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Data-Driven Storytelling and Historical Heritage: A Virtual Reality Experience of the Silk Road

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Abstract

The burgeoning domain of virtual reality (VR) has ushered in novel avenues for traditional data storytelling, particularly in the context of cultural heritage. This project embarks on an exploration to discover effective narrative design modalities and interaction methodologies specifically tailored for virtual reality. Utilizing the Silk Road as a thematic focus, the project encompasses data collection, narration, and interactive design, addressing the history, trade, and geographical facets of the Silk Road. From meticulous data collection, the project crafts interactive narratives spanning three dimensions: historical chronicles, Silk Road trade dynamics, and geographical information. It introduces three innovative VR narrative design patterns: (1) incorporation of 2D content within a 3D VR environment. (2) employment of a three-dimensional spatial display. (3) development of an immersive visual experience that users can engage with. A user testing process was initiated to validate the efficacy of these design patterns in enriching the narrative pertaining to cultural heritage. The empirical results indicate an overall positive reception of the application, highlighting the promising potential of this new storytelling paradigm. Nevertheless, areas for future refinement have been identified, such as enhancing the immersive quality of the scenes and designing adaptive experiences for individuals prone to motion sickness. In sum, this project exemplifies a pioneering effort in translating cultural heritage into an interactive and immersive virtual experience, offering valuable insights and methodologies that can inspire and guide future innovations in virtual reality storytelling.

Acknowledgements

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1 Introduction

This project will undertake a detailed examination of the representation of historical heritage within the sphere of virtual reality. An exploration will be conducted to discern optimal strategies for gathering and showcasing historical and cultural data within an engaging narrative framework. Additionally, an analysis of varying interaction design approaches within VR will be undertaken to understand their potential impact on enhancing the overall user experience, illustrated through practical work showcasing a history of the Silk Road.

In the contemporary era, burgeoning interest has been observed in the employment of immersive technologies like virtual reality (VR) as an innovative conduit for experiential learning. These advancements grant users an unprecedented degree of immersion, facilitating virtual exploration across various temporal and spatial dimensions. “Such a characteristic is particularly potent in the context of historical and cultural heritage education. The deployment of VR provides a powerful platform for illuminating, and reconstructing histories that may have been forgotten by time” (Mosaker, 2001). By merging immersive technologies with strategic narrative and interaction design, it is plausible to breathe new life into historical epochs, thereby revolutionizing traditional methods of experience and learning.

The Silk Road serves not merely as a commercial conduit bridging East and West, but also as an emblem of global history. The project aims to explore to the audience the story of the Silk Road told in a virtual reality environment. The journey is elucidated via a data-driven narrative, offering information and guidance. In order to construct this digital voyage, I have amassed and categorized pertinent data from an array of resources including relevant webpages, books, visual media, and documentaries pertaining to the Silk Road. These resources facilitated the comprehensive representation of diverse facets of the Silk Road including historical events, traded commodities, transportation methods, and geographical features.

The collated data, in essence, has been segregated into three primary domains: historical events pertinent to the Silk Road, geographical data associated with the route, and the trading dynamics that existed on the Silk Road. These categories are embodied in three distinct scenes crafted for demonstration purposes.

The first segment, relevant historical events, synthesizes a chronological narrative that elucidates the evolution of the Silk Road. This narrative employs interactive elements such as maps, charts, and related digital interplay to effectively communicate the sequence of events. Regarding the geographical data associated with the Silk Road, I implemented visual design strategies for certain parameters such as altitude. My intention was to cultivate an immersive interactive experience, thus deepening the user's sense of involvement and enhancing their spatial perception within the virtual representation of this historical trade route. Finally, the trading scene, as the third element, recreates the distinctive characteristics of various traded commodities and their geographical origins. This is achieved through model elements that facilitate a heightened sense of historical verisimilitude for the audience within the virtual environment. In the process of presenting certain content that may feel remote from our

current societal context, for instance, Silk Road transportation, such as camels, and infectious diseases like the spread of the Black Death, the strategy is to enhance comprehension by rendering the data and information visually accessible. This approach aids the audience in fully grasping the historical context and impact of these elements.

Current developments indicate a profound potential for virtual reality in the realm of data-driven storytelling. Despite the nascent stage of this intersection with relatively few case studies, my project identifies and implements three immersive interactive design patterns to facilitate data-driven narratives effectively.

Immersive interactive design patterns

The first pattern involves the incorporation of 2D content within a 3D VR environment. Certain types of data, such as geographical coordinates or lightweight statistical data, can be more efficiently communicated via 2D formats like maps or charts. To improve users' comprehension of the storyline, I've infused interactivity into the 2D data displayed within the scene. Furthermore, I've designed animations synced with a chronological narration of events and auditory accompaniment, intending to minimize the learning cost for users.

The second pattern employs a three-dimensional spatial display. By constructing a three-dimensional scene in VR and visualizing the related information, I've enabled users to navigate the storyline immersively, transcending temporal and spatial boundaries.

The final pattern is participatory visualization. Data visualization allows users to make effortless comparisons and observations of various data sets, potentially leading to insightful conclusions. The immersive nature of VR provides users with an expansive range of options. They can partake in visualization within the VR setting and experience the effects of diverse data sets firsthand. For instance, in the geographical data scene, I visualized the altitudes of various mountains along the Silk Road. Users, through VR controllers, can ascend these virtual peaks to perceptually grasp the disparities in elevation.

These patterns aim to expand the scope of data-driven storytelling in VR, bringing an enriched level of user engagement and understanding.

This dissertation is structured into six chapters: Introduction, Background, Methodology, Implementation, User Testing, and Conclusion. Accompanying the documentation is an APK build for Quest and Unity and project files for Maya, Cinema 4D,Photoshop, and Substance Painter.

Click on the link to check project screen recording：
https://media.ed.ac.uk/media/Traverse%20the%20Silk%20Road/1_xamblf7h

2 Background

2.1 Immersive Data Storytelling

Data storytelling has been widely used in various media platforms in recent years. Segel and Heer(2010) pioneered an analysis of narrative visualization, delineating seven distinct genres: magazine style, annotated chart, infographic, video, slide show, flowchart, positioned poster, and comics. Their findings illustrate that certain genres may be more aptly suited for specific purposes, depending on the context and objectives of the visualization. In the realm of visual storytelling, striking a delicate equilibrium between the author's intended narrative and the reader's exploratory journey within the story becomes paramount. This balance manifests itself in various ways. A purely author-driven approach, for instance, follows a strictly linear path in visualization, emphasizes message transmission, and eschews interactivity. Conversely, a reader-driven approach refrains from prescribing image order or message conveyance, fostering an environment rich in interactivity. An essential characteristic of narrative visualization lies in its inherent flexibility to harmonize these contrasting elements. Contemporary visualizations are increasingly adept at achieving this balance, judiciously integrating limited interactions within the framework of more structured narratives.

Lee et al.(2015) conducted a more in-depth analysis of the process involved in crafting data stories. They suggest three key features that define a visual data story: Firstly, the story must be supported by a series of data-backed facts, underscoring the need for data-driven reality. Secondly, most of these facts should be presented visually to reinforce the central message. Lastly, the visualization should present a logical sequence or links that fortify the main message. This underscores the importance of an underlying dataset, a clear intention, and a well-structured series of visualizations in distinguishing a story-driven visualization from those primarily intended for exploration and analysis.

In the wake of advancing XR technology, the nascent field of immersive data storytelling is surfacing as a viable tool to amplify user engagement (Isenberg et al., 2018). Recent years have witnessed its application in diverse sectors, including healthcare(Hardie et al., 2020) and education(Lantz, 2009). In the study conducted by Hardie et al., students were invited to participate in "Wonderful You," an innovative virtual reality narrative experience that depicts the journey of a fetus during the first nine months of life within the womb. Utilizing questionnaires, participants appraised several elements of the project, including storytelling immersion, interactivity, imagination stimulation, motivational aspects, and its potential to enhance problem-solving abilities. Overall, these elements received positive feedback. The virtual reality storytelling approach effectively engaged students' attention and interest, thereby stimulating their desire for further exploration. This suggests the substantial potential of immersive technologies in fostering an active learning environment.

Nevertheless, in contrast to other forms of data-driven narratives, immersive data storytelling remains under-researched with respect to its unique design patterns and

conceptual underpinnings. In a study by Jian (2023), immersive data storytelling was explored across three distinct immersive environments, based on the dimensions of being static versus dynamic and fully virtual versus hybrid. Despite these strides, the study remained largely in the exploratory stage of categorizing forms of immersion, without delving into specific data narrative design methodologies within a particular technological framework. Consequently, there remains a significant gap in understanding the optimal utilization of immersive data storytelling, necessitating further research into its application and development.

Isenberg et al. (2018) explored the concept of translating the contrasting immersive modes found in games into the realm of visual data-driven storytelling. While the notion of immersion is well-articulated within the gaming industry, applying and understanding it in the context of visual data narratives remains an emerging area of inquiry.

Viewers approach visual data-driven stories with expectations and biases distinct from those they might have for games. Unlike games, which often revolve around central characters, immersive visual data stories might seek to foster a robust connection to the narrative, provoke an emotional response to its content, and facilitate profound interaction with its components. Both genres, however, exhibit shared characteristics concerning graphics and interaction.

The primary objective of a data story is to effectively communicate information. Existing studies on narrative visualization have predominantly emphasized the way data can be harnessed to tell stories, but there remains a limited understanding of how audiences interpret and engage with these visualizations. Comprehensive exploration is required to discern how immersion can be efficaciously implemented within this field and to comprehend its consequent effects on viewers' perception and comprehension of data.

This project builds upon prior research in the domain of data storytelling and sets its sights on investigating the unique characteristics of immersive environments, with an emphasis on virtual reality. By devising a series of carefully crafted scenes and employing interaction design techniques, the study aims to fortify users' comprehension of the narrative. This approach seeks not only to lower the threshold for user understanding but also to elevate the overall user experience. The aspiration is to contribute fresh insights and practical methodologies to the burgeoning field of immersive data storytelling, enhancing its potential as an effective tool for conveying complex information in an engaging and accessible manner.

2.2 Immersive Experience of Historical Heritage

The swift advancement of multimedia technology, coupled with the widespread adoption of virtual technology, has broadened the scope of historical heritage representation. “Notably, virtual reality technology marks a significant departure from conventional mediums like videos and webpage museums, revolutionizing the way historical heritage is consumed” (Cecotti, 2022). The employment of VR in the portrayal of historical heritage transcends both geographical and temporal limitations. Primarily, VR facilitates access to remote or unreachable locations, enabling exploration beyond the typical purview of the average individual. “Moreover, it creates a conduit to the past by offering users an immersive journey through digitally reimagined historical structures, replicating their state at specific moments in history” (Soto-Martin, Fuentes-Porto and Martin-Gutierrez, 2020). This groundbreaking approach opens up innovative avenues for the dissemination and appreciation of historical heritage. The manifestation of historical heritage in virtual reality substantially enhances the user's experience while simultaneously diminishing the experiential cost. Equipped with a VR headset, users can virtually explore distant locales without the necessity of physical travel. This technology circumvents the discomfort associated with crowded venues, allowing users to scrutinize various details up close and at their own pace. Moreover, it provides unprecedented access to otherwise inaccessible locations and periods, such as submerged ruins or epochs thousands of years in the past. Thus, VR revolutionizes the exploration of historical heritage, offering an immersive, affordable, and highly accessible platform for historical and historical engagement.

In light of the aforementioned context, numerous teams have undertaken pertinent explorations in recent years. Fan, Chen, and Huang (2022) introduced the MDF-HF framework, a novel approach towards the provision of information services and immersive experiences related to historical figures in the Metaverse. The framework encompasses five distinct domains: Basic Information, Figure Achievements, Cultural Heritage, Posthumous Research, and Tourism Elements. By utilizing an array of technologies, including photogrammetry, 3D modeling, panoramic imaging, VR animation, and virtual museum techniques, an immersive system has been developed for both educational and experiential purposes. This innovative application of emerging technologies offers promising implications for enhanced engagement and learning within the realm of cultural heritage.

Häkkilä et al. (2019) harnessed the immersive potential of VR to transform the German soldier cemetery, located in the border region between Finland and Russia, into a virtual reality experience. Given that physical access to the cemetery requires a border zone permit from Russian border authorities, a process often marred by extensive delays, the team envisaged the project as an enabling tool for relatives of the interred, history enthusiasts, and students to visit the site virtually. Drawing upon visitor photographs, they meticulously reconstructed the cemetery environment and local weather conditions. Additionally, they incorporated interactive features, such as the lighting and placement of candles, enhancing the authenticity and immersive quality of the user experience. This innovative approach underscores the potential of VR in access to sites of cultural and historical significance.

Egea-Vivancos and Arias-Ferrer (2020) embarked on an investigation into the potential of Immersive Virtual Reality (IVR) games as pedagogical tools for imparting cultural heritage and historical knowledge in secondary education. The authors introduced the CREAM model, encapsulating the key principles of civic education, historical relevance, player engagement, applicability, and multimodality. These tenets are essential to the design of effective educational video games, specifically those aiming to integrate archaeological and historical content into the learning environment. The CREAM model was operationalized in the development of the IVR video game, Carthago Nova. The authors underscored the necessity of thoughtful consideration regarding the objectives, content, methodologies, actions, and resources employed during the conception and creation of any serious game centered around historical and cultural heritage. Their work further underscores the emerging role of IVR in contemporary education, particularly in enriching students' understanding of history and heritage.

While existing research offers substantial guidance for the immersive experience of historical heritage, particularly within the domain of virtual reality, there remains a discernible gap in the realm of immersive data-driven storytelling. Current literature has not fully explored or provided comprehensive case studies in this specific field. In response to this lacuna, the present study seeks to build upon the existing body of work by investigating the influence of various factors within virtual reality, including scenarios, interaction design, and historical heritage content, on data-driven storytelling. The goal is to contribute to a more nuanced understanding of these complex interrelationships and to foster the development of innovative approaches that enhance the immersive experience of historical heritage.

2.3 Design Patterns for Immersive Data Storytelling

Design patterns can serve as a crucial framework for effectively structuring scholarly work. In their seminal study, Bach et al. (2018) proposed an ensemble of narrative design patterns, meticulously tailored for data-driven storytelling. Their ground-breaking work categorized 18 distinct narrative modes into five predominant mode groups namely; argumentation, flow, framing, emotion, and engagement. Moreover, they dissected the interdependencies among these modes, elucidating their respective utilization scenarios. These patterns, whether employed individually or synergistically, allow for a broad spectrum of narratives in data storytelling. They are specifically engineered to facilitate the crafting of compelling, data-centric narratives. Given the goals and the intended audience, these design patterns can be harnessed to narrate the same story in multiple ways. This underscores the inherent flexibility and adaptability that these narrative frameworks offer, a trait crucial to effective storytelling in the data-driven paradigm.

The aforementioned design patterns furnish essential guidance for the cultivation of data-driven storytelling content, many data stories bearing testament to their application. Yet, the realm of immersive data stories is presently marked by a dearth of examples and implementations. Although there exist specific immersive tools, such as IATK (Maxime Cordeil et al., 2019) and XRCreator (Ren, Lee, and Höllerer, 2018), they principally target the design and interaction of virtual data visualization, thereby offering limited assistance in the domain of storytelling.

Within the confines of virtual reality, the immersive environment proffers extensive opportunities for data narrative design, and the enhancement of interactivity can potentially enrich the user experience. This correlation was also tentatively validated by Zhang, Bowman, and Jones (2019), who posited that within an immersive environment, an augmentation in interaction could bolster user engagement in learning and foster a more profound understanding of the content.

Therefore, this project will also place emphasis on interaction and content design across various scenarios within the virtual reality environment, seeking to present a comprehensive summary.

3 Methodology

In this research project, I developed a virtual reality application entitled "Traverse the Silk Road." By collecting, organizing, and analyzing data pertaining to the Silk Road, I created three distinct scenarios that depict the history, transactions, and geography of the Silk Road, aiming to narrate a coherent and accessible story about this historic trade route.

Beyond the conceptualization of the story and its content, this project was designed with a particular focus on the unique attributes of virtual reality. In alignment with the specific scenarios and content, I explored and summarized three design patterns for storytelling within a VR context. These include the integration of 2D content within a 3D VR environment, the utilization of three-dimensional spatial displays, and the creation of an immersive visual experience that allows for user interaction.

To assess the efficacy of these designs in fulfilling the objectives of data-driven storytelling within the virtual reality space, a small-scale user test was conducted. The insights gleaned from this study provide valuable understanding and guidance for future endeavors in creating engaging and informative narratives through the innovative use of VR technology.

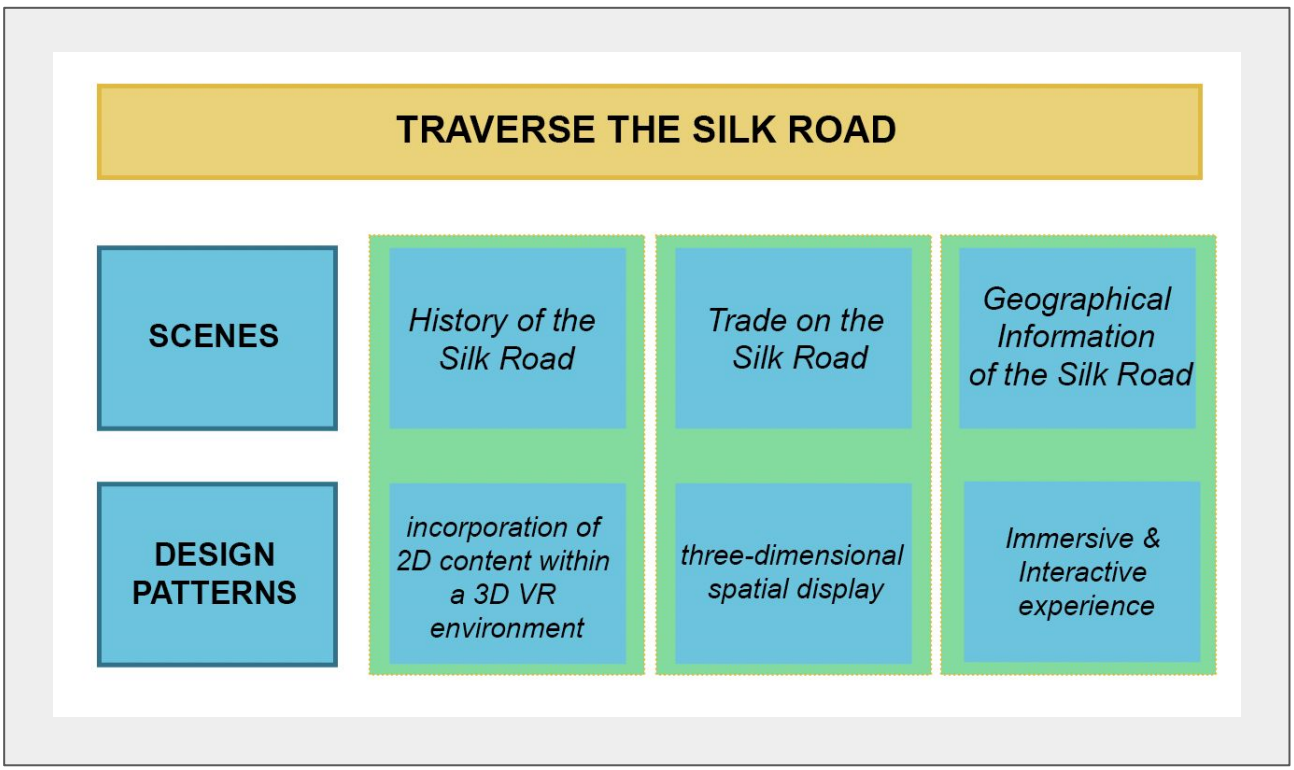

Fig.1 project structure

3.1 Data Collection and Story Design

Upon determining the thematic focus of the project, I embarked on an extensive data collection process using a diverse array of sources, including literature, books, documentaries, websites, and videos. To enhance the narrative design, I meticulously organized the data into three thematic chapters, each addressing a distinct aspect of the Silk Road.

History of the Silk Road: This chapter delves into the territorial shifts of countries connected to the Silk Road across various eras, chronicling its birth, development, the importance of the Hexi Corridor, the influence of warfare, and the notable contributions of figures such as Zhang Qian and Marco Polo.

Trade on the Silk Road: This section provides a comprehensive overview of the commercial activities along the Silk Road. I have compiled information on the various commodities traded from different countries, an exploration of camels as a prominent means of transportation, and an account of how the Black Death spread along this critical trade route.

Geographical Information of the Silk Road: The final chapter focuses on geographical insights, including the altitudes and locations of the towering peaks of the Himalayas, Tianshan, and the Pamirs. Additionally, I have gathered details on several key cities along the Silk Road, such as Chang'an, Serevan, Palmyra, and Constantinople, including their mean elevations and geographical coordinates.

By structuring these contents into three distinctive chapters and employing interactive features and voice-over narration, this project endeavors to immerse users in the multifaceted and rich story of the Silk Road. The integrative approach allows for an engaging and informative experience that not only informs but also captivates the users, providing a nuanced understanding of the complex history and legacy of the Silk Road.

3.2 Scene Design

Within the virtual expanse of this project, I executed four distinct scenes, incorporating an introductory scene alongside the previously discussed three chaptered experiences. The initial scene serves a dual function. First, it offers users a comprehensive introduction to the mechanism of the handle controller, ensuring a seamless navigation experience. Second, through specific triggering actions, it directs users to the trio of subsequent story-centric scenes, thus establishing a narrative trajectory.

The "History of the Silk Road" scene adopts a museum-like exhibit format. A meticulously curated exhibition table stands central to this space, with various 2D elements systematically categorized and displayed. Dominating the user's immediate visual field is a sequence of historically sequenced maps. Through immersive interactivity, users can delve deeper into specific regions or countries depicted on these maps, gleaning insights into their respective roles and significances within the broader Silk Road narrative. An essential feature of this exhibition table is the presence of a time-switching operation button. This interactive feature facilitates transitions between the three distinct historical epochs, granting users can browse in the relevant order.

Transitioning to the "Trade on the Silk Road" tableau, the scene morphs into a spatial anthology. Comprising six unique environments, each space becomes a repository of goods, emblematic of its respective narrative. Interconnecting these spaces are serpentine pathways, reminiscent of flowing silk, a poignant nod to the Silk Road's legacy. Eschewing a linear narrative, this scene champions user autonomy, permitting them to chart their explorative journey based on personal inclinations.

Finally, the "Geographical Information of the Silk Road" scene paints a topographical tapestry. Emulating the Silk Road's actual cartographic layout, mountains and cities are strategically placed, with elevations scaled to actual altitudes. Distinctive landmark models accentuate the cities, providing visual markers. To enhance the user's spatial awareness, an on-demand mini-map feature is integrated, enabling real-time positional tracking along the Silk Road.

3.3 Design Patterns for Virtual Reality Storytelling

In optimizing the narrative experience within a VR environment, this project strategically integrates three core design patterns:

3.3.1 incorporation of 2D content within a 3D VR environment

In 1999, Lindeman, Sibert, and Hahn embarked on an exploration of the challenges and opportunities posed by the transition from traditional 2D human-computer interaction paradigms to immersive 3D environments. Recognizing the vast repository of knowledge accumulated over the preceding decades in 2D HCI, they sought ways to leverage this familiarity while addressing the unique demands of 3D spaces. They aimed to apply established 2D interaction knowledge to the immersive 3D world. A key innovation was their mobile window: effectively a floating interface, that moves in sync with the user's hand motions. This ingenious solution straddled the worlds of 2D and 3D, offering users a familiar interaction method (akin to interacting with a 2D screen or window) within the immersive environment.

In this endeavor, I adopted familiar elements from historical museums or exhibitions, specifically the information panels, as a point of entry for users. Within the virtual space, users trigger the animation of the 2D panels (maps) by placing a 3D model onto them. These animations sequence the story on the panels, providing users with a structured narrative. The added interactivity not only enriches user engagement but also fortifies their retention of the story. This aligns with James et al.'s (2002) perspective, which underscores that in an immersive environment, active user engagement fosters more effective learning than mere passive reception.

3.3.2 three-dimensional spatial display

This approach capitalizes on the spatial nature of VR, presenting information in a manner that mimics real-world interactions. It encourages users to explore and interact, making the narrative more engaging and memorable. In this part, I expect to bring users into an immersive world by simulating or creating the environment in which the story takes place, so as to enhance users' understanding of the story. The style of the scene can also be changed according to different experience objects or different narrative contents.

3.3.3 Immersive & Interactive experience

In this segment, I endeavor to transform users from mere spectators to active participants within the story's milieu. By leveraging immersive interactions, users engage with the visual elements, experiencing the narrative as though it were tangible reality. Such immersive experiences foster a more profound connection between the

narrative and the user, amplifying both retention and emotional resonance. Illustratively, in one scene of this project, the participatory design allows users to virtually scale mountains using controllers, offering an intuitive understanding and comparison of the mountains' elevations.

3.4 User Testing and Analysis

I conducted a user test for the VR project based on the aforementioned content. The evaluation was structured around a questionnaire that addressed various facets such as VR experience comfort, the efficacy of different design patterns in narrative enhancement, and interaction design. Participants who engaged with the VR experience provided their feedback via this questionnaire. Analyzing the collected responses has offered insights into potential areas of improvement for future iterations.

4 Implementation

4.1 Evaluations & Overview

In the data processing phase of this project, I employed four distinct methods, each contributing uniquely to the representation and accessibility of the information. These methodologies were carefully chosen to enhance the visual and experiential aspects of the project, thereby enriching the user's engagement with the content:

Map Design: This approach involved the selection and focus on specific geographic information within maps. I curated these details and unified them under a newly designed map style, ensuring consistency and a fresh visual appeal(Fig.2).

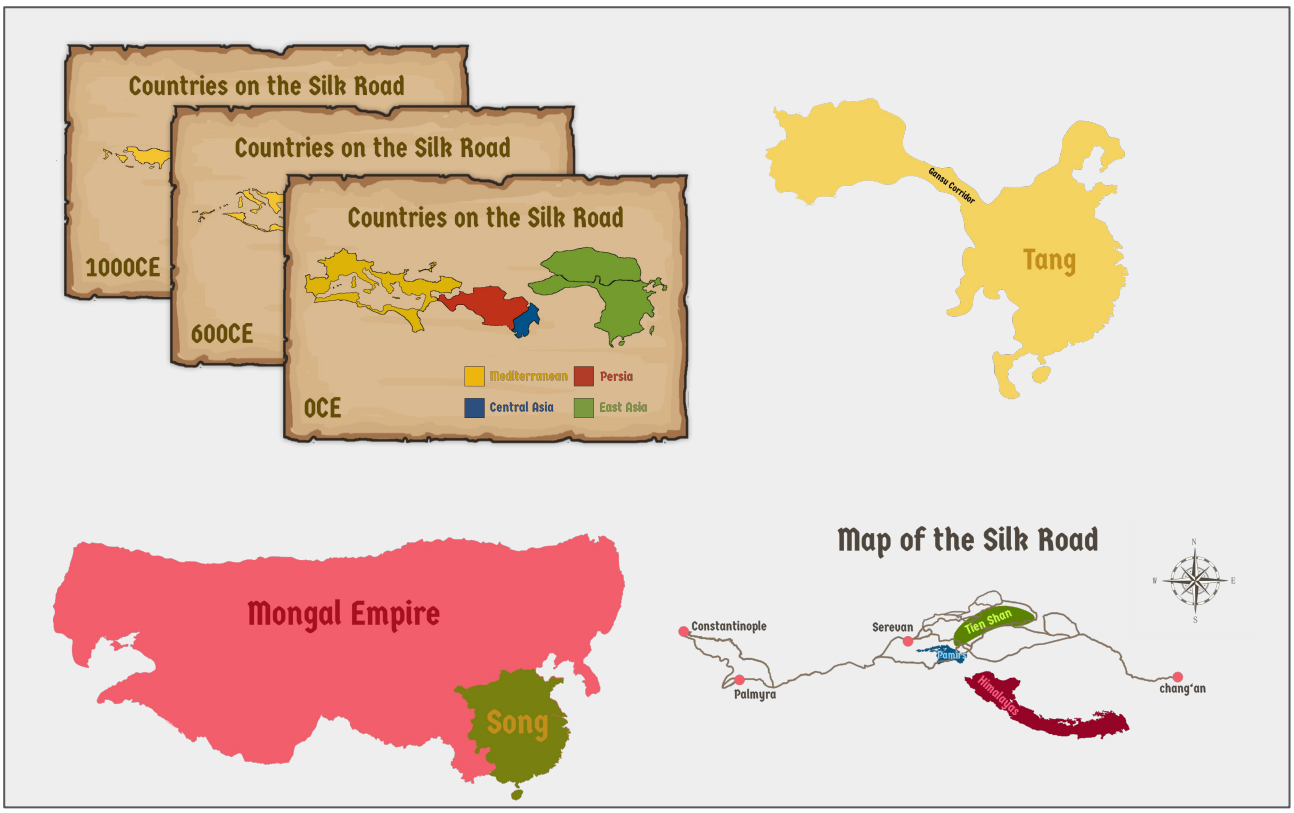

Fig.2 map design

Data Visualization: This method required the transformation of raw data into a more digestible form. The information was organized into CSV format, facilitating the creation of both 2D and 3D chart displays. These visualizations provided a more immediate and intuitive understanding of the data's underlying patterns and meanings.

Model Design: This innovative approach involved converting certain information into three-dimensional models and constructing corresponding scenes. This immersive technique allowed users to explore the information spatially, adding a layer of realism and tangibility to the otherwise abstract data.

Text and Voice-Over Narration: Lastly, I carefully selected and composed essential content such as stories and historical documents, presenting them either in written text or through voice-over narration. This method helped in crafting a narrative that connects with the user on a personal level, providing context, depth, and a human touch to the information.

Together, these methods form a cohesive and multifaceted approach to data processing, each contributing to a comprehensive and engaging exploration of the subject matter. By combining traditional and innovative techniques, this project creates an immersive experience, inviting users into a rich, interactive, and emotionally resonant journey through the history and culture of the Silk Road.

After organizing the content, I segmented the narrative of this project into three distinct chapters.The "History of the Silk Road" chapter delves into its evolution over time by segmenting the narrative into three pivotal eras. In the period from 206 BC to 220 AD, the spotlight is on Zhang Qian's diplomatic expedition to Central Asia. This journey was instrumental in the birth of the Silk Road, fostering increased cultural and trade exchanges between the East and West. Additionally, the significance of the Hexi Corridor is accentuated, with its role as the primary conduit for China's Western trade endeavors and the establishment of four crucial counties within. Transitioning from 618 to 917 AD, the narrative captures the westward journey of the Buddhist monk Xuanzang. His travels mirrored those of Zhang Qian in amplifying cultural and religious exchanges along the Silk Road. However, this era also marked challenges, especially the geopolitical upheavals towards the end of the Tang Dynasty that saw the Hexi Corridor's fall, disrupting trade. The last segment, spanning from 960 to 1279 AD, centers on the Mongol Empire's ascendancy. Under formidable leaders like Genghis Khan and Kublai Khan, the Silk Road witnessed a renaissance, ensuring the fluid exchange of trade, ideas, and culture. Intertwined within this period is the tale of Marco Polo, whose iconic travels from Venice to the Mongol Empire offer a captivating Western perspective on the East. Throughout this chapter, thematic maps enrich the narrative, providing a visual representation of the Silk Road's spatial evolution and the political dynamics of the regions it encompassed.

The chapter "Trade on the Silk Road" delves deep into the nexus of trade, culture, and adversity that defined this ancient route. Within this chapter, the different goods from the different countries on this trade route are first introduced. China, as the birthplace of silk and tea, forms the foundation, highlighting its crucial role in the initial exchange of these precious commodities. Next, the expertise of Europe is showcased through the lens of the Italian glass factories, illuminating the delicate art of glass-making that was transported eastwards. Southeast Asian farms transport users to the aromatic world of spices, a coveted commodity that reshaped global palates. Meanwhile, the European medieval stables serve as a testament to the trade of livestock, with majestic horses

symbolizing power and status. At the heart of this journey are the camels, resilient 'ships of the desert', essential for the very functioning of the Silk Road. Fascinating facts about their capabilities, such as traveling four days at a stretch, bearing 200 kilograms, and storing nearly 100 kilograms of water in their first stomach, come alive in this zone. However, not all tales are of prosperity; the chapter also delves into the grim era of the Black Death. Through immersive three-dimensional data visualization, users confront the harrowing toll of the epidemic across regions and timelines. This journey transcends mere trade, offering a rich tapestry of cultural exchanges, resilience, and the interconnected saga of our shared past.

Within the section titled "Geographical Information of the Silk Road," a meticulous exploration was undertaken to elucidate the topographical landmarks pivotal to the Silk Road's narrative. Data pertaining to three prominent mountain ranges—the Himalayas, Tianshan, and the Pamirs—was collated, encapsulating both their altitude specifics and geographical coordinates. These mountainous terrains, apart from their evident geographical impediments, also resonated with historical and cultural significance, testifying to the intrepid spirit of ancient traders. Additionally, the exposition delves into the urban nodes that punctuated this transcontinental route. Four cities, namely Chang'an, Serevan, Palmyra, and Constantinople, are highlighted, detailing their respective mean elevations and precise locational information. These metropolises, often referred to as the linchpins of the Silk Road, facilitated multifaceted interactions ranging from commerce to cultural exchange.

4.2 Scene Development

In the initial scene, I crafted an indoor setting. The walls prominently feature some detailed paintings of the Silk Road, alongside the project's title, "Traverse the Silk Road." These images were generated by entering the keyword "Silk Road" into mid journey. To ensure users can navigate the virtual space effectively, an instructive comic is also displayed, offering guidance on the controller's operations(Fig.3). In the initial scene, I integrated three distinct models: a book, a globe, and a treasure chest. Upon user interaction with the handle, these models are highlighted with a green outline, signaling their interactive nature. When users approach these elements and press the trigger button, they're teleported to corresponding scenarios, thus allowing for an immersive navigation experience.

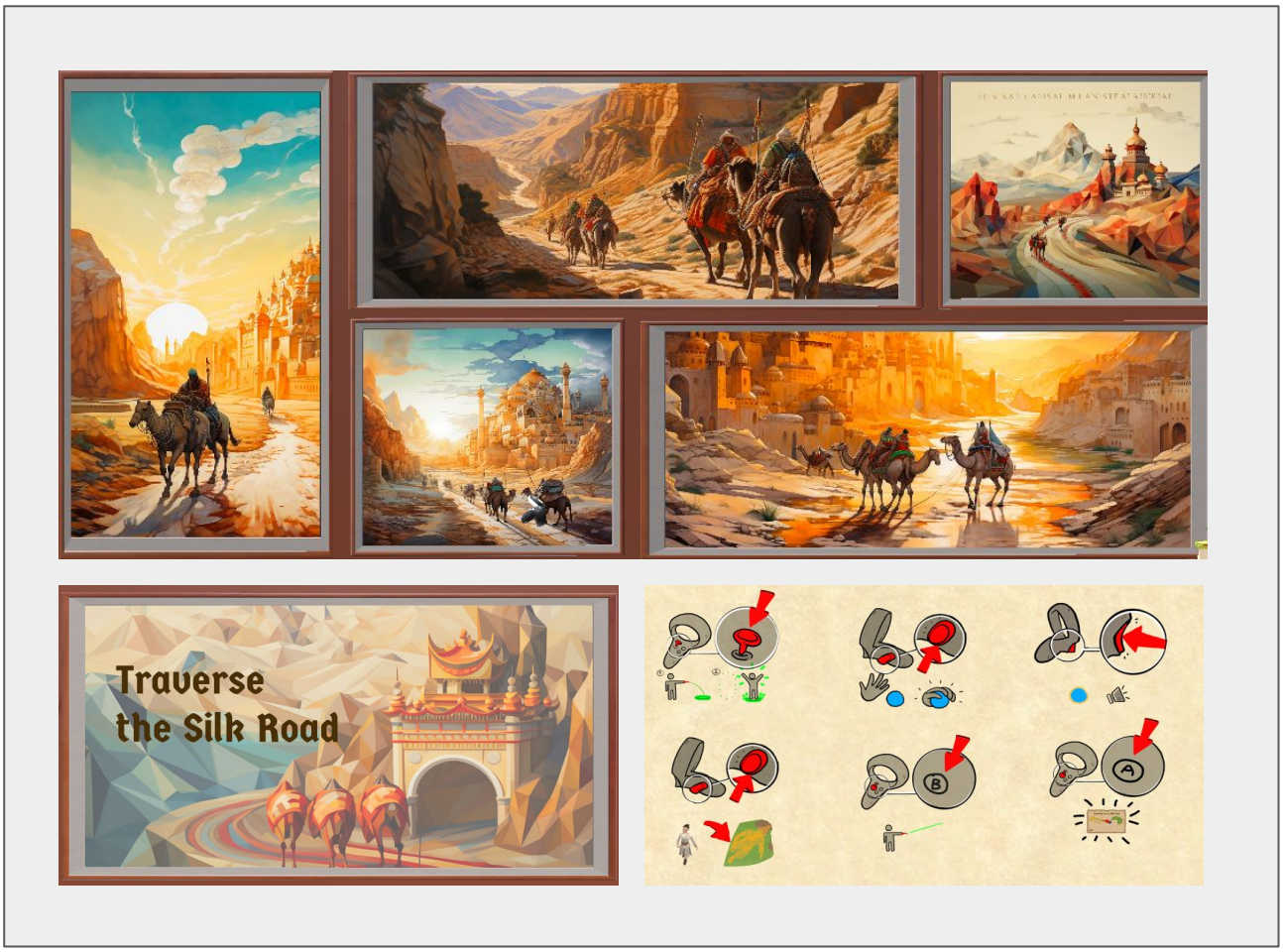

Fig.3 screenshot of the project's initial scene

In the "History of the Silk Road" segment, I showcased three period-specific maps highlighting Silk Road's pivotal regions during those times. The maps demarcate Persia, the Mediterranean, East Asia, and Central Asia in distinct colors—blue, green, red, and yellow respectively. Each region on the map is interactive, offering users insights about the corresponding country upon engagement.

Centrally positioned is a display table with thematic maps and models. Interacting with these models activates map animations accompanied by voiceovers, offering historical narratives. Notable stories like Zhang Qian's western mission, Xuanzang's western journey, and the Mongol unification utilize this interactive design. For Marco Polo's tale, I opted for a scrollable axis. Furthermore, I incorporated the "IATK" tool (Maxime Cordeil et al., 2019) for data visualization, enabling a more comprehensive representation of information within the project. Users can slide through it horizontally, revealing Marco Polo's chronologically ordered adventures and his whereabouts during various events(Fig.4).

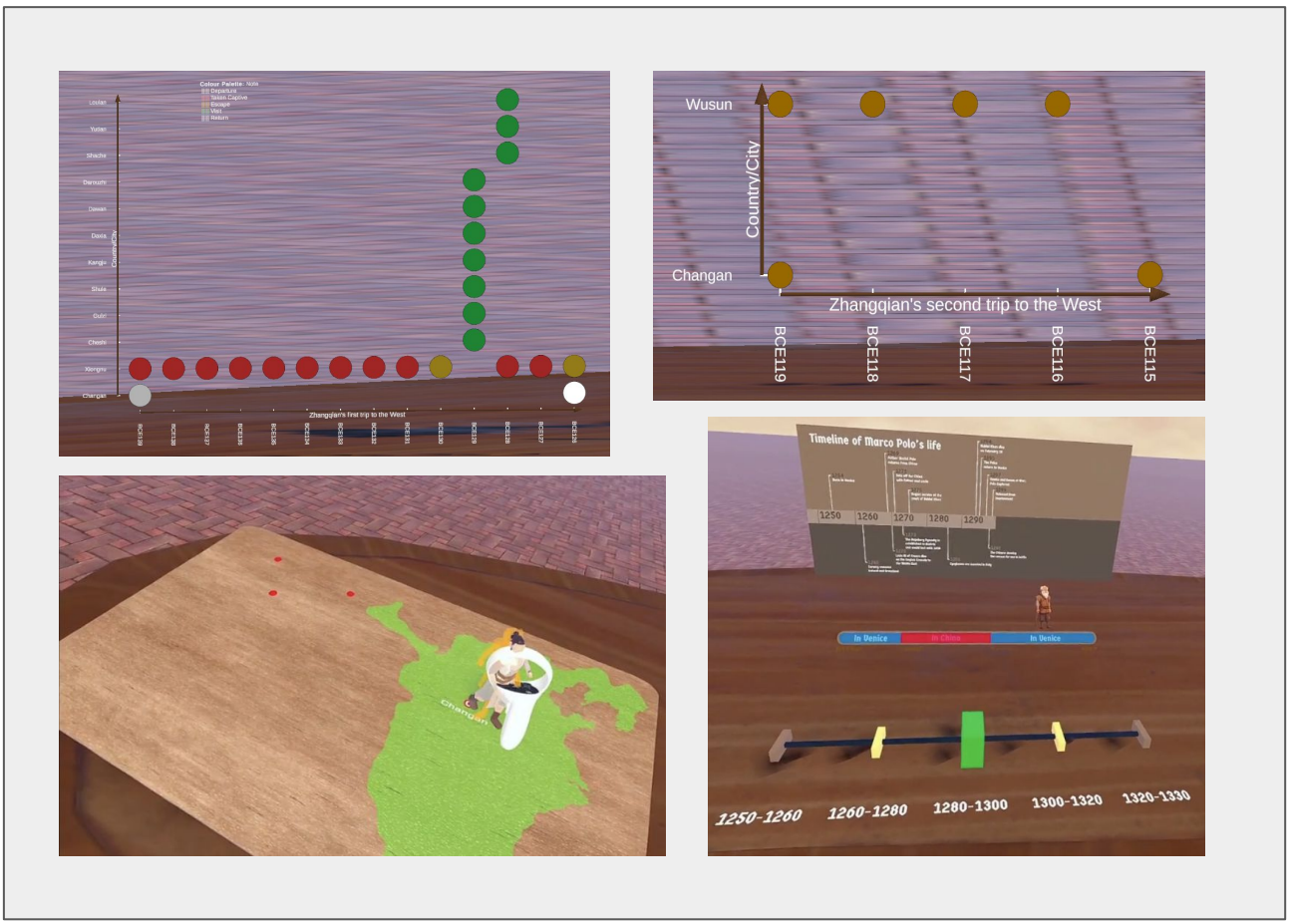

Fig.4 screenshot of the project's first scene

In the "Geographical Information of the Silk Road" scene, I showcased three mountains and four cities integral to the Silk Road, arranged geographically(Fig.5). For the cities, I represented them with cubes, where the cube's height corresponds to the city's mean altitude. Atop each cube, I placed scanned models of each city's iconic landmarks. For the mountains, I created stone formations that mimic their real-world contours, and I proportionally scaled their height in relation to the tallest peak of each range. Users can interactively climb these virtual mountains. A mini-map feature is also integrated: by pressing the 'A' button on their controller, users can see their real-time location, providing context as they explore landmarks along the Silk Road.

Fig.5 screenshot of the project's second scene

In the "Trade on the Silk Road" scene, I designed six interconnected spaces, linked by a pathway reminiscent of silk's winding texture. Each space, representing a distinct environment, offers users an entrance and exit(Fig.6).
Southeast Asian Spice Fields: Users can interact with spice models to hear a narrative about the spice's significance.
Italian Glass Factory: This area illuminates the Silk Road's role in spreading glass products, allowing users to delve into its history.
Chinese Region: An immersive scene showcases silk and tea, quintessential Chinese exports, enhancing user understanding of their importance.
Horse Stable: This segment highlights the horse trade, letting users explore how horses became valuable commodities.
Camel Caravan: Emphasizing camels' critical role in Silk Road transport, I've visualized data like camels' impressive ability to drink up to 100kg of water in one go and their capacity to carry 200kg for four days. This is imaginatively represented through models: envision 300 cans of Coke alongside two adult sheep.
Black Death Zone: Here, users can engage with narratives about the Black Death's impact. Furthermore, a three-dimensional data visualization depicts the staggering death toll across regions and eras due to this pandemic.
Through these distinct spaces, users can grasp the multifaceted trade activities and events that shaped the Silk Road's legacy.

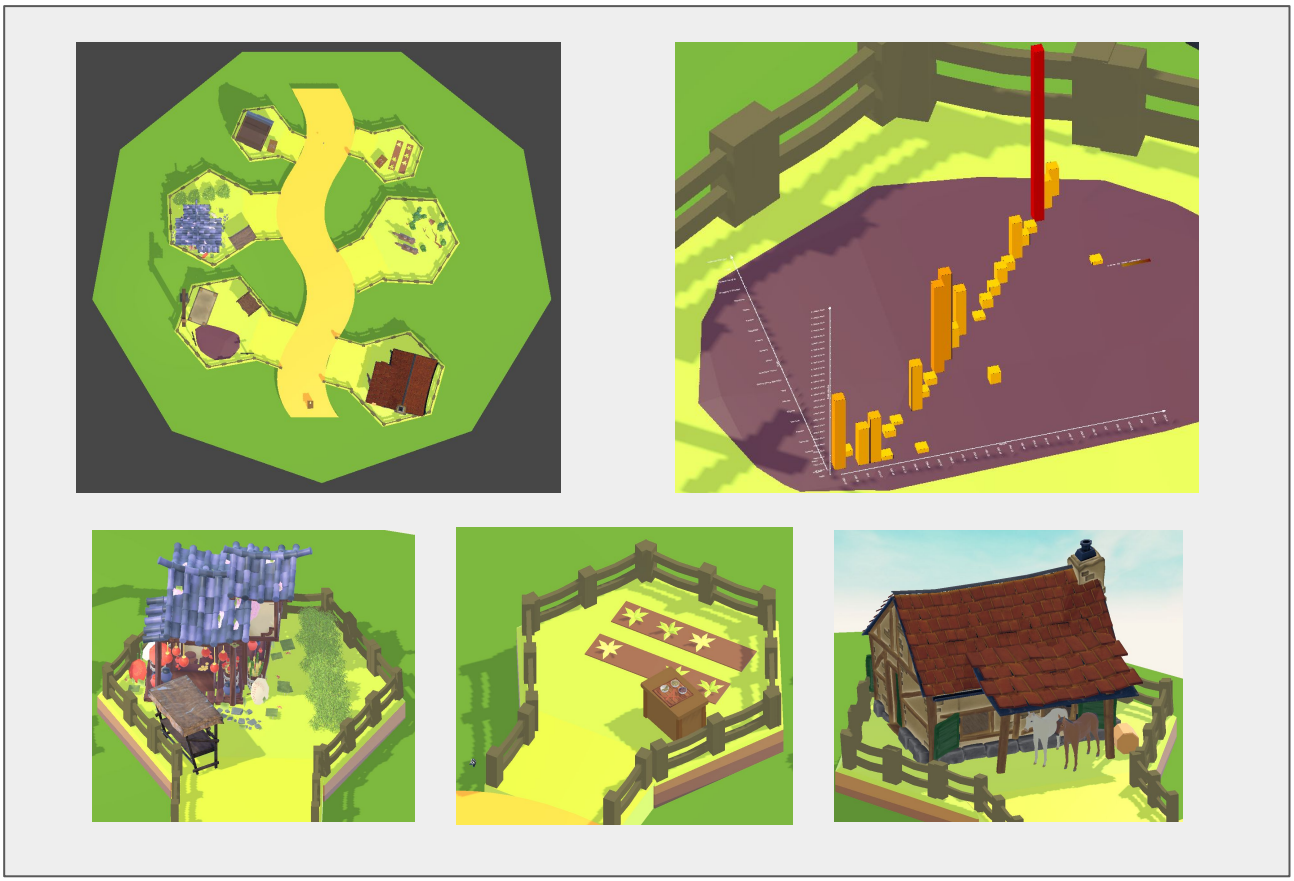

Fig.6 screenshot of the project's third scene

4.3 Virtual Reality Interactive Production

In the development of this interactive project, I predominantly utilized VRTK4.0 in tandem with Unity. VRTK stands as a well-established tool for virtual reality development, offering a plethora of handy VR functionalities. Additionally, it boasts notable compatibility across various equipment brands. Within this project's interaction design, item-based interactions encompassed actions like item pick-up, movement, scaling, and virtual button-press functionalities, along with ray emissions. Player-centric interactions comprised character teleportation and virtual mountain climbing. The majority of these functionalities were efficiently executed using the Tilia Packages within VRTK4.0.

5 User Testing

In this evaluation, six participants were invited to engage with the "Traverse the Silk Road" application. All participants had a basic knowledge of the Silk Road but lacked detailed understanding. They were required to use a Meta Quest 2 virtual reality headset for the experience. An intermediate assessment of the project highlighted that the collision boundaries in the scenes were excessively large, making it challenging for users to interact closely with in-scene objects. Additionally, there was a common sentiment among users that incorporating background music would elevate the immersive quality of the experience. Subsequent to the feedback obtained, adjustments were made to the application. The collision boundaries within the scenes were optimized to facilitate smoother user interactions. Additionally, appropriate background music was integrated into the experience to further immerse users in the narrative of the Silk Road. In the culminating evaluation, participants were engaged in a completely immersive experience. Subsequently, they were provided with a questionnaire encompassing the following aspects:

1. What is your usual way of learning about cultural heritage?
2. Have you ever used a Virtual Reality (VR) device before this test?
3. Did you experience any discomfort or dizziness during or after the experience?
4. What discomfort did you experience during the experience？
5. On a scale of 1 (Nothing) to 5 (A lot), how much did you know about the Silk Road before using this VR application?
6. How well do you think you understand the history of the Silk Road after experiencing the VR application? (Scale from 1 (Not well) to 5 (Very well))
7. How well do you think you understand the geographical data about the Silk Road after experiencing the VR application? (Scale from 1 (Not well) to 5 (Very well))
8. How well do you think you understand the trading dynamics of the Silk Road after experiencing the VR application? (Scale from 1 (Not well) to 5 (Very well))
9. How would you rate the interactivity of the VR application? (Scale from 1 (Not interactive) to 5 (Very interactive))
10. How easy was it to navigate through the VR experience? (Scale from 1 (Very difficult) to 5 (Very Easy))
11. Were there any parts of the VR experience where you felt lost or confused? If so, please explain.
12. Did the VR application change your perspective or understanding of the Silk Road? If yes, how?
13. What part of the VR experience was the most engaging or interesting to you and why?
14. Are there any improvements you would suggest for this VR application?

Fig.7 user testing

Based on the feedback obtained, the application's scenes, narratives, and interactive designs effectively facilitate storytelling objectives. Post-experience, users reported a more comprehensive understanding of the cities, trade, and historical occurrences associated with the Silk Road. Additionally, the three distinct design patterns utilized were positively acknowledged in the context of VR narratives. This encompasses the incorporation of 2D content into the scene via interaction and delineating equivalences between different entities through varied models. Notably, the innovative mountain climbing feature to interpret data was universally lauded. This interaction not only heightens participant engagement and immersion but also offers an unparalleled experience often challenging to replicate.

Despite the application's merits, a series of constructive critiques emerged, directing avenues for future enhancement. From a virtual reality (VR) experiential perspective, issues surrounding visual stability became evident. One participant noted occasional screen flickers during movements or teleportation, which engendered mild discomfort. More critically, another user prematurely terminated their session due to vertigo elicited by the 3D environment. Such feedback underscores the importance of continually refining VR experiences. Some of these challenges might be mitigated by enhancing device performance and scene optimization. For users susceptible to disorientation within 3D virtual realms, modularizing the experience into distinct chapters could be advantageous, potentially limiting singular exposure durations. Furthermore, the introduction of buffer zones, interspersed throughout the narrative, may alleviate some of the disorientation stemming from continuous in-scene movement.

Regarding the application's usability, a prevalent sentiment was users' initial uncertainty, compounded by unfamiliarity with specific operations. In the maiden scene, my design concept revolved around a virtual room, aiming to inspire user-initiated exploration to identify interactive models. Regrettably, the embedded comic instructions, intended to familiarize users with controller operations, proved insufficient in fortifying user habit. This deficiency was particularly pronounced amongst VR novices, who, while enamored by the novelty of VR interactions, often overlooked the scene's integral content elements, such as voiceovers, texts, or diagrams. To circumvent this, future versions could benefit from adopting Meta's official guideline application, amalgamating auditory and textual cues with hands-on interactions. This iterative approach ensures users internalize the application's requisite interactions. Additionally, novice VR users could be availed of a preliminary session, acquainting them with VR's immersive dynamics, thereby ensuring undivided attention during the primary narrative.

Feedback also highlighted a palpable desire for more dynamic and interactive 3D spatial displays. While certain scene elements were interactively designed, the overarching environment remained largely static. Users expressed aspirations for more intricate animations and scene adaptability, synchronized with voiceover progressions. The enormity of this undertaking is acknowledged, and while temporal constraints hindered its inclusion in the present iteration, it remains an integral facet for subsequent enhancements.

Lastly, while the feedback garnered was insightful, the limited sample size for testing could restrict the depth of the insights. Engaging with a larger, more diverse user group in future tests would offer a more comprehensive understanding of user needs and preferences.

6 Conclusion

The present project embarks on an innovative exploration into the realms of data-driven storytelling and the virtual representation of cultural heritage. By leveraging the immersive capabilities of virtual reality (VR), it pioneers three distinctive design patterns: Incorporation of 2D content within a 3D VR environment; Employment of a three-dimensional spatial display; Development of an immersive visual experience that users can engage with.

These patterns were not merely theoretical constructs but were implemented and subjected to preliminary empirical validation. Engaging six users in a test setting, the project yielded initial indications of the models' proficiency in shaping immersive narratives within a virtual reality milieu. Feedback from the participating users predominantly endorsed the application's storyline, scenic design, interaction, and the employed design patterns. Moreover, participants reported an enhanced comprehension of the Silk Road post-experience. Such findings, while provisional, offer invaluable insights and substantiate a framework that could guide future design within immersive narrative content.

However, this study is not without its limitations. Several challenges surfaced, including inefficiencies in user operation guidance and scenes where immersion within particular environments could be further enriched. These insights are not deficiencies but rather opportunities for future refinement.

In forthcoming research and development, there will be a continued emphasis on augmenting immersion within virtual reality. This will encompass a holistic approach that intertwines environment, interaction, and animation design. Moreover, the endeavor to tailor virtual reality experiences for those prone to motion sickness reflects an inclusive vision, striving to make the technology accessible to a broader audience.

Ultimately, this project signifies a step forward in the uncharted territories of immersive data-driven storytelling. It also opens up novel avenues for cultural engagement, education, and a deeper human connection to our shared heritage.

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Software

Adobe Photoshop, Illustrator, After Effects and InDesign
Autodesk Maya
Cinema 4D
Unity 3D (Oculus Integration, VRTK4.0)
Substance Painter

Music

https://pixabay.com/music/adventure-marrakesh-159030/
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Models

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AI Tools

I utilized various technological tools to enhance and refine my project. OpenAI's ChatGPT played a pivotal role in proofreading and refining the text. I leveraged Mid Journey to create the pictures for the initial scene, while Microsoft's Azure was for converting text into speech for the voiceovers.

Appendix 1

Questionnaire results from user testing

1. **What is your usual way of learning about cultural heritage**

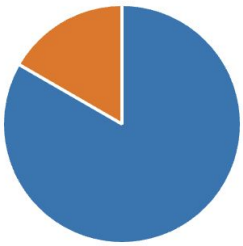
more details

Social Media	4
News	1
Museum	5
Video Game	0
other	1

2. **Have you ever used a Virtual Reality (VR) device before this test?**

more details

Yes	5
No	1



3. **Did you experience any discomfort or dizziness during or after the experience?**

more details

Yes	2
No	4

4 . What discomfort did you experience during the experience?

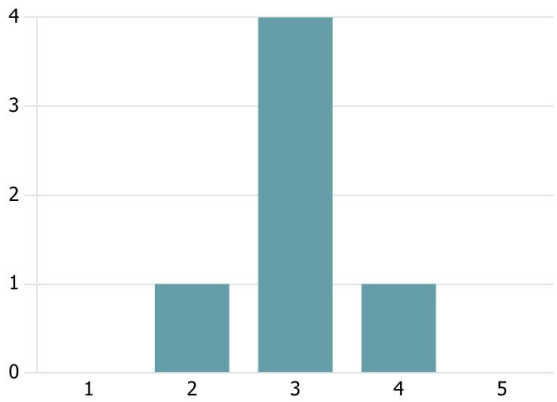
5 reply

ID ↑	name	reply	language
1	anonymous	The screen sometimes is flickering, causing slight dizziness.	
2	anonymous	no	
3	anonymous	None	
4	anonymous	No	
5	anonymous	Motion sick	

5. **On a scale of 1 (Nothing) to 5 (A lot), how much did you know about the Silk Road before using this VR application?**

more details

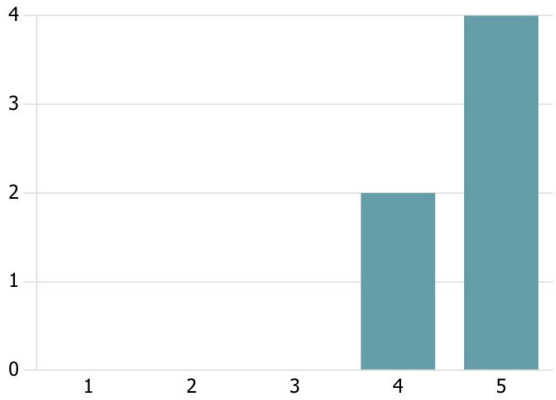
3.00
average score



6. **How well do you think you understand the history about the Silk Road after experiencing the VR application? (Scale from 1 (Not well) to 5 (Very well))**

more details

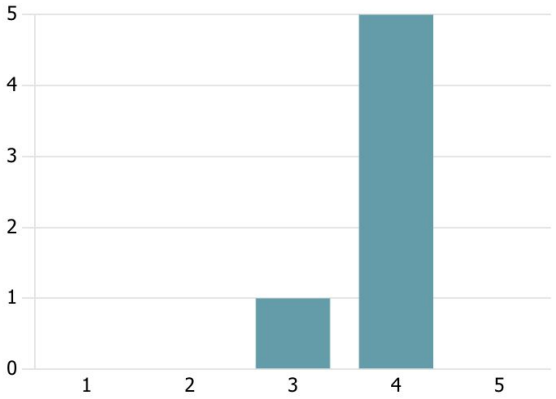
4.67
average score



7. **How well do you think you understand the geographical data about the Silk Road after experiencing the VR application? (Scale from 1 (Not well) to 5 (Very well))**

more details

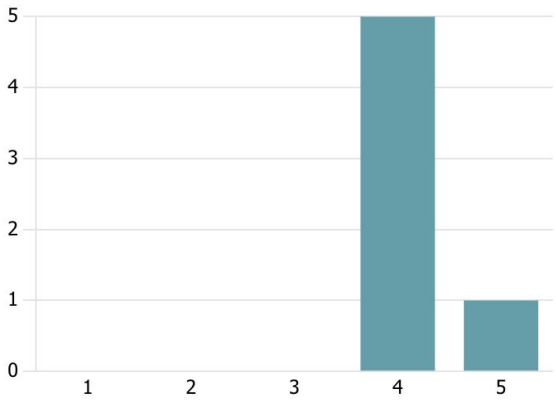
3.83
average score



8. **How well do you think you understand the trading dynamics of the Silk Road after experiencing the VR application? (Scale from 1 (Not well) to 5 (Very well))**

more details

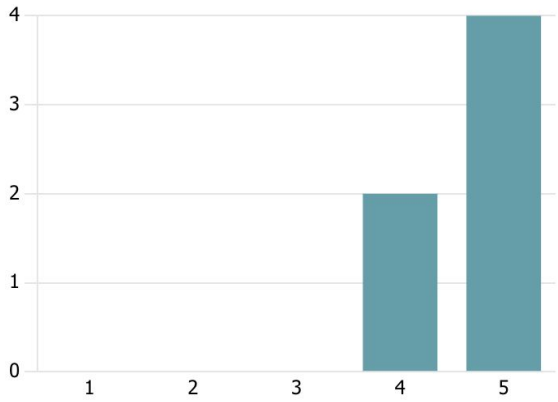
4.17
average score



9. **How would you rate the interactivity of the VR application? (Scale from 1 (Not interactive) to 5 (Very interactive))**

more details

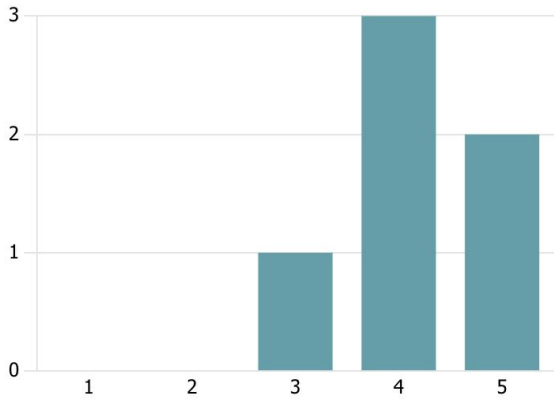
4.67
average score



10. **How easy was it to navigate through the VR experience? (Scale from 1 (Very difficult) to 5 (Very Easy))**

more details

4.17
average score



11. Were there any parts of the VR experience where you felt lost or confused? If so, please explain.

6 reply

ID ↑	name	reply	language
1	anonymous	The initial scene is somewhat unclear regarding which objects are interactive, and the yellow highlighting isn't distinct. I initially thought I could interact with the painting, but upon entering, I realized there are quite a few distracting elements around the room.	
2	anonymous	It's easy to forget which button should I press	
3	anonymous	sometime in the room, I don't know where I can go	
4	anonymous	In the Home section, I experienced confusion as I wasn't certain which item I could interact with in order to navigate to different scenes. More hints or guidance could be on the side to tell the player which item is functioning.	
5	anonymous	No	
6	anonymous	The instructions are not clear enough to determine clickable items	

12. Did the VR application change your perspective or understanding of the Silk Road? If yes, how?

6 reply

ID ↑	name	reply	language
1	anonymous	yes,I can see the data more clearly and enjoy it with game	
2	anonymous	Yes. I know more country on the Silk Road	
3	anonymous	Yes, it gives me a clearer view of routes and historical timelines due to 3D models	
4	anonymous	I appreciate the scene where I can visually grasp the equivalence between different objects. For instance, the representation of water being equal to numerous bottles of coke is quite captivating!	
5	anonymous	Yes, let me better understand the Silk Road	
6	anonymous	Yes, it gave me a clear sense of the Silk Road from a data point of view	

13. What part of the VR experience was the most engaging or interesting to you and why?

6 reply

ID ↑	name	reply	language
1	anonymous	climb the mountain and the life of Marco Polo	
2	anonymous	I like the way to pick up something in VR experience.	
3	anonymous	The interaction of climbing mountain	
4	anonymous	Love climbing mountain a lot!!!	
5	anonymous	climb mountains, cuz it can make my body move	
6	anonymous	I think mountain climbing is the most fun! The height of each mountain can be seen, which inspires me to challenge! I think this part is interesting and very interactive!	

14 . Are there any improvements you would suggest for this VR application?

6 reply

ID ↑	name	reply	language
1	anonymous	stable and jump a scene smoothly	
2	anonymous	The tutorial for how to use VR could be add in the game scene.	
3	anonymous	More prompts are better	
4	anonymous	The user guidance system could be revised a little bit, adding background music for immersive feeling	
5	anonymous	It is possible to keep a little bit of freedom that can make users feel interested in this application. Because VR players may also be gamers, and some gamers value freedom, like me. But considering that it's not a game app, it's a narrative app, and that's actually pretty good right now.	
6	anonymous	If possible, I hope to provide a larger field, so as to avoid motion sick	

Appendix 2

voiceover scripts

In 138 BCE, General Zhang Qian embarked on a momentous mission as an envoy to the Western Regions. His objective was twofold: to survey the territories and to attempt an anti-Xiongnu alliance with the people of the West. Departing from Chang'an, the capital of the Western Han Dynasty, Zhang Qian navigated through vast western lands, eventually reaching the trio of kingdoms - Loulan, Qiuci, and Yutian, situated on the northeastern fringe of the desert. The repercussions of his journey were immediate and far-reaching. Diplomats and tradesmen from China, began exchanging silk and jade, for horses and cotton, signaling the dawn of the Silk Road trade.

The Hexi Corridor was initially the territory of the Rouzhi, but it was occupied by the Xiongnu during the era of the Old Shanyu. During the mid-Western Han Dynasty, due to Zhang Qian's mission to the Western Regions, Emperor Wu of Han sent Huo Qubing to defeat the Xiongnu Xutu and Hunye tribes. As a result, the Hexi Corridor was opened up, and four prefectures were established: Wuwei, Zhangye, Jiuquan, and Dunhuang. The Hexi Corridor served as a crucial part of the eastern end, of the ancient Northern Silk Road, and was an essential international channel for political, economic, and cultural exchanges between the Han territories, in ancient China and the Western world.

The growth and prosperity of the Silk Road trade, during this era can also be attributed to the renowned monk, Xuanzang. during his epic voyage from Chang'an to the Gansu Corridor, Hami, and Turpan, and further westward to India. Xuanzang's journey and the warm reception he encountered along his route, significantly fostered improved relationships between the Tang Dynasty, and the various tribes ,and kingdoms he visited.
Regrettably, by the year 768 AD, the Tang Dynasty lost its dominion over the western regions. This unfortunate turn of events, led to a significant cessation, of trade activities along the Silk Road.

In the 13th century, the Song Dynasty found itself under the relentless assault of the Mongols. Despite this turmoil, the western routes of the Silk Road experienced a resurgence under Mongol influence, during their expansive thrust into Central Asia, and Europe. This was thanks to the Mongols' proactive promotion, of trade across their vast empire. Trade activities along the Silk Road experienced a rebirth, and under the auspices of the Yuan Dynasty, the Silk Road reached a golden era, of prosperity and cultural exchange.
One of the famous explorations conducted via the Silk Road routes, was the journey to China from Italy by Marco Polo, a Venetian explorer. Embarking on a daring journey, that lasted over two decades, Polo traversed this complex network of trade routes stretching, from Europe to Asia, reaching as far as the splendid courts of Kublai Khan in China. Polo's journey, brave and groundbreaking, played a significant role in bridging East and West, fostering mutual understanding, and encouraging cultural exchange.

Silk. a product of exquisite craftsmanship, first originated in China as early as 3,000 B.C. This timeless fabric was the perfect trade commodity for merchants, and diplomatic caravans journeying overland, traversing thousands of miles to reach their final destinations. Valued for its lightness, versatility, and inherent worth. silk found itself, at the heart of many an exchange.
The Silk Road bore witness to one of the most profound exchanges in history – the trade of silk for horses. Bolts of Chinese silk, celebrated for their superior quality and intricate craftsmanship, were traded for the sturdy, finely-bred horses from the vast Mongolian steppes and the lofty

Tibetan plateau. horses were not just the prized possession in this trade; they were also the very means of transport that facilitated these transactions. They stood as the epitome of a high-value, low-weight commodity on the Silk Road.

East and South Asia, regions rich in spice cultivation, gave birth to exotic commodities like cinnamon from the lush lands of Sri Lanka and cassia from the expansive terrains of China. These treasured items, however, did not usually grace the dusty overland routes of the Silk Road. Instead, they embarked on a journey along the ancient maritime Silk Road, a network that intricately linked port cities stretching from Indonesia, westward through India, and reaching as far as the Arabian Peninsula.

Among the coveted belongings of the Asian elite, archaeologists have discovered Roman glassware, creating a tangible link to a distant culture. This distinct soda-lime glass, crafted with Roman finesse into elegant vases and goblets, was a coveted item in the East. Such artifacts would have been eagerly traded for silk - a commodity that had become something of an obsession for the Romans.

Known to the world as a symbol of hospitality and tranquility, tea originated in the serene valleys of ancient China. this cherished commodity journeyed across the extensive pathways of the Silk Road, fostering connections between the East and West. From China's distant borders to the bustling markets of Persia and the noble houses of Rome. the allure of tea traversed cultures and traditions.
As a network of commerce and cultural exchange, the Silk Road connected distant lands, fostering the exchange of goods, ideas, and unfortunately, diseases. Among them, the most devastating was the Black Death. From the heart of Asia to the corners of Europe, the Black Death left a path of destruction. It wasn't a traded good, nor a coveted item, but an unintended consequence of global interaction. Though it brought unprecedented tragedy, the Black Death also irrevocably altered the course of history, shaping societies, economies, and cultures in its wake.

Revered as the 'Ships of the Desert', camels were vital lifelines, making the long, arduous journey across shifting sands and treacherous terrains possible, were the stalwarts of the Silk Road. Camels have amazing endurance. When the temperature is 50°C, and the water loss reaches 30% of their body weight, they can still go without water for 20 days. Although they walk very slowly, they can carry a lot of things, even carrying 200 kilograms at a speed of 75 kilometers per day for 4 consecutive days. The stomach and muscles of a camel can also store a certain amount of water. Its first stomach can store nearly 100 kilograms of water at a time. Therefore, when food and water cannot be found for a while, it can use the stored fat and water to maintain life.

The Silk Road encompassed a vast geography, stretching over 4,000 miles from the capital of the Han Dynasty in ancient China, Chang'an, to the heart of the Roman Empire in the Mediterranean. The main artery of the Silk Road traversed through challenging terrains such as the Gobi Desert and the formidable Tian Shan and Pamir mountain ranges, as it passed through present-day Kazakhstan, Kyrgyzstan, Tajikistan, Afghanistan, Iran, Iraq, and Syria, before reaching the Mediterranean.

The Silk Road was not a single route but a web of paths, including maritime routes, collectively known as the Silk Roads. One of its major branches went through the Hexi Corridor, a critical gateway for traders traveling between China and Central Asia.