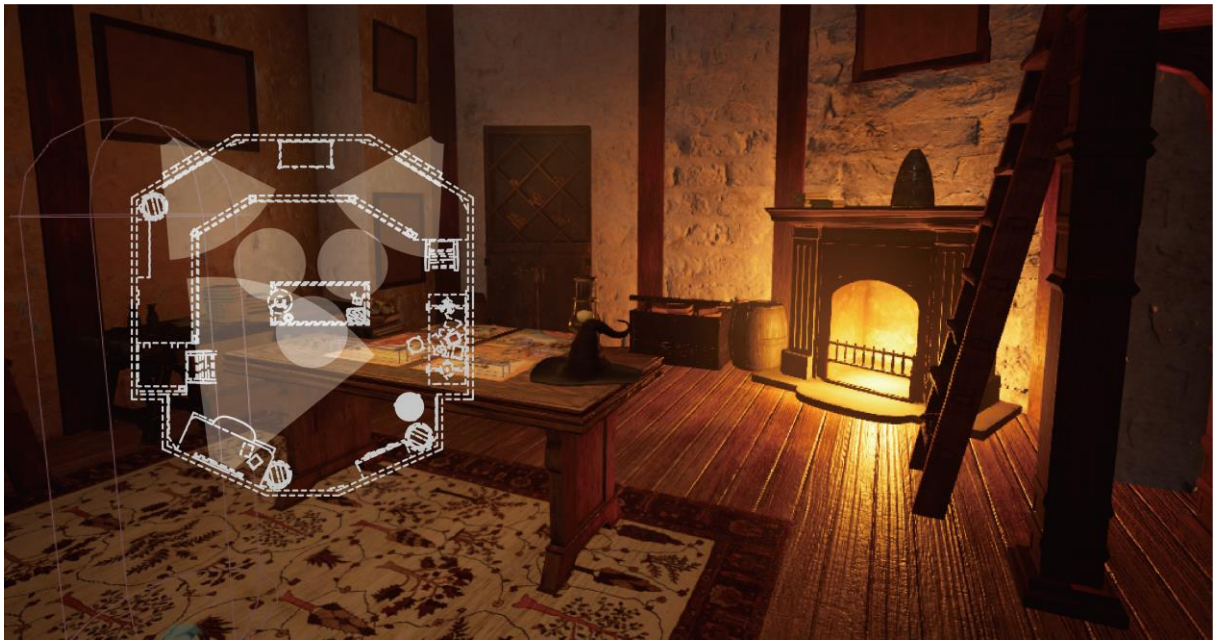

Figure 42: Final environment design and lighting

With the layout of the environment finalized, I proceeded to import the model into Blender, where I edited its UV and then utilized Adobe Substance 3D Painter to draw textures. Finally, these models were imported into Unreal Engine [54] for final processing.

In Unreal Engine, I focused on designing the lighting for the environment. To create a warm and cozy home-like atmosphere, I incorporated a cool-colored sky light during nighttime and utilized strong warm-colored firelight to illuminate the interior, thereby creating a visual contrast. To soften the lighting, I added volumetric fog to the scene, allowing the fog to refract the light and fill the entire space. The table served as the focal point of the environment, as a result, I deliberately reduced the lighting in the surrounding areas, relying mainly on candlelight to outline the general shapes of the furniture. However, I included multiple light sources to illuminate the volumetric fog, accentuating the centrality of the table within the overall experience.

Furthermore, I incorporated numerous soundscapes within the scene. Within the attic, users can hear the nocturnal chirping of insects, while proximity to the hearth affords them the auditory experience of crackling firewood. Additionally, in the vicinity of Pop-up book, users are treated to music that is thematically tied to the narrative, with the music dynamically shifting in tandem with different pages.

6.4 Interaction making

After setting up the environment, I imported the previously created Pop-up book model into Unreal Engine. Then utilizing Unreal Engine's built-in programming language to implement the envisioned interactions.

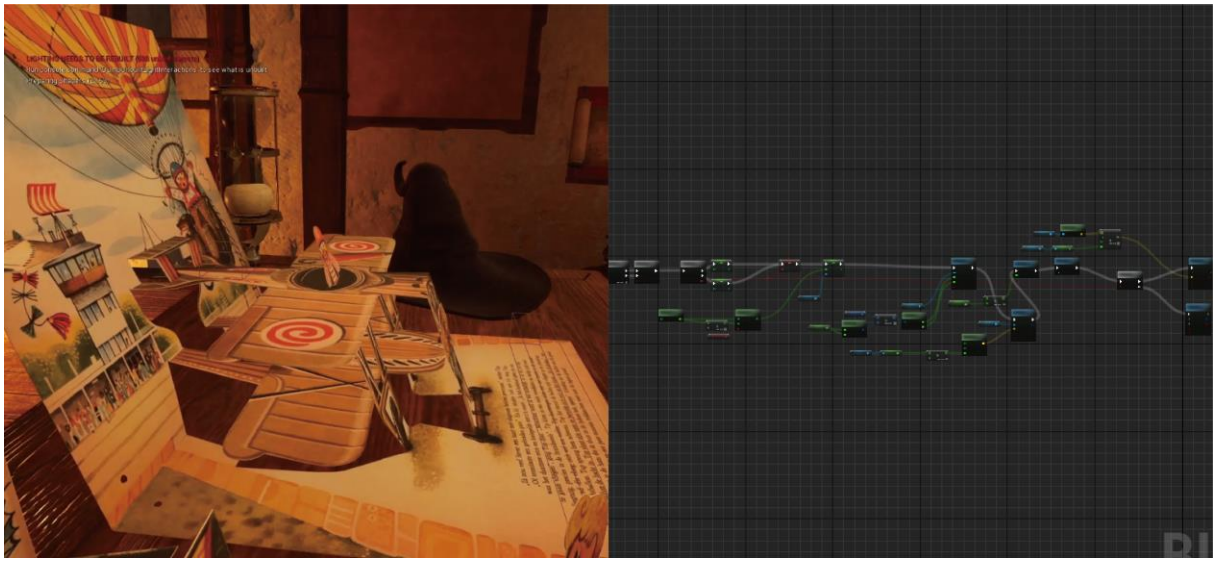

Figure 43: Code to implement scaling of Pop-up book size

- **Interaction: Scalable Pop-up book size**

  Scaling the dimensions is relatively straightforward; it merely involves uniformly enlarging all objects except for the camera representing the user's perspective. and adjusting to the properties of the camera, such as movement speed and jump height.

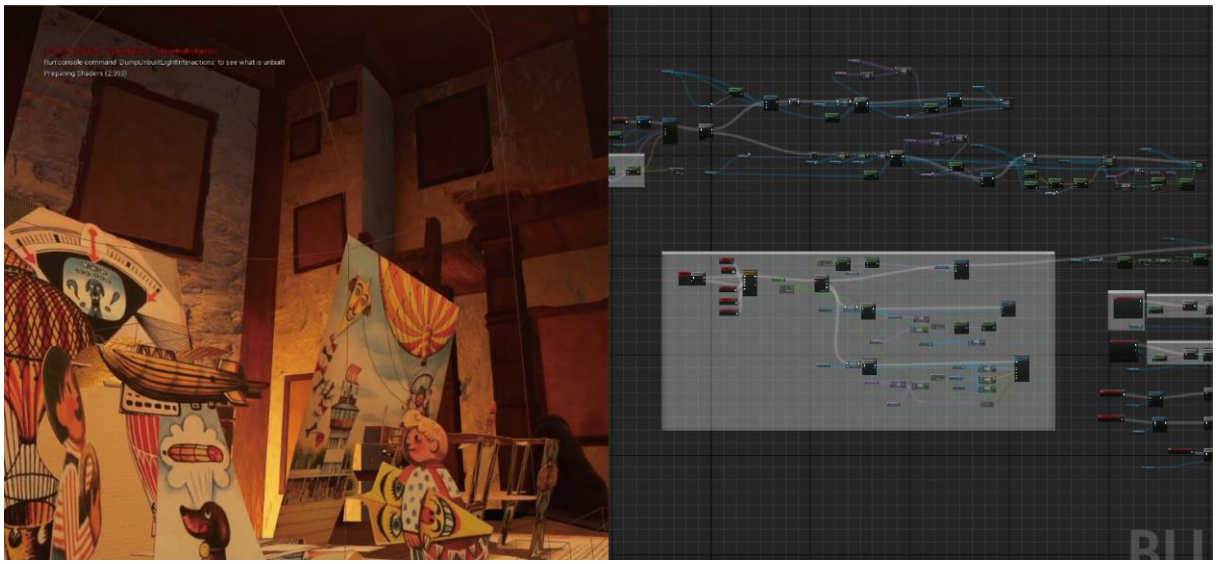

Figure 44: Code to implement the pop-up process

- **Interaction: The pop-up process**

  Since I have already established the hierarchical relationships and rotation axes for the components during modeling, achieving the pop-up effect only requires inputting an angle Y via the VR controller and applying this angle calculation to each component. During the page-turning process, there are only three possible calculation methods: Y is equal to 0 (moves with the parent layer), Y (rotates Y degrees further than the parent layer's direction), and -Y (rotates Y degrees in the opposite direction of the parent layer).

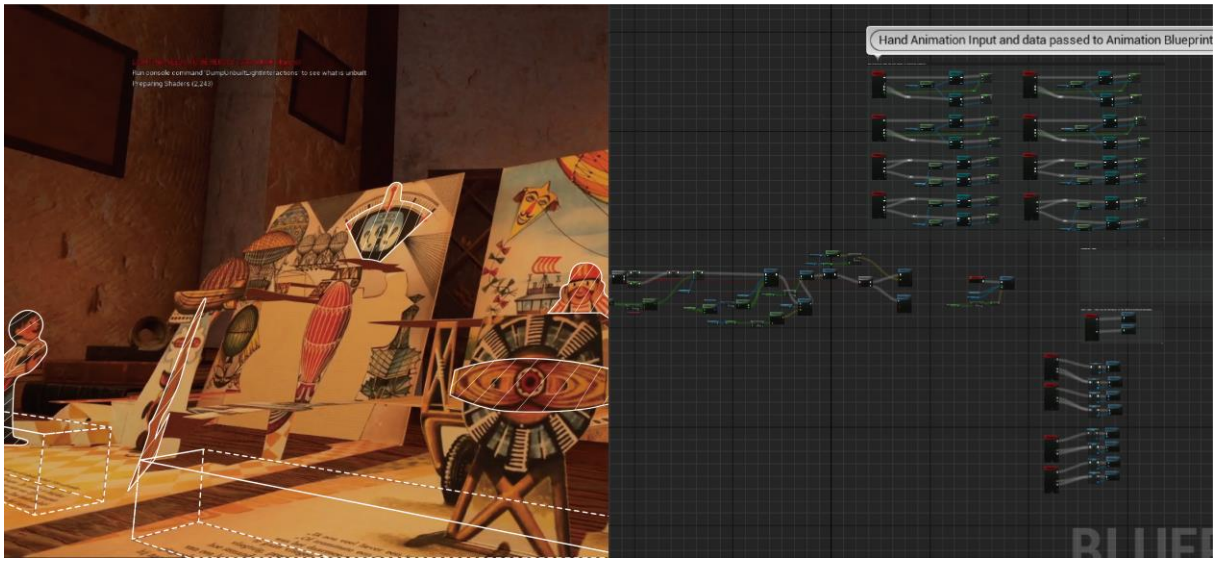

Figure 45: Code to implement the story-telling

- **Interaction: Exploration-triggered story-telling**
  For the storytelling component, I began by translating the story of "TIP+TOP Boven De Wolken" into English, breaking the English version into smaller segments, and then had my friend record the voice narration. Subsequently, I strategically placed the interactions that trigger these story segments throughout the Pop-up book.
  You can find the English version of the story separated by its voice actor in Appendix F.

6.5 Iteration

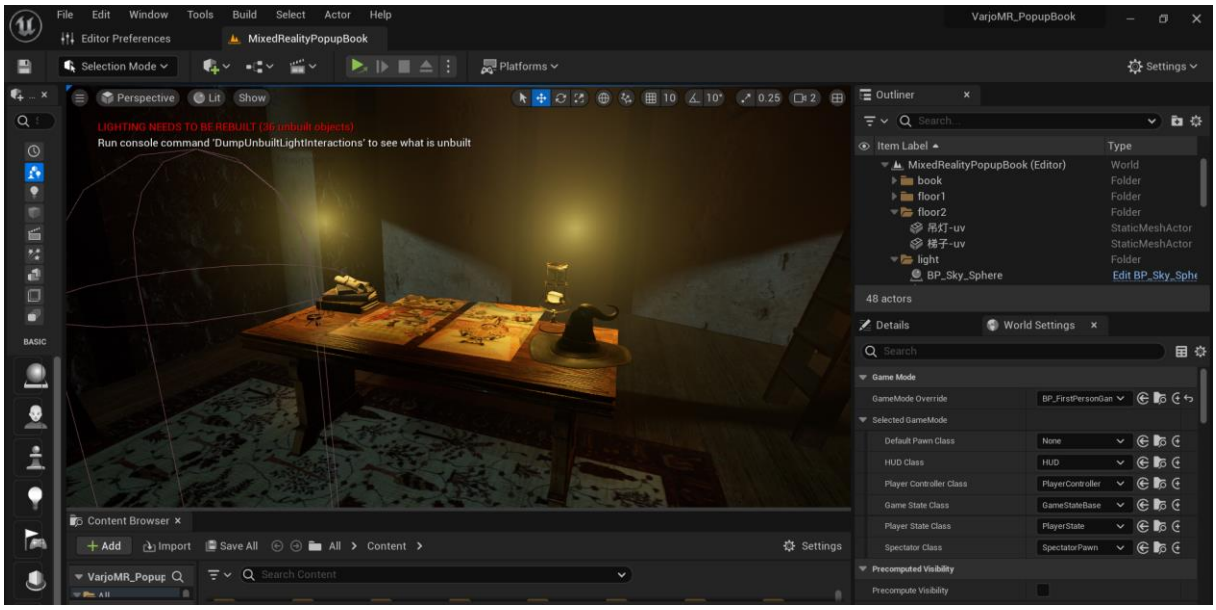

Figure 46: The layout and lighting of Version X at that time

During the development phase, I made the decision to conduct a user test in order to validate whether my design for interaction and environment could indeed provide users

with the level of immersion I had envisioned. Simultaneously, to collect feedback from participants to facilitate further improvements. I will then refer to the version used in user test as "Version X." In Version X, the arrangement of furniture and lighting differs from the final version, with interaction limited to opening and closing the Pop-up book and scaling user's size. There has not yet implemented any audio elements in Version X also.

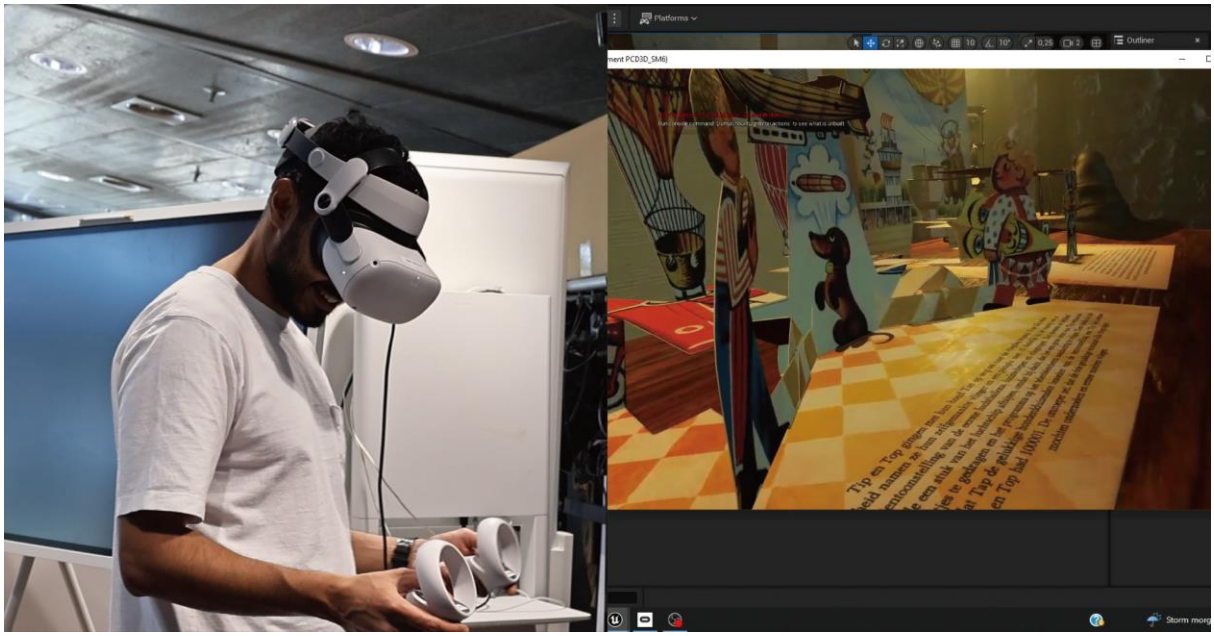

Figure 47: I analyze behavior of the test subjects through reality and VR

The experimental process unfolds as follows: I will begin by guiding participants through Version X of the experience while observing their behavior and understanding their immediate thoughts. Following the completion of the test, I will conduct a brief interview. The primary objectives of the interview are to gauge whether participants felt a sense of immersion during the experience, what they believe contributed to it, and whether they have any suggestions on enhancing immersion.

A total of 8 subjects participated in the test. After the test, I collected videos of each subject's experience, screen recordings of the VR process, and recordings of the post-test interviews. I analyzed these data based on my core conclusions, focusing on seven aspects: "Sensory," "Curiosity," "Concentration," "Comprehension," "Control," "Challenge," and "Empathy." The analysis considered the participants' performance during the test and their subjective thoughts expressed during the interviews. If a subject's performance or thoughts related to any of these aspects, I recorded them under the corresponding category. Finally, I summarized the take-away feedback for each aspect:

Sensory

- Many people mentioned that the whole environment and lighting are very realistic.
- Many people mentioned that the upward viewing angle brings a strong visual impact.

- Many people mentioned a lack of auditory stimulation. They felt that adding sound effects would help them increase their immersion.

Curiosity

- Increasing the size of Pop-up book does generate curiosity. The larger Pop-up book evokes curiosity about the heights and the internal structures within the book, as well as possible interactions with certain components.
- Curiosity about the story has been overlooked. It turns out that 50% of the participants expressed curiosity about the story. Several participants mentioned the desire to combine interaction with storytelling.
- Many of the participants' behaviors can be interpreted as follows: "I wonder if I can do this" - "I expect certain feedback if I do this" - "I would be happy if that feedback occurs."

Concentration

- Curiosity alone is not sufficient to concentrate people's attention. After the initial curiosity wears off upon entering the experience, some participants quickly lost their focused attention due to the absence of other interactive elements.

Comprehension

- The smaller size does allow people to see more detail, increasing their understanding of the Pop-up book.

Control

- People have an expectation of having control over most elements within the scene. For example, when they see a propeller, they expect to be able to rotate it.
- People also desire control over their own actions. Initially, I fixed the position of scaling to a specific point. However, this resulted in users feeling a loss of control. During the testing, they expressed a desire to shrink wherever they pressed the shrink button.

Challenge

- Challenge is a core aspect that I overlooked. People need a goal to strive for and to experience a sense of achievement. Often, users set their own goals in the initial stages of exploration. For example, players who enjoy exploration might subconsciously view finding all the hidden interactions as a challenge, while those who enjoy physical activity might see climbing to the highest point as a challenge. Therefore, instead of explicitly telling players what challenges to undertake, the focus should be on providing satisfying rewards after completing these challenges.

- Although it's not necessary to impose challenges on players, it can be helpful to provide subtle hints. Some users may struggle to set goals for themselves, so providing gentle guidance can be beneficial.

Empathy

- Having a cohesive story and setting does indeed enhance people's sense of immersion.
- Many participants mentioned that the current environment evoked a feeling of abandonment, and they expressed a desire for a warmer and more joyful atmosphere.
- Participants expressed a desire for joy and surprise in their interactions, as well as a sense of satisfaction upon achieving certain goals.

Overall, the subjects found version X to provide a high sense of immersion. The Scalable Pop-up book size contributed to immersion in the aspects of "Sensory," "Comprehension," and "Curiosity," although there was a slight lack in "Concentration" and "Challenge." This highlights the importance of incorporating the "Exploration-triggered story-telling" to address these areas. By combining these interactions, more challenges can be introduced and immediate feedback can be provided to sustain user focus. The two interactions complement each other and are crucial in creating a sense of immersion.
Regarding the environment, the current design contributed to immersion in terms of "Sensory" and "Empathy," but there is still room for further development. Enhancements such as adding auditory stimulation and creating a warmer atmosphere through the environment can enhance immersion.
Based on these findings, the design direction for immersion appears to be on the right track, and the core theory has been proven effective in improving user immersion. Development can continue along the current line of thought. Within the week following the test, I successfully completed the development of the exploration-triggered story-telling interaction and further optimized the environment, leading to the final state.

6.6 Final result

After going through brainstorming, conceptual design, model creation, programming, user testing, and several iterations, spanning a development period of three months, I ultimately completed my VR Pop-up book experience. Below are some screenshots from it:

Figure 48：Screenshots of my final version of the VR Pop-up book experience

Chapter 7：

Final user test

With the experience production completed, it is now time for the final testing phase. In this chapter, I will elucidate the process and outcomes of the user test, aiming to ascertain whether I have successfully met the objectives established at the outset of the project.

7.1 Purpose

With the final version of the VR Pop-up book experience now complete, it is time to evaluate whether my design has successfully met the goals set at the project's outset. At the project's initiation, I established one main goal and two sub goals:

- **Main goal: I aim to bring users an immersive Pop-up book experience.**
- **Sub goal: I aim to make the experience easy to operate.**
- **Sub goal: I aim to bring user new perspective to look at Pop-up book.**

The primary purpose of this final user test was to utilize participant feedback to determine whether I have achieved these goals.

The central inquiry revolves around "immersion." I hope to discern from participant feedback whether my new designs for the environment and interactions have indeed enhanced the sense of immersion. How intense is this immersion? Have the various new interactions each contributed to this immersion? Are there any issues that have hindered the participants' sense of immersion? These pivotal questions that reside in my mind will be answered through the data gathered during the test.

In regard to the sub goals, I aim to evaluate the ease of operation in the current experience by closely observing participants' interaction processes. Furthermore, after participants have completed the experience, I intend to conduct interviews to understand whether the experience has influenced their perceptions of Pop-up books. Is this influence predominantly positive or negative? How participants now perceive physical Pop-up books?

7.2 Preparation

To summarize, in this user test phase, I aim to address the following key questions:

- Does the "Wizard's attic environment " enhance users' sense of immersion?
- Does the new interaction of "Scalable Pop-up book size" enhance users' sense of immersion?
- Does the new interaction of "Exploration-triggered story-telling" enhance users' sense of immersion?
- Is the level of operational difficulty reasonable?
- Does the experience influence users' perspectives on physical Pop-up books, and if so, in what ways?

Considering the test duration, I have decided to divide the testing into three groups:

- The first group of participants will experience a version with new environment and regular-sized Pop-up books.

- The second group of participants will experience a version with new environment, regular-sized Pop-up books, and the ability to zoom into the Pop-up book but without any story-related interactions.
- The third group of participants will experience a version with new environment, regular-sized Pop-up books, the ability to zoom into the Pop-up book, and the ability to trigger all story-related interactions.

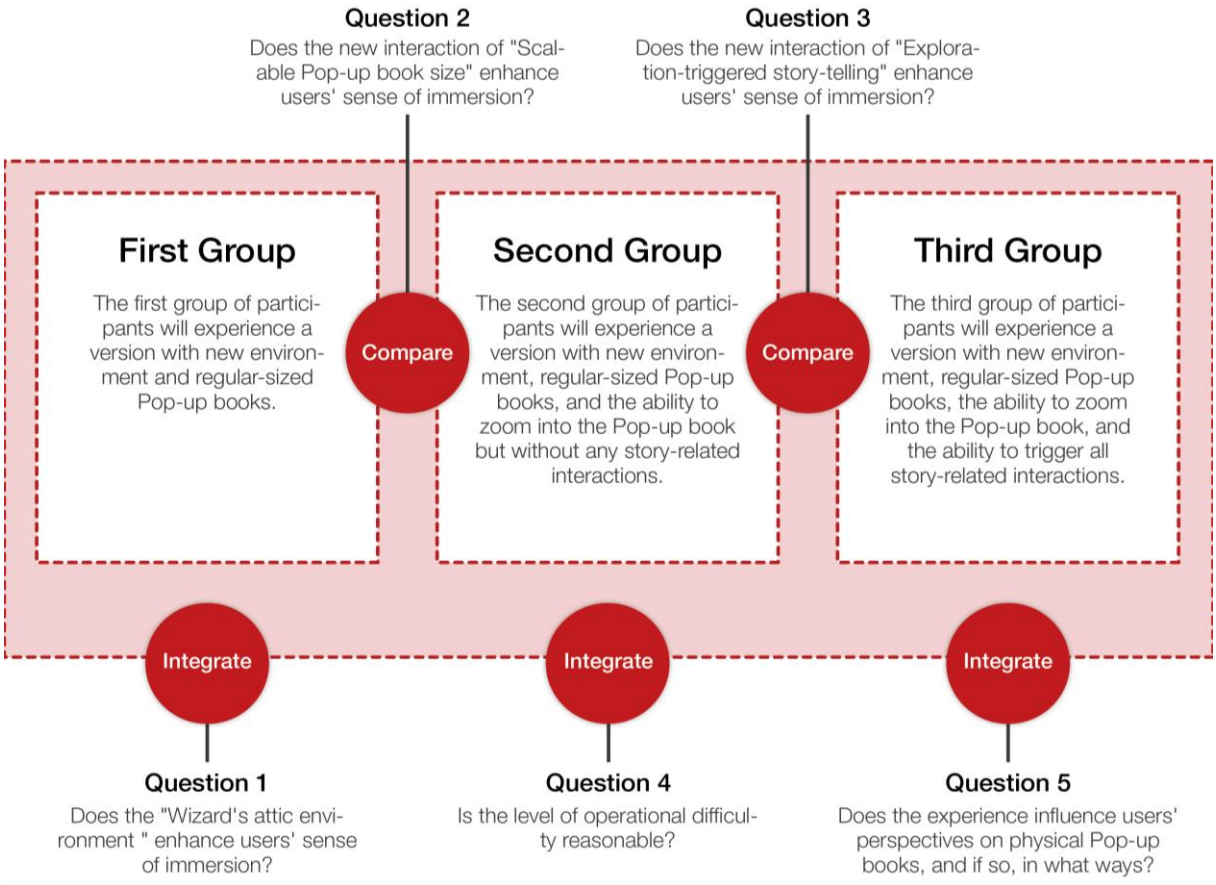

Figure 49: The relationship between three groups of subjects and five questions

By conducting these three groups of tests and comparing their resulting data, I aim to address the five questions I outlined. The relationship between the three groups of participants and the five questions is depicted in the diagram above.

My plan is to invite 8 participants for each group, totaling 24 participants for the test. Given that the questions involve physical Pop-up books, I have borrowed a copy of "TIP+TOP Boven De Wolken" from my chair, which will serve as the testing material.

Regarding the test content of each group, building upon the framework of the immersion assessment questionnaire found in the paper "Measuring and Defining the Experience of Immersion in Games," [41] I devised an evaluation form with the goal of quantifying the level of immersion within my VR experience. After participants complete the VR experience, I will provide them with this form to fill out. The form consists of 16 descriptions and corresponding scores. Participants will assign a score to each description based on their

experiences. If a participant strongly agrees with a particular description, they will assign a higher score, if not, they will assign a lower score. Each description has a score range of 1 (Not at all), 2, 3, 4, to 5 (Very much so).

The design logic of the evaluation form is based the conclusion I drew during literature review. The first 14 descriptions are related to these seven crucial factors for immersion: "Sensory," "Curiosity," "Concentration," "Comprehension," "Control," "Challenge," and "Empathy," with two questions for each factor. The last two descriptions are directly associated with the sense of immersion. For example, "I was interested in exploring the experience's environment" is related to "Curiosity."

I established that if the average score of the 16 descriptions falls between 2.5 and 3.5, it indicates that the participants neither felt immersed nor detached from the experience. If the average score is below 2.5, it suggests that the participants did not experience immersion and may have felt highly disconnected. If the average score exceeds 3.5, it indicates that the participants were immersed in the experience. Comparatively higher average scores between participants suggest a greater sense of immersion. Furthermore, as each description is associated with a specific factor, I can discern from the scores which aspects of immersion participants experienced more strongly and which factors may have disrupted their sense of immersion.

You can find the complete evaluation form in Appendix G.

In addition to the evaluation form, post-test interviews capture the more subjective viewpoints. Based on the distinct content of the three groups of testing, I have designed three sets of questionnaires. Each of these sets comprises three sections: "Questions related to immersion," "Questions related to the ease of operation," and "Questions related to new perspectives on physical Pop-up books." The latter two sections contain identical questions across all three sets, while the first section has subtle variations based on the experience.

You can find the questionnaires for the final user test in Appendix H.

7.3 Process

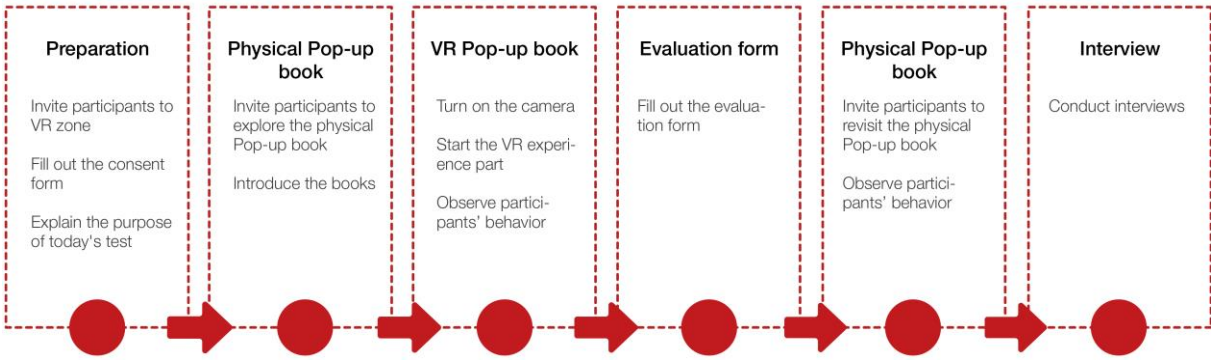

Figure 50: The flow chart for the final user test

When participants arrive, I begin by providing a brief explanation of my graduation project. Following this, I invite participants to explore the physical copy of "TIP+TOP Boven De Wolken" and briefly explain the story behind this Pop-up book. After participants finish observing the physical book, I guide them to experience the VR Pop-up book version corresponding to their assigned group. Throughout this process, I record their interactions via video and observe their behavior.

Once participants complete the VR part, I have them fill out the evaluation form. Following this, I provide participants with some time to revisit the physical "TIP+TOP Boven De Wolken" book. Finally, I conduct interviews with them based on the group.

Figure 51: A total of 24 subjects participated in this user test

I am deeply moved that all 24 invited participants ultimately participated in the test and provided valuable feedback. The user test conducted over 5 days at TU Delft VR Zone [55].

7.4 Analysis

After completing the tests, a substantial volume of data was obtained. This data includes the following: evaluations of immersion by 8 participants for the first experience group,

evaluations of immersion by 8 participants for the second group, evaluations of immersion by 8 participants for the third group, audio recordings of interviews with 24 participants, and video recordings of 24 participants experiencing the VR Pop-up book.

Given the significant scale of this dataset, a systematic approach is necessary for analysis. The data has been categorized into evaluation forms and interview feedback. While the evaluation forms exclusively reflect immersion, the interview feedback encompasses immersion, operational difficulty, and participants' new perspectives on physical Pop-up books. These two distinct methodologies have been employed for analysis:

- **Evaluation form**

In the case of evaluation forms, data has been subjected to statistical analysis. Initially, each participant's 16 assessment scores within each group were averaged, followed by the averaging of these means within their respective groups. This process yielded the average immersion scores for each group, as illustrated in the following table:

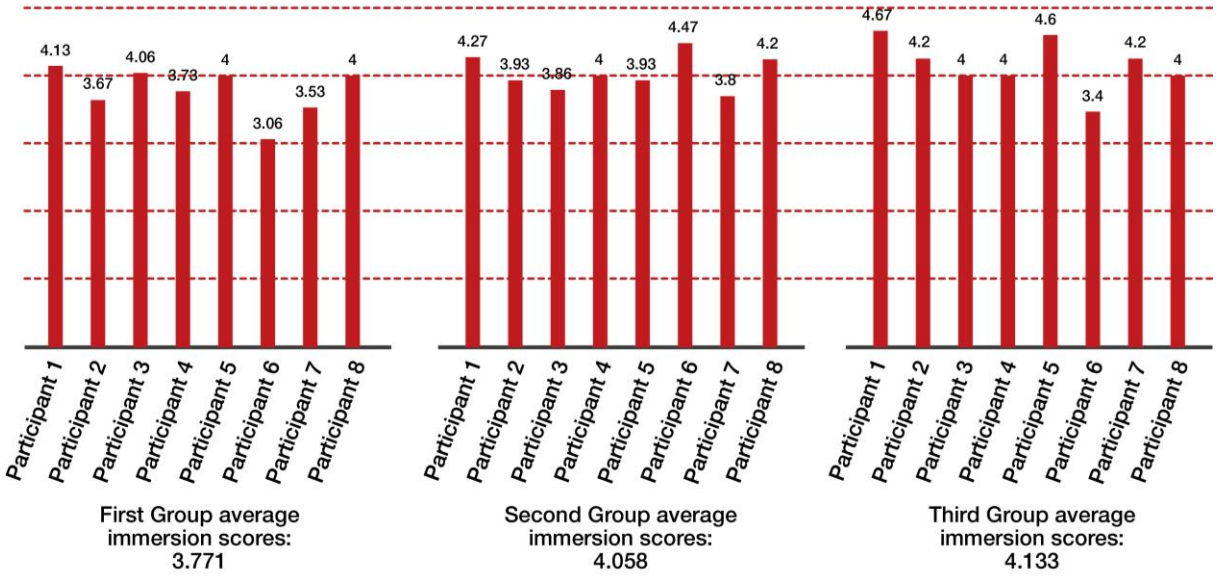

Table 2: Average score tables for three different group

Subsequently, the 16 assessment scores were disaggregated into seven factors: "Sensory," "Curiosity," "Concentration," "Comprehension," "Control," "Challenge," and "Empathy." The averages of the two scores related to each factor for all 8 participants within a group were calculated. This resulted in the average scores for the seven factors influencing immersion within each group, as presented in the following table:

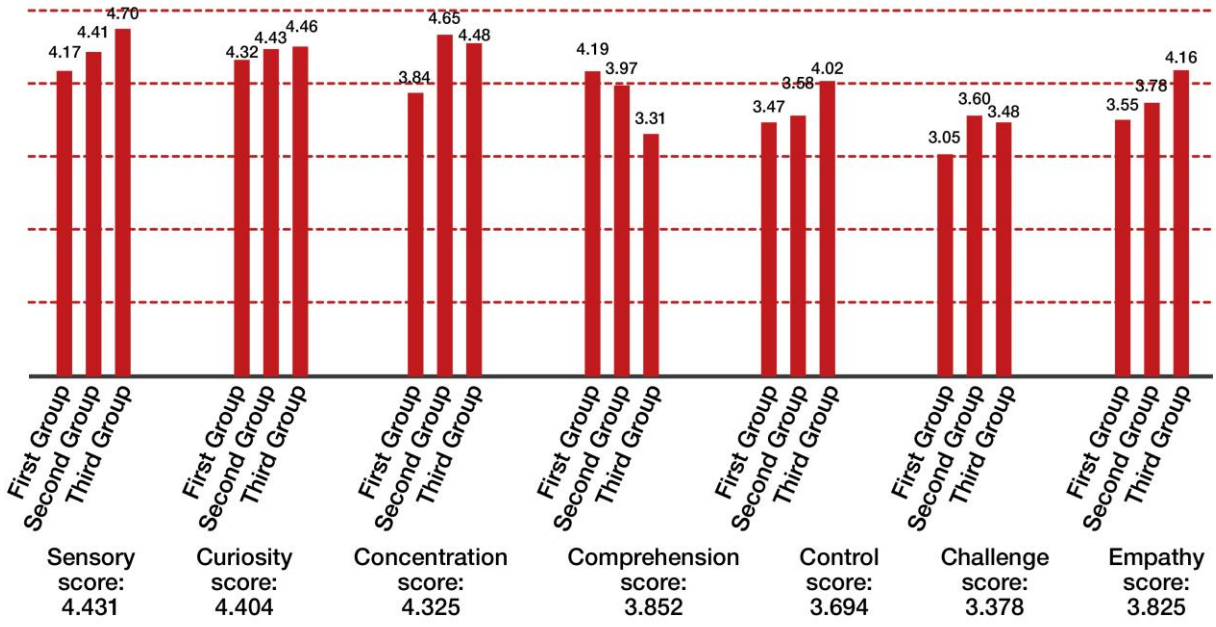

Table 3: Average factor-related score tables for three different group

This process has yielded average immersion scores for each experimental group as well as average scores for the seven factors influencing immersion. A comparison of these eight average scores between the first and second groups is depicted in the following "Comparison Table 1-2":

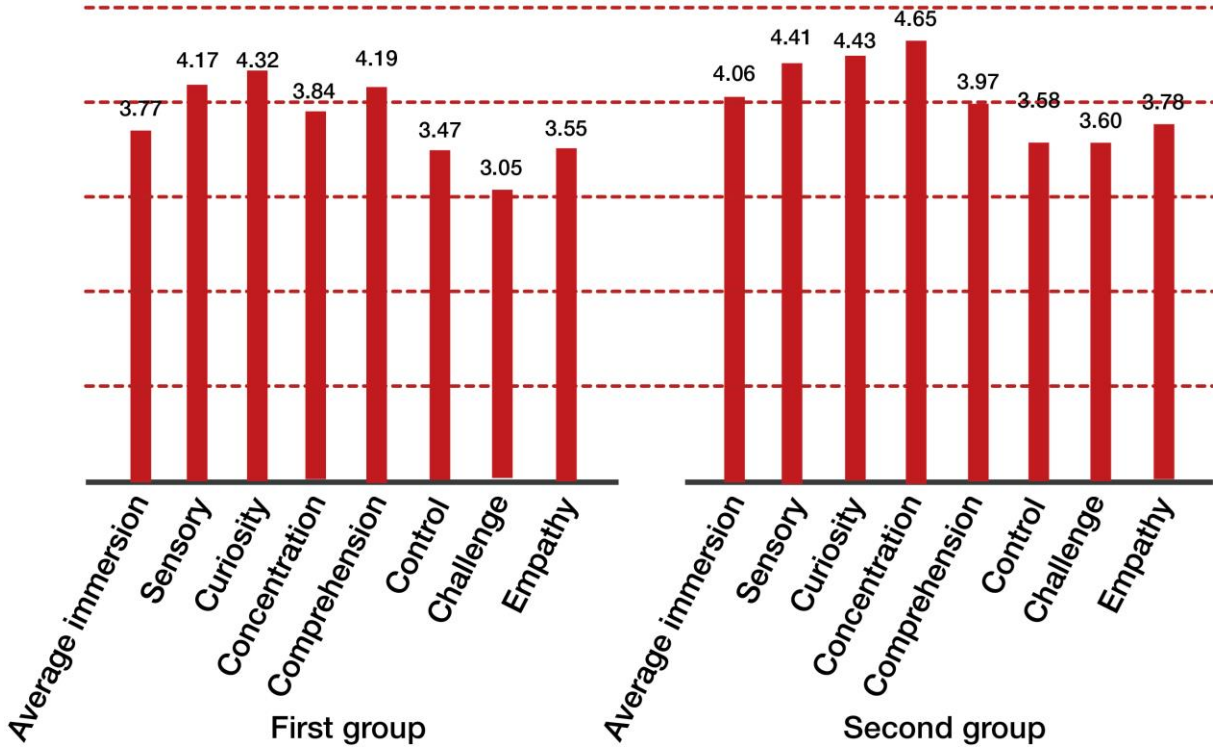

Table 4: Comparison between the first group and the second group

Similarly, a comparison of these eight average scores between the second and third groups is presented in the "Comparison Table 2-3" below:

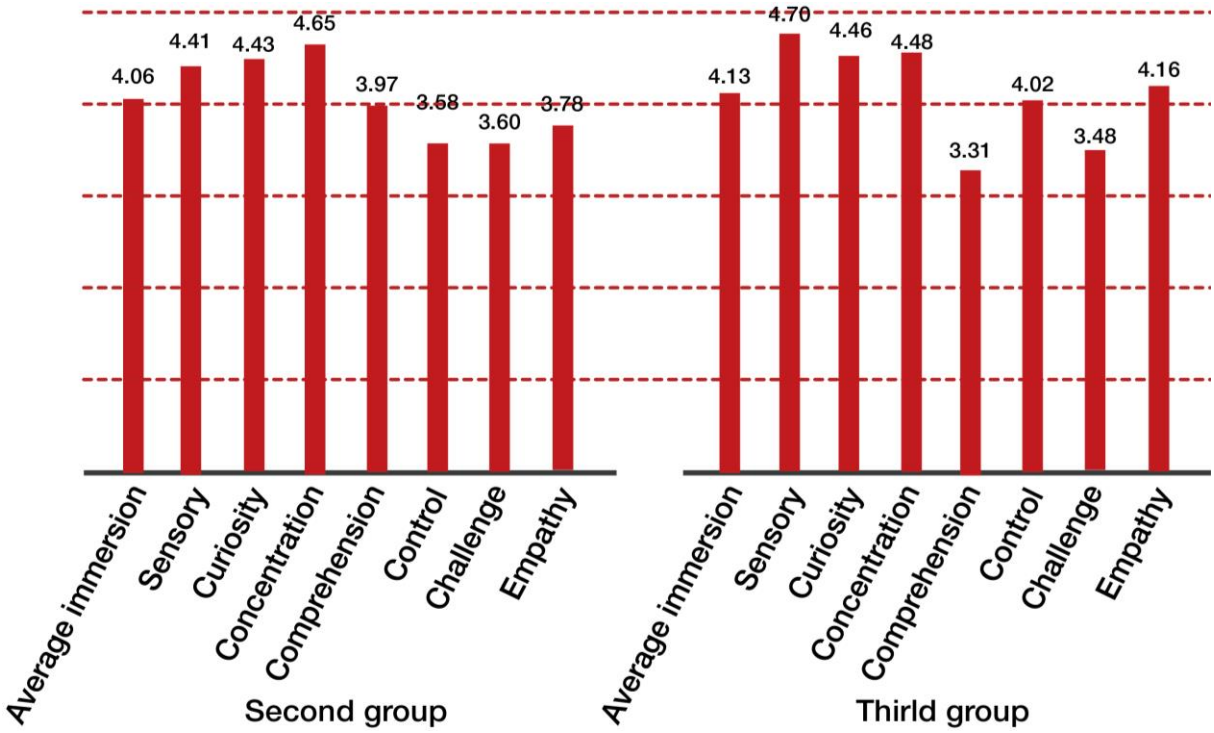

Table 5： Comparison between the second group and the third group

- **Interview feedback**

In terms of Interview feedback, I have categorized it into three distinct sections based on the content of the questions: Immersion, Operational difficulty, and Perspectives on physical Pop-up books. Furthermore, within the immersion section, I have further subdivided the feedback based on the mode of interaction into "Wizard's attic environment," "Scalable Pop-up book size," and "Exploration-triggered story-telling."

Whenever a participant provided feedback related to any of these sections during the interview, I diligently recorded it under the corresponding category. Subsequently, by consolidating the recorded content within each section, I derived the corresponding conclusions. It is worth noting that the feedback obtained during the interviews also serves as valuable evidence for elucidating the results derived from evaluation forms.

7.5 Result

7.5.1 Evaluation form

Based on Table 2, the average immersion scores for the three groups were 3.771, 4.058, and 4.133, respectively. All of these scores exceeded 3.5 and exhibited a gradual upward trend. This indicates that the design elements of "Wizard's attic environment," "Scalable Pop-up book size," and "Exploration-triggered story-telling" all contributed to enhancing the participants' sense of immersion.

However, the second group's average score showed a more significant increase compared to the third group, with a smaller variance. This suggests that the "Scalable Pop-up book size" interaction had a more pronounced impact on immersion and was more readily accepted by a broader range of participants. On the other hand, the "Exploration-triggered story-telling" interaction contributed to immersion but to a relatively lesser extent, and it even presented some issues that affected the experience of certain participants, leading to a reduction in their sense of immersion.

Table 3 underscores the clear strengths and weaknesses of my VR Pop-up book experience. My experience received high praise in terms of "Sensory," "Curiosity," and "Concentration" factors, but there is significant room for improvement in "Control" and "Challenge."
The higher ratings can be attributed to participants' positive perceptions of the environment and the visual impact and the novelty feeling of the giant Pop-up book. On the other hand, the issues can be attributed to a lack of clear cues in the experience, which prevented participants from correctly interacting with the VR Pop-up book and left them without a clear objective to drive their interactions.

By comparing the first and second sets of data (see Table 4), I found that the “Scalable Pop-up book size” interaction brings almost a positive improvement to all factors for immersion experience. It stimulates sensory perception, ignites curiosity, enhances concentration, improves the sense of control, and fosters emotional engagement among the participants.

By comparing the data from the second and third groups (see Table 5), I observed that the "Exploration-triggered story-telling" interaction, while providing users with more intense sensory stimulation and a deeper understanding of the story, did not offer users a complete process of overcoming challenges as initially envisioned. The reasons for this structure can be identified through the interview feedback.

7.5.2 Interview feedback

- **Immersion**
  - **Wizard's attic environment**

    Among the 24 participants, 17 expressed their fondness for this novel environment, finding it cozy and suitable for reading. 8 participants likened it to a "Harry Potter-like environment," perceiving a harmonious blend between the enchanting atmosphere and the fantastical sense of Pop-up books. 5 participants felt that the current environment's allure struck a balance, offering initial surprise without diverting their attention from the Pop-up book. Additionally, 12 participants lauded

the overall environment for its realism, encompassing aspects such as texture, lighting, and sound.

Several participants also shared suggestions. Some expressed a desire for interactive features allowing them to switch between different Pop-up books by engaging with the bookshelves. However, 6 participants remarked on a perceived disconnection between the environment and the story within the Pop-up book. They advocated for greater synergy between environmental elements and the narrative, such as being situated in a room with two young boys, alongside a doghouse.

- **Scalable Pop-up book size**

  Out of 16 participants, 14 displayed an overwhelming preference for this innovative interaction, particularly the moment they entered the enlarged Pop-up book, which evoked unparalleled astonishment and excitement. Many participants underscored that VR's essence lies in enabling users to experience situations they cannot encounter in real life, with scaling into the Pop-up book being a prime example. Inside the magnified Pop-up book, 5 participants reported increased activity, while 3 felt a heightened concentration of attention. This novel experience sparked a diverse array of associations among participants, ranging from classic side-scrolling game "Super Mario Bros" [56] to the story of "Alice's Adventures in Wonderland" [57] and even personal experiences at "The Corpus Museum" in Leiden [58].

  However, certain recommendations for improvements also garnered attention, with the central theme being the provision of greater control to participants. Suggestions included enabling users to perform scaling interactions from any location and allowing users to adjust the scaling ratio.

- **Exploration-triggered story-telling**

  The evaluation of this interaction yielded complex feedback. While all 8 participants agreed that listening to the story via narration was preferable to reading within VR, they also conveyed occasional difficulties in locating interactive objects. They also felt that the feedback provided after initiating an interaction was sometimes insufficient. Some participants expressed a desire for an increased number of interactive components, as they felt that certain objects appeared interactive but turned out not to be, which they found less logical.

  The first category of feedback highlighted deficiencies in the prompting aspects of my design. The latter two categories of feedback indicated that simply using "hearing the complete story" as a reward might not be sufficient motivation for users to engage effectively with challenges. Users require more impactful interactions to maintain their focus. However, it's important to note that an excessive increase in

interactions might not necessarily translate to a better experience, as the core of the experience still revolves around Pop-up book.

- **Operation difficulty**

  Among the 24 participants, 10 indicated that the current level of operational difficulty was entirely acceptable, 9 said that although somewhat complex, it could be mastered through a brief explanation, and 5 found the operations to be moderately challenging to learn. While the data suggests that the current level of operational difficulty is not particularly high, considering that most participants were graduate students under the age of 30, it appears essential to continue efforts to reduce operational complexity.

  Many participants provided consistent recommendations for improving the operation. They pointed out that the current buttons for adjusting the viewpoint differed significantly from the layout found on common gaming controllers. Therefore, I should consider drawing insights from a broader range of gaming controller designs and applying those principles to VR controllers.

- **New perspective on Pop-up books**

  Among 24 participants, 12 mentioned that the experience had aided them in gaining a better understanding of the structure of Pop-up books. It enabled them to notice previously overlooked details and even some interactive elements within the books. Notably, this mutual enhancement of understanding worked both ways, as some participants found that physical Pop-up books helped them plan their virtual visits within the VR environment. 4 participants noted that the experience deepened their comprehension of Pop-up book's narrative. This was because the storytelling, triggered by various interactions, was easier to remember.

  7 participants expressed that the experience had fundamentally changed their perspective on viewing Pop-up books. In the past, they would only view Pop-up books from the conventional overhead perspective. Now, they would imagine themselves as diminutive observers gazing upwards within the book. Additionally, 7 participants mentioned that the experience had rekindled their interest in Pop-up books, a passion they had forgotten since adulthood. They realized that, even as grown-ups, Pop-up books could still captivate them, and they expressed a desire to explore more Pop-up books after the experience.

  However, 4 participants felt that the appeal of VR Pop-up books and physical Pop-up books was distinct, making direct comparisons challenging. Nevertheless, it is undeniable that VR technology had ignited their interest in the experience. On the contrary, 6 participants believed that the experience did not significantly alter their perspective on Pop-up books.

Chapter 8:

Discussion

In this concluding chapter, I will summarize the results obtained and draw conclusions. I will also explore the potential avenues for future project development and engage in reflective analysis of the entire project.

8.1 Conclusion

Based on the analysis of data from the evaluation form and interview feedback, I believe I can draw conclusions regarding whether my VR Pop-up book experience has achieved its predefined goals:

- **Main goal: I aim to bring users an immersive Pop-up book experience.**
  The statistical results demonstrate that my VR Pop-up book experience has provided participants with a sense of immersion. The three design elements work in synergy, each positively contributing to immersion, and they are interdependent. "Wizard's attic environment" and "Scalable Pop-up book size" have been confirmed to stimulate participants' "Curiosity" and "Sensory," help them "Concentrate" their attention, and thereby contribute significantly to the creation of immersion. However, "Exploration-triggered story-telling" falls short of expectations in terms of its impact on immersion due to deficiencies in "Comprehension," "Control," and "Challenge,"

  The consolidation of feedback also supports the results obtained from data. Participants' evaluations affirm that my VR Pop-up book experience indeed fosters a sense of immersion. However, there is room for improvement in all three design elements. "Wizard's attic environment" could be better integrated with multiple Pop-up book to make it more coherent. "Scalable Pop-up book size" could offer users more control. "Exploration-triggered story-telling" needs more prompts and feedback to provide participants with clearer objectives and a greater sense of achievement.

- **Sub goal: I aim to make the experience easy to operate.**
  The current level of difficulty in operation has been accepted by most participants, but there is still room for improvement.

- **Sub goal: I aim to bring user new perspective to look at Pop-up book.**
  I believe the current experience can provide most people with a new perspective on Pop-up books. This new perspective primarily focuses on the following aspects:
  - Discovering more details from the book
  - Gaining a deeper understanding of the story
  - Discovering more viewing perspective for the book
  - Altering notions about the appropriate age for experiencing Pop-up books
  - Sparking interest in Pop-up books

  Interestingly, experiences with higher levels of immersion tend to trigger this change in

perspective more effectively. Of the 18 participants who felt that the experience had altered their perspective on Pop-up books, 4 were from the first group, 7 from the second group, and 7 from the third group. This indicates that interactive methods different from reality can help participants open up new ways of thinking. For example, "Scalable Pop-up book size" can change participants' viewing perspective, while "Exploration-triggered story-telling" can deepen their understanding of the story.

Moreover, the combination of VR technology and Pop-up books can indeed attract a wider audience. When combined with improved experiences, VR Pop-up books can help enthusiasts gain a deeper understanding of them, encourage those who seldom engage with Pop-up books to develop an affinity for them, and motivate individuals who were previously disinterested in Pop-up books to give them a try.

In summary, I believe the results are quite satisfactory: I have largely achieved the intended goals, and my graduation project marks a significant milestone in its development.

8.2 Future work scope

While my graduation project has concluded, I firmly believe that there is still significant room for improvement, which can be categorized into two main areas: immediate modifications based on participant feedback and long-term project prospects.

8.2.1 Modification

- **Incorporate additional cues**

  Currently, participants struggle to identify interactive elements, necessitating the addition of a subtle hint mechanism. However, it is crucial to ensure that these cues do not disrupt the immersion. For example, interactive elements could undergo slight movements if the user hasn't interacted with them for an extended period.

- **Design new rewards**

  The current mechanism of "hearing the complete story" may not sustain participants' engagement. Therefore, there is a need for a more enticing reward system triggered by interactions, such as synchronized movements of components with the story.

- **Add introductory section**

  Upon entering the VR environment, participants often feel disoriented due to the lack

of initial guidance. Therefore, introducing an overview of the experience at the beginning would help participants understand what they are facing.

- **Enhance operating feedback**
  Some participants reported discomfort, including a sense of vertigo caused by the rapid descent after jumping and grabbing objects that are too close to them. Adjusting these aspects to provide a more comfortable experience is necessary.

- **Granting control freedom**
  Some users expressed a desire to physically flip pages of the Pop-up book using VR controllers instead of pressing buttons. Additionally, the ability to "scale" at any location was a common request. Offering users greater control freedom in these aspects would enhance the experience.

8.2.2 Promotion

- **Add more Pop-up books**
  Expanding further, it is envisioned to include multiple Pop-up books within the attic's bookshelf. Users can interact with the bookshelf behind them to switch between books, take out their preferred choice, and place it on the table for interaction. This evolution could transform the application into a platform for users to interact with their favorite Pop-up books.

- **Increase interaction with environment**
  The magical environment holds substantial untapped potential. Each magical item in the environment could offer new ways to interact with the Pop-up books. For instance, the current "Scalable Pop-up book size" could be an ability gained through interacting with the magnifying glass, and using a wand could grant users the power to bring objects within the book to life.

- **Broaden the channels of delivery**
  Consider expanding the availability of VR Pop-up book experiences beyond just libraries. Platforms like the Meta store [59], established by VR device manufacturers, could be explored as an alternative. This would enable a wider audience of VR users to enjoy Pop-up books from the comfort of their homes.

8.3 Reflection

It's hard to believe that my graduation project has finally come to an end. As I stand here at the finish line, reflecting on the entire journey and the culmination of my efforts, my heart is filled with a profound sense of nostalgia.

From the moment I first laid eyes on this project, I knew that I wanted to do it as my graduation work. My deep-rooted love for Pop-up books has been a constant in my life. Whenever I traveled, I would immerse myself in the local libraries, seeking out Pop-up books in the native language. I feel incredibly fortunate to have been entrusted with this graduation project, and I extend my heartfelt gratitude to my chair, Willemijn Elkhuizen, for selecting me for this endeavor.

However, the project faced significant initial challenges. My relatively slow reading speed in English proved to be a major hurdle during the literature review phase. I grappled with uncertainties regarding what to research and where to find relevant literature. Additionally, the wealth of user feedback I received from prior VR Pop-up book experiences led to an inclination towards my intuitive design thinking. Early on, I had already formulated a vision for the final experience. This inclination sometimes led me down the path of "choosing theory to explain what I wanted to do" rather than "using theory to derive and evaluate an idea." It wasn't until the mid-project phase that I invested substantial time in organizing the literature, ultimately discovering research papers that provided quantitative insights into "immersion." In retrospect, this phase of the project proved to be a valuable learning experience, refining my research skills.

As I transitioned into the production phase, my progress significantly accelerated. This acceleration can be attributed partly to my previous experience in game development and partly to the invaluable support I received from the instructors at VR Zone. One particularly challenging technical aspect was the control of each component's movement trajectory within the Pop-up book to faithfully replicate the real-world pop-up process. With nearly 30 components on each page, each having distinct rotation centers, connection point, and rotation directions, this presented a formidable technical challenge. During this period, Yoshua, one of the VR Zone instructors, tirelessly assisted me, explaining the logic behind the programming. This phase of the project also proved to be another valuable learning experience, greatly enhancing my proficiency in using Unreal Engine. Witnessing the gradual transformation of the experience filled me with an innate sense of pride.

Throughout this journey, I discovered that every obstacle presented an opportunity for growth. Overcoming challenges led to the development of new skills. However, upon reflection, I recognize areas where I could have performed better.

Firstly, I acknowledge that I failed to adequately address the fundamental question of "why enhance immersion." Immersion had long been considered a prerequisite without delving into its underlying significance. Questions such as "Why does a VR Pop-up book experience require immersion?" and "How does enhancing immersion benefit the overall Pop-up book experience?" should have been explored more thoroughly from the project's outset.
Secondly, the distinction between a "research project" and a "commercial project" should have been recognized earlier. My project leaned more toward the former, focusing on an investigative approach to a specific topic, such as whether scaling the size of VR Pop-up books could enhance immersion. However, I initially approached it with a commercial mindset, contemplating questions like, "What interactions would attract users to experience VR Pop-up books?" This cognitive dissonance created friction, leading to difficulties in the project's progression.
Lastly, the matter of user test warrants discussion. Properly structured user test demands a well-considered plan and timely execution, as soliciting feedback at each stage enables designers to make necessary adjustments promptly. While I ultimately conducted a total of 24 test sessions, many valuable insights emerged from these sessions. However, due to the project's timeline, the feedback received arrived rather late. In future projects, I aspire to be more proactive in seeking user feedback.
Certainly, there is still ample room for making mistakes. I hope to learn from these experiences in future projects.

I would like to take this opportunity to express my heartfelt gratitude to all those who have generously supported me throughout my graduation project. My sincere thanks go to my chair and mentor, Willemijn Elkhuizen and Maarten Wijntjes, whose unwavering guidance and assistance have been invaluable. They have consistently provided direction, particularly during moments of uncertainty, granting me significant leeway for creative expression. I am also immensely grateful to the instructors at VR Zone for their open-handed sharing of their expertise in Unreal Engine development. I firmly believe that this knowledge will prove to be a priceless asset in my future endeavors. To all my friends who enthusiastically participated in the user test process, your involvement was truly remarkable! It has been an honor to have crossed paths with each of you during my time at TU Delft.

I have no intention of concluding my exploration of VR Pop-up book development at this point. As mentioned earlier, I aspire to continue refining and expanding in the direction that requires modification. Perhaps one day, you may encounter a platform on Steam [60] that allows you to immerse yourself in multiple Pop-up books. I encourage you to keep an eye out, as this cozy magical abode will always welcome your presence.

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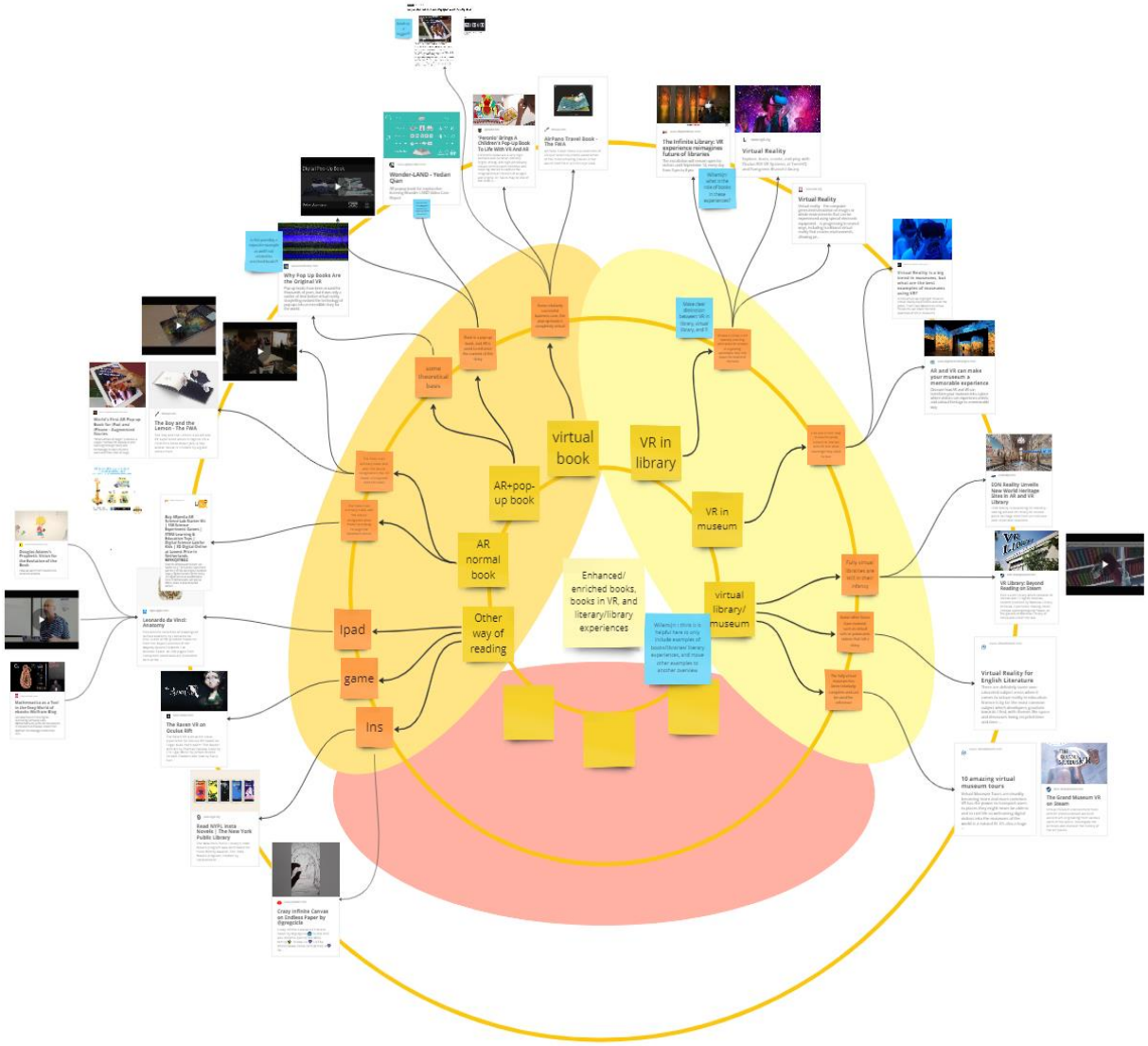
Appendix

A. Summary of related projects currently on the market



B. Questionnaire for the user study

PART A - VR EXPERIENCE

General

1. What did you think of the experience?
2. What did you like about the experience?
3. What didn't you like about the experience?
4. What did you notice?
5. Was there something missing from the experience?

Performative level

6. What does the VR experience allow you to do, in terms of interacting with the books? e.g. looking, touching, moving, holding etc.

Sensory level

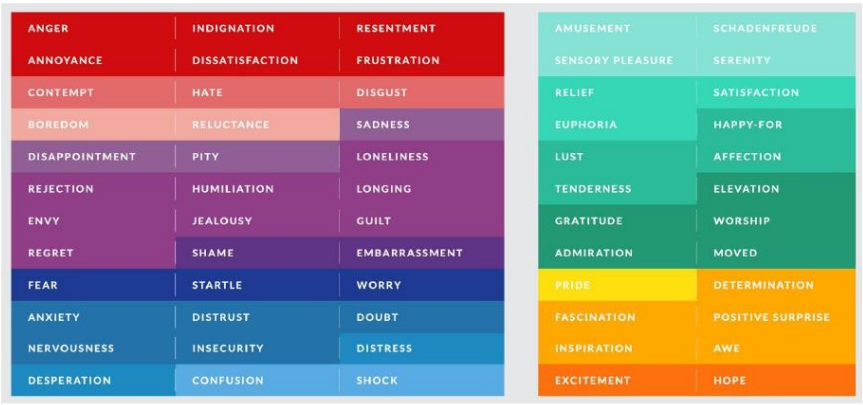
7. How would you describe the following aspects of the experience:
   A) visual, b) auditory, and c) Haptic/movement interaction?
8. Was there anything that stood out or was missing regarding these points?
9. How would you describe the material expression of the books in the experience, in terms of image, sound, haptics/movement?

Interpretive level

10. What do you associate with the experience? What does the experience remind you of?
11. Are any elements of the experience unclear?

Affective level

12. What emotions does the experience evoke? And can you elaborate on that?



Completion

13. What is the most enjoyable part of the experience?
14. What is the most disturbing part of the experience?
15. What is the most unique part of the experience?

PART B - POP-UP AND MOVABLE BOOKS

General

1. What did you think of the experience?
2. What did you like about the experience?
3. What didn't you like about the experience?
4. What did you notice?
5. Was there something missing from the experience?

Performative level

6. What can you do with the books, in terms of interaction? e.g., looking, touching, moving, holding etc.

Sensory level

7. How would you describe the following aspects of the experience:
   a) Visual, b) Auditory, and c) Haptic/movement interaction?
8. Was there anything that stood out or was missing regarding these points?
9. How would you describe the material expression of the books in the experience, in terms of image, sound, haptics/movement?

Interpretive level

10. What do you associate with the experience? What does the experience remind you of?
11. Are any elements of the book experience unclear?

Affective level

12. What emotions does the experience evoke? And can you elaborate on that?

Completion

13. What is the most enjoyable part of the experience?
14. What is the most disturbing part of the experience?
15. What is the most unique part of the experience?

PART C - COMPARISON

General

1. What is similar or different between the VR experience and books?

Performative level

2. To what extent is the VR experience able to convey the experience of interacting with a real artifact?
3. To what extent is the VR experience able to convey a historical sensation, as if you were touching a piece of history?

Sensory level

4. How does the sensory experience differ between VR and the books?
5. What do you think of this difference?

Interpretive level

6. Can you explain which aspects of the VR experience or the books evoke different associations?
7. What do you think of this difference?

Affective level

8. Can you explain how which aspects of the VR experience or books make the emotional response differ?
9. What do you think of this difference?

PART D - CONTROL QUESTIONS

1. What is your previous experience with VR?
2. Do you have experience with computer games?
3. Have you ever read or worked with a pop-up or movable book before today?
4. How often do you visit a museum or make cultural trips? (How many times have they been to a museum in the last 6 months)
5. Age
6. Gender
7. Do you have any suggestions for us regarding the VR experience?

C. Flow chart for the user study

D. Tag collection

#Information Tag	01. BOOK SENSORIAL	08. VR SENSORIAL
#AGE	01. BOOK SENSORIAL: Less precise haptic interaction	08. VR SENSORIAL: (No) grabbing/pinching with fingers
#AGE: 20-29	01. BOOK SENSORIAL: Smell - of glue (of replica)	08. VR SENSORIAL: Sense of touch is missing
#AGE: 30-39	01. BOOK SENSORIAL: Sound - Scratching of paper	08. VR SENSORIAL: Smell of old book is lacking
#AGE: 40-49	01. BOOK SENSORIAL: sound of ripping paper	08. VR SENSORIAL: Sound is lacking in (most) of the experience
#CH EXPERIENCE	01. BOOK SENSORIAL: Touch - Not touching pop-up elements	08. VR SENSORIAL: Visual effects is similar to physical books
#CH EXPERIENCE: Not often	01. BOOK SENSORIAL: Touch - Smooth feeling of the paper	08. VR SENSORIAL: Visual interactions effect is too simple/underwhelming
#CH EXPERIENCE: Very often	01. BOOK SENSORIAL: Touch/Haptic - feel friction (between pages/paper)	08. VR SENSORIAL: Visual material appearance is not realistic
#GAMING EXPERIENCE	01. BOOK SENSORIAL: Vision - Colorful appearance	08. VR SENSORIAL: Visual signs of wear/ageing are missing
#GAMING EXPERIENCE: Experienced	01. BOOK SENSORIAL: Vision - Dynamic effect	
#GAMING EXPERIENCE: Limited		09. VR INTERPRETIVE
#GENDER	02. BOOK INTERPRETIVE	09. VR INTERPRETIVE: Experience is like being in a candy store
#GENDER: Female	02. BOOK INTERPRETIVE: Expensive	09. VR INTERPRETIVE: Experience is like horror movie
#GENDER: Male	02. BOOK INTERPRETIVE: Hidden layers/not seeing everything	09. VR INTERPRETIVE: Experience is like playground
#Pop-up book experience	02. BOOK INTERPRETIVE: Interactive elements are attractive	09. VR INTERPRETIVE: VR breaks nostalgic association
#Pop-up book experience: No	02. BOOK INTERPRETIVE: Intricately made	09. VR INTERPRETIVE: VR experience is immersive
#Pop-up book experience: Yes	02. BOOK INTERPRETIVE: Mechanisms are like science museum exhibit	09. VR INTERPRETIVE: VR experience is like a test
#VR EXPERIENCE	02. BOOK INTERPRETIVE: Nostalgic	09. VR INTERPRETIVE: VR experience is like gaming
#VR EXPERIENCE: Experienced	02. BOOK INTERPRETIVE: Not suitable for children	09. VR INTERPRETIVE: VR experience is like playing in ball pit (ballenbak)
#VR EXPERIENCE: Limited	02. BOOK INTERPRETIVE: Pop-up books are immersive	09. VR INTERPRETIVE: VR experience is like theater
#VR EXPERIENCE: Very little/none	02. BOOK INTERPRETIVE: Pop-up elements are attractive	09. VR INTERPRETIVE: VR is new version of pop-up book experience
	02. BOOK INTERPRETIVE: Pop-ups are like explosions	
	02. BOOK INTERPRETIVE: Reading/interacting with book is intuitive	10. VR AFFECTIVE
	02. BOOK INTERPRETIVE: remind of books with sound effects (speaker)	10. VR AFFECTIVE: Confusion - unexpected interaction effects (Books appears behind you)
	02. BOOK INTERPRETIVE: Sturdy	10. VR AFFECTIVE: Doubt
		10. VR AFFECTIVE: Excitement/anticipation for (next) page
	03. BOOK AFFECTIVE	10. VR AFFECTIVE: Experience is exciting
	03. BOOK AFFECTIVE: Admiration for paper engineering complexity	10. VR AFFECTIVE: Experience sparks joy
	03. BOOK AFFECTIVE: Boredom - excitement wears off when reading twice/again	10. VR AFFECTIVE: Fear of crashing into things (physical space)
	03. BOOK AFFECTIVE: Boredom - Interactions are monotomous/not surprising	10. VR AFFECTIVE: No fear of damaging book
	03. BOOK AFFECTIVE: Boredom - Not as exiting as modern technology	10. VR AFFECTIVE: positive surprise with pop-up effects

#Information Tag	01. BOOK SENSORIAL	08. VR SENSORIAL
	03. BOOK AFFECTIVE	10. VR AFFECTIVE: Experience is exciting
	03. BOOK AFFECTIVE: Admiration for paper engineering complexity	10. VR AFFECTIVE: Experience sparks joy
	03. BOOK AFFECTIVE: Boredom - excitement wears off when reading twice/again	10. VR AFFECTIVE: Fear of crashing into things (physical space)
	03. BOOK AFFECTIVE: Boredom - Interactions are monotomous/not surprising	10. VR AFFECTIVE: No fear of damaging book
	03. BOOK AFFECTIVE: Boredom - Not as exiting as modern technology	10. VR AFFECTIVE: positive surprise with pop-up effects
	03. BOOK AFFECTIVE: Boredom - Not interesting for kids today?	
	03. BOOK AFFECTIVE: Confusion - Interaction possibility unclear	11. VR PERFORMATIVE (ACTIONS)
	03. BOOK AFFECTIVE: Confusion about (visual) effect of interaction	11. VR PERFORMATIVE (ACTIONS): Book appears/dissappears
	03. BOOK AFFECTIVE: Excitement/anticipation for (next) visual effect	11. VR PERFORMATIVE (ACTIONS): Cannot grab the book/page
	03. BOOK AFFECTIVE: Fear of damaging	11. VR PERFORMATIVE (ACTIONS): Move body
	03. BOOK AFFECTIVE: Fear of overlooking something	11. VR PERFORMATIVE (ACTIONS): Move closer to look at details
	03. BOOK AFFECTIVE: Positive surprise with pop-up/interactive elements	11. VR PERFORMATIVE (ACTIONS): Non-working interaction attempted
	03. BOOK AFFECTIVE: Satisfaction with tactile experience	11. VR PERFORMATIVE (ACTIONS): Pull tab (VR)
		11. VR PERFORMATIVE (ACTIONS): Push book around
	04. BOOK PERFORMATIVE (ACTIONS)	11. VR PERFORMATIVE (ACTIONS): Repeat motion several times
	04. BOOK PERFORMATIVE (ACTIONS): Careful/slowly turn the page	11. VR PERFORMATIVE (ACTIONS): Rotate steering wheel
	04. BOOK PERFORMATIVE (ACTIONS): Grab to pick up & put down book	11. VR PERFORMATIVE (ACTIONS): Stand in/walk through the book
	04. BOOK PERFORMATIVE (ACTIONS): Looking into 3D structure	11. VR PERFORMATIVE (ACTIONS): Turn the page
	04. BOOK PERFORMATIVE (ACTIONS): Move book around (by grabbing edges)	11. VR PERFORMATIVE (ACTIONS): Walking around the books
	04. BOOK PERFORMATIVE (ACTIONS): Not touching (pop-up)	
	04. BOOK PERFORMATIVE (ACTIONS): Open and close pages (repeatedly)	12. VR PERF. (AFFORDANCE/LIMITATION)
	04. BOOK PERFORMATIVE (ACTIONS): Open flap single/multiple fingers	12. VR PERF. (AFFORDANCE/LIMITATION): Huge books are cool
	04. BOOK PERFORMATIVE (ACTIONS): Open page partially	12. VR PERF. (AFFORDANCE/LIMITATION): Interaction changes to a full body experience
	04. BOOK PERFORMATIVE (ACTIONS): Participant changes relative perspective/position	12. VR PERF. (AFFORDANCE/LIMITATION): Interaction effect is not realistic/defies reality
	04. BOOK PERFORMATIVE (ACTIONS): Pull out element (grab multiple fingers/hand)	12. VR PERF. (AFFORDANCE/LIMITATION): Interaction not working/unclear/fluent
	04. BOOK PERFORMATIVE (ACTIONS): Pull tab/element pinch (two fingers)	12. VR PERF. (AFFORDANCE/LIMITATION): Visual details are disappointing
	04. BOOK PERFORMATIVE (ACTIONS): Push page(s) down	12. VR PERF. (AFFORDANCE/LIMITATION): VR allows for interaction
	04. BOOK PERFORMATIVE (ACTIONS): Repeat motion several times	12. VR PERF. (AFFORDANCE/LIMITATION): VR have fewer possibilities than reality
	04. BOOK PERFORMATIVE (ACTIONS): Rotate wheel and see visual effect	12. VR PERF. (AFFORDANCE/LIMITATION): VR is less subtle than reality
	04. BOOK PERFORMATIVE (ACTIONS): Rub fingers across (textile) surface	12. VR PERF. (AFFORDANCE/LIMITATION): VR is not same as pop-up book experience
	04. BOOK PERFORMATIVE (ACTIONS): Slide book across the table (1-2 hand grab)	

Codes

#Information Tag	01. BOOK SENSORIAL	08. VR SENSORIAL
	04. BOOK PERFORMATIVE (ACTIONS): Pull out element (grab multiple fingers/hand)	12. VR PERF. (AFFORDANCE/LIMITATION): Interaction not working/unclear/fluent
	04. BOOK PERFORMATIVE (ACTIONS): Pull tab/element pinch (two fingers)	12. VR PERF. (AFFORDANCE/LIMITATION): Visual details are disappointing
	04. BOOK PERFORMATIVE (ACTIONS): Push page(s) down	12. VR PERF. (AFFORDANCE/LIMITATION): VR allows for interaction
	04. BOOK PERFORMATIVE (ACTIONS): Repeat motion several times	12. VR PERF. (AFFORDANCE/LIMITATION): VR have fewer possibilities than reality
	04. BOOK PERFORMATIVE (ACTIONS): Rotate wheel and see visual effect	12. VR PERF. (AFFORDANCE/LIMITATION): VR is less subtle than reality
	04. BOOK PERFORMATIVE (ACTIONS): Rub fingers across (textile) surface	12. VR PERF. (AFFORDANCE/LIMITATION): VR is not same as pop-up book experience
	04. BOOK PERFORMATIVE (ACTIONS): Slide book across the table (1-2 hand grab)	
	04. BOOK PERFORMATIVE (ACTIONS): Slide movable part with fingertip	13. VR STORY/CONTENT
		13. VR STORY/CONTENT: Content of book shows age
	05. BOOK PERF. (AFFORDANCE/LIMITATION)	13. VR STORY/CONTENT: Sounds/effects immerse you into content/story
	05. BOOK PERF. (AFFORDANCE/LIMITATION): Allows reading to someone else	13. VR STORY/CONTENT: Too many sounds could be distracting to read
	05. BOOK PERF. (AFFORDANCE/LIMITATION): Book not read (completely)	13. VR STORY/CONTENT: VR immerses you into story
	05. BOOK PERF. (AFFORDANCE/LIMITATION): Connection interaction and visual effect not directly clear	
	05. BOOK PERF. (AFFORDANCE/LIMITATION): Missing/mistake interaction	14. VR ENVIRONMENT/CONTEXT
	05. BOOK PERF. (AFFORDANCE/LIMITATION): Pop-up books are fragile/require careful handling	14. VR ENVIRONMENT/CONTEXT: (Virtual) environment is immersive
	05. BOOK PERF. (AFFORDANCE/LIMITATION): Pop-up triggers to read book	14. VR ENVIRONMENT/CONTEXT: Virtual environment is nice
	05. BOOK PERF. (AFFORDANCE/LIMITATION): Text and images reinforce each other	14. VR ENVIRONMENT/CONTEXT: Virtual environment is NOT nice
		14. VR ENVIRONMENT/CONTEXT: VR has more possibilities than reality
	06. BOOK STORY/CONTENT	
	06. BOOK STORY/CONTENT: Effects fit the content of book	15. VR TECH USABILITY (GENERAL)
	06. BOOK STORY/CONTENT: Interpretations/emotions related to the content	15. VR TECH USABILITY (GENERAL): Boundary/space inhibits free movement/breaks immersion
		15. VR TECH USABILITY (GENERAL): Confusion/frustration/doubt about use cues/controllers
	07. BOOK ENVIRONMENT/CONTEXT	15. VR TECH USABILITY (GENERAL): Excitement with tech novelty
	07. BOOK ENVIRONMENT/CONTEXT: Experiment context makes you behave differently	15. VR TECH USABILITY (GENERAL): Fear - Movement in space is scary
		15. VR TECH USABILITY (GENERAL): Fear of bumping into something (in reality)
		15. VR TECH USABILITY (GENERAL): Jittery (visual) effects breaks the immersion
		15. VR TECH USABILITY (GENERAL): More critical on VR
		15. VR TECH USABILITY (GENERAL): Use instructions given/needed
		15. VR TECH USABILITY (GENERAL): Using VR has learning curve

Codes

E. Table of existing models

Author	Engaging experience	Application	Dimensions
Csikszentmihalyi (1988)	Flow	Human psychology	Focused concentration Merging of activity and awareness Perceived control Time distortion Loss of self-consciousness
Hoffman and Novak (1996)	Flow	A computer-mediated environments	Consumer learning Perceived behavioral control (or confidence) Exploratory behavior Positive subjective experiences Distortion in time perception
Chou and Ting (2003)	Flow	Online computer game	Concentration Playfulness Distortion in time perception Telepresence Exploratory behavior
Skadberg and Kimmel (2004)	Flow	Browsing a website	Enjoyment Lost track of time Telepresence
Pace (2004)	Flow	Web information-seeking activities	Duration Frequency and intensity Joy of discovery Reduced awareness of irrelevant factors Distorted sense of time Merging of action and awareness Sense of control Mental alertness Telepresence
Sweetser and Wyeth (2005)	Flow	Game player experience	Concentration Challenge Skills Control Clear goals Feedback Immersion Social interaction
Agarwal, Sambamarthy, and Stair (1997)	Cognitive absorption	Information technology	Control Attention focus Curiosity Intrinsic interest Computer Playfulness Ease of use
Agarwal and Karahanna (2000)	Cognitive absorption	Information technology usage	Temporal dissociation Focused immersion Heightened enjoyment Control Curiosity
Witmer and Singer (1998)	Presence and immersion	Virtual environment	Presence: Control Sensory Distraction; Realism Immersion: Tendency to become involved in activities Tendency to maintain focus on current activities Tendency to play video games
Brooks (2003)	Immersion	Narrative in virtual reality and other interfaces	Time Context Participation
Brown and Cairns (2004)	Immersion	Game	Emotional involvement Transportation to different place Attention Control and autonomy
Ermi and Mäyrä (2005)	Immersion	Game play experience	Sensory immersion Challenge-based immersion Imaginary immersion

F. English version of the "TIP+TOP Boven De Wolken"

Tip:

Tip and Top went with their dog Tap to go to the flying day. Immediately at the entrance there was an exhibition of the first balloons, airships and airplanes. They had to see that!
(Happy tone)

Just to be on the safe side, they brought their home-made kite and an umbrella.
(Normal tone)

"Hey what are you doing? Don't touch our kite and umbrella"
(*Tone of blame*)

Tap wanted to bite off a piece of the airship, thinking it was a big sausage. Tip admonished him to behave properly and to carefully follow the program on the television screen.
(*Joking tone*)

Then the loudspeaker announced that Tap was the lucky one hundred thousandth visitor to the exhibition. Tip had number 99999 and Top had 100001. The announcer said that the three lucky winners got to examine and fly all the planes.
(Happy tone)

Top:

Tip climbed into an old biplane and imagined how someone flying would feel. Top, on the other hand, climbed into the basket of a hot air balloon with great difficulty. Tap jumped after him.
(Normal tone)

"I would much rather have won a cake with whipped cream," Tip sighed. "Or at least a roast goose." He smacked loudly with his tongue. Tap agreed and wagged his tail.
(Tense and regretful tone)

"I don't feel like flying at all," Tip continued. "Maybe I'll get sick, or I'll fall out of the plane, right in the nettles."
(Tense and regretful tone)

Top launched his kite from the balloon and suddenly the balloon also went up in the air. Top closed his eyes and prepared for the worst. "If I die", he shouted to Tip, "you can eat the ham I have in the fridge at home".
(Critical tone)

Fortunately, the balloon was secured to the ground with an anchor and a few men pulled it back down to ground level.
(Relief tone)

G. Evaluation form of immersion for the final user test

Note: This evaluation form has been adapted from the questionnaire utilized in the research paper "Measuring and Defining the Experience of Immersion in Games." I have made modifications to certain questions to align them more closely with the investigation of my personal experience.

Please make your evaluation now.

Empathy	I felt that I empathized/felt for with the experience. Not at all 1 2 3 4 5 Very much so
Curiosity	I was interested in seeing how the experience would progress. Not at all 1 2 3 4 5 Very much so
Curiosity	I was interested in exploring the experience's environment. Not at all 1 2 3 4 5 Very much so
Challenge	I found a goal to achieve during the experience. Not at all 1 2 3 4 5 Very much so
Challenge	This experience brought me the motivation to continue. Not at all 1 2 3 4 5 Very much so
Concentration	I sometimes found my attention to become so involved with parts of the experience. Not at all 1 2 3 4 5 Very much so
Sensory	I enjoyed the graphics and sound of the experience. Not at all 1 2 3 4 5 Very much so
Sensory	I enjoyed the vibe of the virtual environment. Not at all 1 2 3 4 5 Very much so
Empathy (Enjoyment)	I enjoyed the way of interaction in the experience. Not at all 1 2 3 4 5 Very much so
Control	The controls were easy to pick up. Not at all 1 2 3 4 5 Very much so
Comprehension	I have a good enough understanding of the content of the experience. Not at all 1 2 3 4 5 Very much so
Control	I felt myself to be directly travelling through the experience according to my own volition. Not at all 1 2 3 4 5 Very much so
Comprehension	I could interact with the virtual world based on my real-world experience. Not at all 1 2 3 4 5 Very much so
Immersion	I felt detached from the outside world during the experience. Not at all 1 2 3 4 5 Very much so
Concentration	At the time the experience was my only concern. Definitely not 1 2 3 4 5 Very much so
Immersion	How immersed did you feel? (10=very immersed; 0=not at all immersed) 0 1 2 3 4 5 6 7 8 9 10

H. Questionnaires for the final user test

User Test group 1 interview questions

"Questions related to immersion"

1. During the experience, are you feeling any kind of immersion?
2. If you feel immersed, what makes you immersed and why?
3. If you're not feeling immersed, what reduces your immersion and why?
4. What do you think about this new way of reading pop-up book?
5. What do you think about the wizard tower-like environment and the background story?

"Questions related to the ease of operation"

6. How difficult do you think it is to operate? Can you complete the experience on your own without other's guidance?

"Questions related to new perspectives on physical Pop-up books"

7. Will the new VR experience change the way you think about physical pop-up book?
8. In what ways does it change your view of physical pop-up book?
9. Does the VR reading experience make you want to read the physical pop-up book more?

User Test group 2 interview questions

"Questions related to immersion"

1. During the experience, are you feeling any kind of immersion?
2. If you feel immersed, what makes you immersed and why?
3. If you're not feeling immersed, what reduces your immersion and why?
4. What do you think about this new way of reading pop-up book
5. What do you think about this new way of zoom in to explore the pop-up book?
6. What do you think about the environment of a wizard attic and the background story?

"Questions related to the ease of operation"

7. How difficult do you think it is to operate? Can you complete the experience on your own without other's guidance?

"Questions related to new perspectives on physical Pop-up books"

8. Will the new VR experience change the way you think about physical pop-up book?
9. In what ways does it change your view of physical pop-up book?
10. Does the VR experience make you want to read the physical pop-up book more?

User Test group 3 interview questions

"Questions related to immersion"

1. During the experience, are you feeling any kind of immersion?
2. If you feel immersed, what makes you immersed and why?
3. If you're not feeling immersed, what reduces your immersion and why?
4. What do you think about this new way of reading pop-up book
5. What do you think about this new way of zoom in to explore the pop-up book?
6. What do you think about the voiceovers that trigger when you explore?
7. What do you think about those interaction inside the pop-up book?
8. What do you think about the environment of a wizard attic and the background story?

"Questions related to the ease of operation"

9. How difficult do you think it is to operate? Can you complete the experience on your own without other's guidance?

"Questions related to new perspectives on physical Pop-up books"

10. Will the new VR experience change the way you think about physical pop-up book?
11. In what ways does it change your view of physical pop-up book?
12. Does the VR reading experience make you want to read the physical pop-up book more?