Hindawi
Scientific Programming
Volume 2022, Article ID 7077261, 7 pages
https://doi.org/10.1155/2022/7077261

Research Article

Virtual Reality Design in Reading User Experience: 3D Data Visualization with Interaction in Digital Publication Figures

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Received 26 May 2022; Revised 7 June 2022; Accepted 9 June 2022; Published 27 June 2022

Academic Editor: Lianhui Li

With computer technology rapidly growing in recent years, there is a significant trend that virtual reality technologies turn into the public. The paper found that VR has a high potential to improve reading efficiency. The research discussed various figures, which is the key element for data visualization in digital publications. Furthermore, the research analyzes the characteristic of VR. The research divides the data into three types: Static Data, Dynamic Data, and Interactive Data. The research designs the framework to transfer the data into VR platforms. In order to evaluate the performance efficiency of the framework, we conducted performance evaluations and a user study with 20 participants. Compared with traditional 2D figures, the experimental results show that the 3D framework can be used as an effective visual tool for reading on VR platforms. The paper indicates the possible future view based on the design study.

1. Introduction

In recent years, virtual reality (VR) technology has developed rapidly in the entertainment, media, education, and medical industries [1]. Developers can use VR devices to integrate virtual content with natural scenes to combine various interaction methodologies. VR technologies mainly use headsets to interact with the virtual world using controllers or hand recognition [2, 3].

VR technology has two significant advantages as a communication medium. The first one is 'simulation' [4, 5]. The VR technologies can build a highly simulated environment [4, 5]. The second advantage is 'immersive' [4, 5]. The users explore the simulated environment with various interactive methodologies [4, 5].

Numerous studies show that the VR has a high potential to improve reading efficiency, considering the VR advantages. Baceviciute summarizes that reading in VR is found to be more cognitively effortful and less time-efficient by his user experiments [6]. Significantly, the reading is transferring from nonimmersive to immersive media [6, 7].

HTC Vive has released Vivepaper with VR digital publication in 2016 [8]. Vivepaper brings lives of pictures, videos, audio, and 3D models. Users can watch and listen to multimedia content in an innovative way by pointing fingers [8, 9]. However, Vivepaper only covers the tourism and fashion journey without a detailed content description. Besides, most VR digital publications only display the content in 2D panels in the 3D environment without considering redesigning its 3D User Interface (UI) layout [6, 10, 11].

We should consider how to use VR technologies as the carrier of digital publications in the era of digitization. The study aims to design a 3D data visualization framework in reading and optimize the VR reading user experience.

There are various types of publications globally. It is necessary to narrow the research scope into a specific aspect and analyze its related UI structure and design framework.

The social science publications include different figures and tables to illustrate the social research output to the public [12]. The figures provide convenience in reading and assist the reader in understanding the content. Suppose the figures remain in 2D modes in VR platforms. In that case, it is significant that the 2D panel cannot improve the VR reading efficiency without applying VR features. Millais' research shows that 3D data visualization can lower the reading barrier and improve reading efficiency [13]. The research focuses on social sciences publications to build the initial design data visualization principle with fundamental VR characteristics. The research tries to provide a general and interactive UI framework to assist the social science publication transfer into the VR Reading field.

In this project, the research aims to design a general interactive data visualization framework. It covers various data figures from our research. It can improve the user experiences in VR reading. The proposed principle is based on VR interaction methodologies. The characteristics are as follows:

(1) The research uses the VR interaction features to build the data visualization principle and provide users with immersive exploratory experiences.

(2) The research balances the reading and VR characteristics. The research refers to 20 social science publications to conclude the general figure types. Meanwhile, 3D layout and gesture interaction are integrated with data visualization to enhance the user's immersive experiences.

(3) The research evaluates the performance efficiency of the framework. We conducted performance evaluations and a user study.

2. Related Works

The session investigates the related publication knowledge and describes how to build up the data visualization principles. The research designs a general 3D data visualization concept by dividing various figures.

The research uses Unreal 4(UE4) UX development tools to design data visualization prototypes based on VR devices. The research uses different publications' data to testify to the possibility of the principles. The prototype can display how the concept plan adapts to the VR environment and the existing social science publications.

2.1. Data Elements in Social Science Publications. Before designing the general data visualization framework, it is necessary to discuss the existing general data figure elements in social publications. The study uses 20 articles from various open-access social science journals including Sage Open, Sustainability, and Agribusiness. We use the articles as case study samples to investigate the general data elements. We summarize the data elements and analyze how the elements achieve usage in data visualization. With critical analysis, we believe that the study can help us better discuss the overall data visualization concept and build the framework.

Through the investigation, the histogram is the most general data element. 75% of articles have used column charts. The line chart occupies the second position which number is 65%. Some articles only use line charts and histograms [14, 15]. The flow chart is in the third position which number is 55%. The pie chart is in the fourth position with 30%. There are other specific charts with mixed types that occupy 20%. Besides, tables have appeared in 60% of articles.

By analyzing the above-given statistic, we can summarize the general data elements: column chart, line chart, flow chart, and pie chart. We should consider transforming them in the VR platforms.

2.2. Design Concept. The data and figure cannot directly transfer to VR platforms. Therefore, the digital publication should contain the data file and the VR system can read the data file when displaying the selected figure. The data visualization framework includes two significant functions: data loading and display, as shown in Figure 1. It is necessary to discuss how to load the data and display the data with immersive experiences.

In data loading, the study requires considering how to transfer the data from various data files to VR platforms. Therefore, it is necessary to customize the function library. The study uses Direct Excel, the plug-in to allow UE4 to load the data files from a specified path [16]. The study builds a customized function library to make reading the data more convenient through the functions provided by the plug-in. The customized function library can read the data of the table more flexibly. The library can read the specific data range and compare it with other ranges. It is beneficial to simplify the data visualization working process and improve efficiency [17–20].

Besides the loading, the framework should provide a suitable visualization in displaying the data. The study divides the data into three types: static data, dynamic data, and interactive data (Table 1).

The static data are the fundamental data visualization element. After loading the data, the static data display as a 3D layout without interaction and animation. Dynamic data does not only include the 3D perspective but also has an animation effect to display how the data transform and straightly to display the comparison trend. Interactive data can use most VR features, including 3D layout, animation, and gesture interaction. The data allows users to modify the data with gesture interaction and display the simulated result in a 3D environment.

3. Framework Overview

The framework [21, 22] contains three major sections: Static Data, Dynamic Data, and Interactive Data. The study sorts out different figures in these sessions and explains the working flow in the principles.

3.1. Static Data. Static Data displays the data in the 3D layout and provides the move manipulation with hand controllers. Static Data supposes to illustrate the data which is hard to use animation to display. By analyzing various figures, single-column charts, pie charts, and line charts can

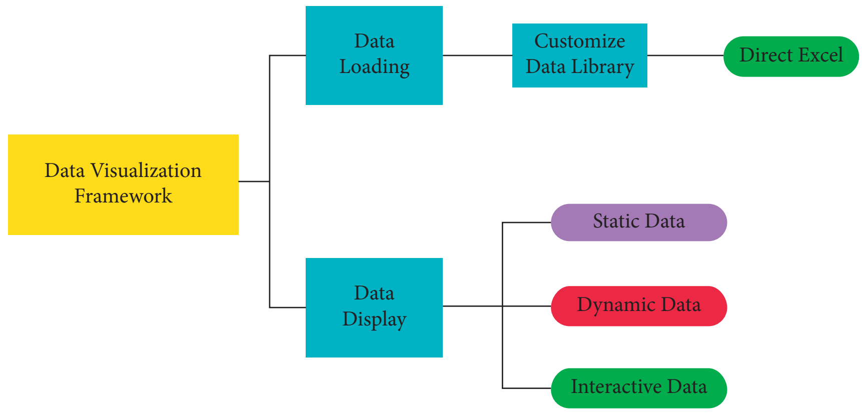


Figure 1: Framework overall structure.

Table 1: Data category.

	3D layout	Animation	Gesture interaction
Static Data	√	×	×
Dynamic Data	√	√	×
Interactive Data	√	√	√

be included with Static Data. The study aims to design the basic 3D visual effect to improve the above-given data figure.

We design the static column chart 3D layout plan as shown in Figure 2. The single-column chart has limited data and is clear to see the data, and the study uses the blue and red colors to highlight both sessions (Figure 2(a)). The single stacked column chart is the extended version of the single-column chart. The framework uses random colors with high contrast to highlight the data (Figure 2(b)). Both static column charts display the detailed percentage number in each session.

The static pie chart displays the pie in a 2D panel with 45-degree angles (Figure 3). The angles can provide the 3D perspective and the percentage number is beside each pie.

The 3D environment offers the line chart display with a three-axis (Figure 4). The line chart can straightly illustrate the trending in 3D mode and the position can display in the 3D environment.

3.2. Dynamic Data. Dynamic Data do not only provide the 3D layout but also allow us to play the trending with animation. The study aims to provide the convenience for users to analyze the dynamics trend. The study summarizes the chart which is suitable for animation. Dynamic Data includes regular column chart, pie chart, and line chart with a limited interaction in playing the animation.

Figure 5 displays the dynamic column chart 3D layout animation plan. The regular column chart has more data than the single-column chart. It usually contains data from multiple groups.

Using the animation can assist the user in contrasting the difference in groups (Figure 5(b)) and analyzing the growing trend (Figure 5(a)). The framework provides the horizontal and vertical columns in Figure 5.

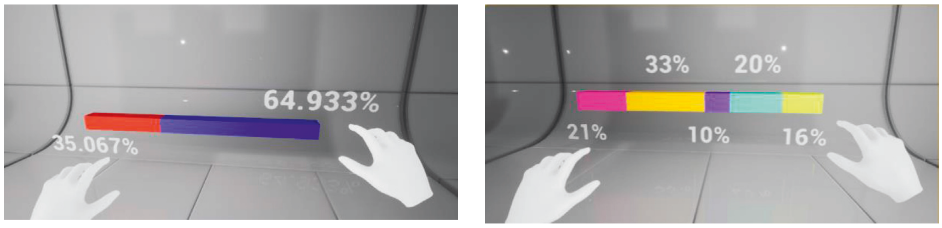
Compared to the static pie chart, the dynamic pie chart uses the growing animation to represent the percentage (Figure 6). Each pie has a different height even though they have the same values. The percentage number is on the top of each pie. Different heights can assist the user in distinguishing the data belongs.

The dynamic line chart uses animation to represent the trend (Figure 7). The framework provides the key point highlight function. When the user marks the highlight option in the Excel file. It can display the key point value when the animation reaches the point.

3.3. Interactive Data. Compared to Dynamic Data, Interactive Data moves further, which focuses on interaction, animation, and 3D layout. The study aims to use interaction to lead the user to analyze the process and compare different groups' data conveniently. Therefore, "comparison" and "controlling" are the key features of Interactive Data.

Comparison figures usually compare different groups' data. Compared to regular column charts, the multiseries column chart has more information by lining different groups. Therefore, multiseries column charts should belong to the "comparison" group. However, different groups are usually hard to distinguish due to too many columns. Therefore, using interaction to display different states can improve the distinguishing result. The study designs the comparison interaction panel as shown in Figure 8. The panel provides the button to switch different groups. It also allows both groups are visible to compare. The user can easily distinguish the advantages of different groups.

A flow chart usually describes a complex working flow. A complex working flow has different conditions and results. It is hard to read due to various information and images. Therefore, it is necessary to provide the control flow



(a) (b)

Figure 2: Static Column Chart Overview in VR platform. (a) Single Column Chart; (b) single Stacked Column Chart.

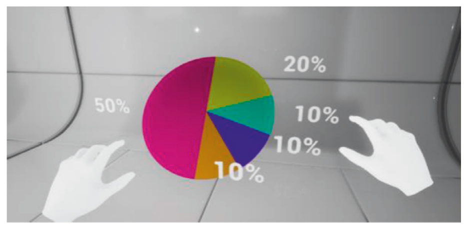


Figure 3: Static Pie Chart in VR platform.

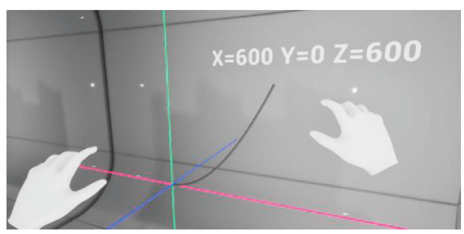
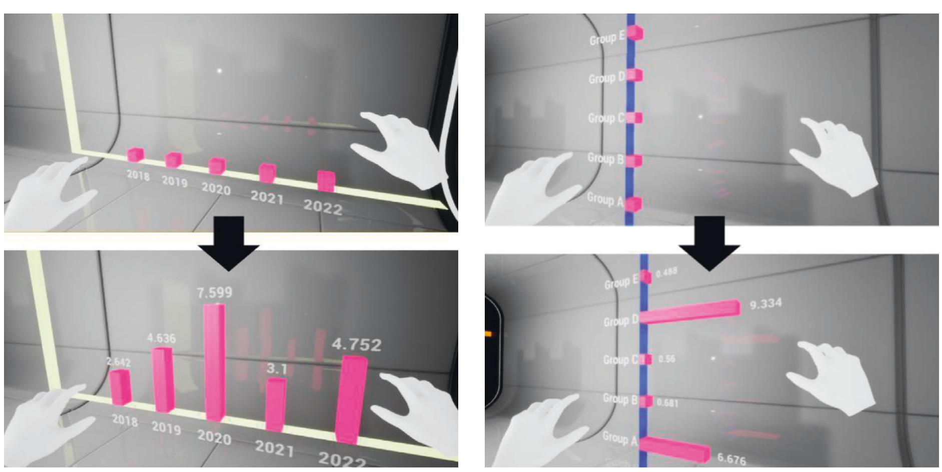


Figure 4: Static Line Chart in VR platform.



(a) (b)

Figure 5: Dynamic Column Chart Overview in VR platform. (a) Horizonal Column Chart; (b) Vertical Column Chart.

function. The ‘controlling’ can efficiently assist the user in checking different statuses.

Figure 9 displays the flow chart in Interactive Data. The interactive panel is in front of the chart. The user can select different statuses (previous and next) and results. The switching interaction can help the user to see how the research moves to the specific result by reducing other result information. Meanwhile, the user can check other statuses by switching the panel.

4. Evaluation

We conducted user studies to investigate the user experience in the VR reading through a questionnaire [23–26]. Formally, we have the following hypotheses: (1) our framework helps the users improve their reading efficiency in checking the figures. (2) Our framework helps increase users’ immersive experience and engagement of the reading.

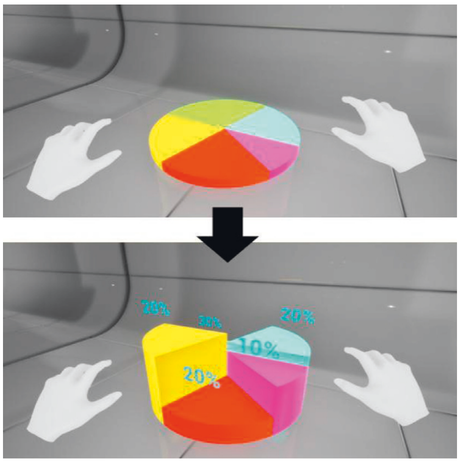


Figure 6: Dynamic Pie Chart in VR platform.

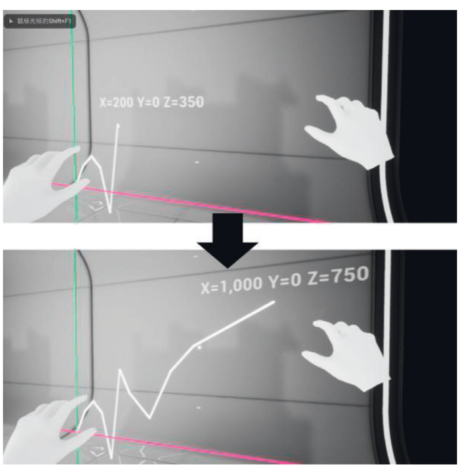


Figure 7: Dynamic Line Chart in VR platform.

4.1. Participants. Twenty participants (10 men, 10 women, aged 20–22 years old, $M = 21$) were recruited from Guangdong University of Finance to take part in this study. The study divides them into Group A and B. Group A and B are the experiment group. Group A uses VR devices (HoloLens (2) to interact with the 3D figures under our framework designed. Group B uses desktops to check the same data with traditional 2D reading mode.

4.2. Procedure. Group A participants took part in the interactive experiment. Figure 10 shows that the participants used HoloLens 2 to interact with the framework. Group B participants used desktops to explore the figures. Group A/B has 20 minutes time limitation to check 10 figures.

Table 2 displays the figures' distribution detail. All of Group B's figures are using the traditional 2D display. After the reading, participants were required to complete a brief questionnaire regarding the data information they watched. The questionnaire section includes five single choices and five judgments. The questionnaire covers the data information overview. The questionnaire asks for exact numbers

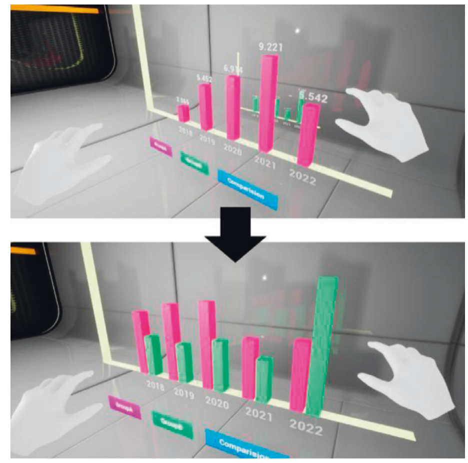


Figure 8: Multiseries column chart switching states in VR platform.

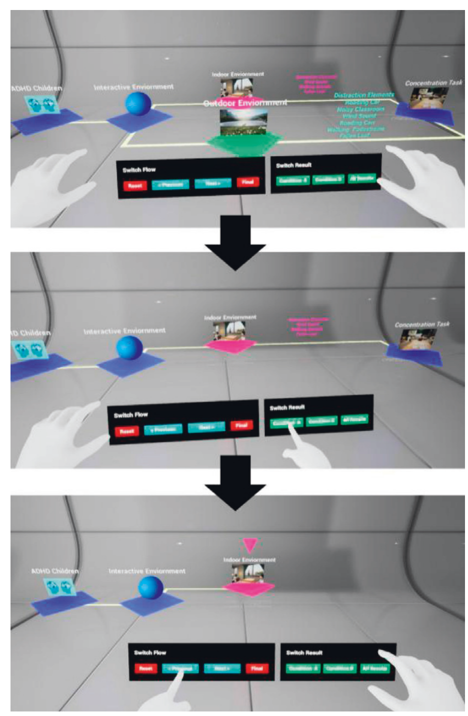


Figure 9: Interactive flow chart in VR platform.

such as maximum and minimum numbers. For instance, a question judges the trend in a dynamic line chart.

5. Results

The research collects the user score in two groups from questionnaire data. Figure 11 displays the user score distribution in each group. The research calculates the average and median score as shown in Table 3. For the data visualization framework, three trends are obtained as follows:

(1) It is encouraging that Group A has better performance in average and median score than Group B. But the superiority is very small which is only 3.07%.

Figure 10: Group a user test.

Table 2: User test Figures Distribution.

		Question numbers
Static Data	Static single column chart	1
	Static single stacked column chart	1
	Static pie chart	1
	Static line chart	1
Dynamic Data	Dynamic horizonal column chart	1
	Dynamic vertical column chart	1
	Dynamic pie chart	1
	Dynamic line chart	1
Interactive Data	Interactive flow chart	1
	Interactive column chart	1

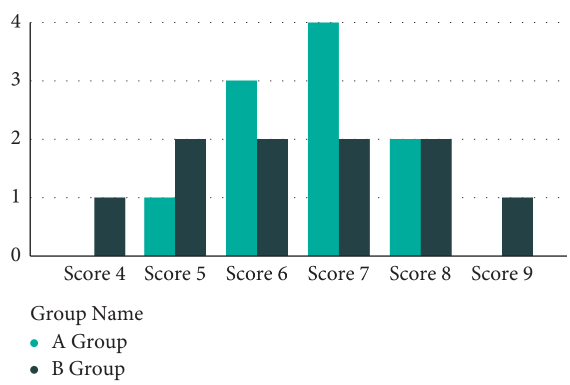


Figure 11: Group score distribution.

Table 3: User test score data.

	Group A (average score)	Group B (average score)
Static Data	2.4	2.7
Dynamic Data	2.8	2.9
Interactive Data	1.5	0.9
Total	6.7 7	6.5 6

(2) Group A has worse performance in Static Data. The average score is number is 11% lower than Group B.

(3) Group A has limited worse performance in Dynamic Data. The average score is number is 3.04% lower than Group B.

(4) Group A has better performance in Interactive Data. The average score is number is 66.67% higher than Group B.

Considering the above-given data, the data visualization framework can significantly improve performance efficiency, especially in Interactive Data. We conclude that the interaction can engage the user participant and remember the data. At the same time, the multiple-column chart and flow chart has more information than the Static and Dynamic Date Group. Therefore, it is significant that the VR interaction can assist with more complicated figures and information. The animation method can also provide similar experiences to the 2D reading. However, there are some existing issues. Significantly, the 3D figure without animation and interaction (Static Data) is worse than the traditional reading. We analysed that the Static Data contains simple figures which are easy to read. If we use the 3D display that may bring distraction due to the 3D environment and receive a negative effect. Therefore, we should consider that the simple figures do not fit with 3D reading.

Future research should optimize the Interactive and Dynamic Data. Furthermore, the controlling difficulty is another challenge for the users not familiar with VR applications. Therefore, the framework should provide more tutorial elements to decrease the difficulty. The study will consider the above data carefully and put forward the optimizing solution. The framework will continue to be optimized and contribute to the VR reading field.

6. Conclusion

In order to improve the reading user experience in VR platforms, the research aims to design a data visualization framework with VR characteristics. The paper finds that VR has a high potential to improve reading efficiency. The research discusses various figures, which is the key element for data visualization in social publications. A 3D data visualization framework is proposed to provide an immersive, explorative, and readable user experience. The framework divides data into three types: Static Data, Dynamic Data, and Interactive Data. The framework follows the VR features to provide a 3D visual effect and immersive interactive experiences. The research runs a comparative user test with 20 participants. The result shows that the framework is more attractive and efficient than reading the traditional 2D figures in VR platforms. Based on these evaluations, we believe that the proposed framework can be used as an effective reading tool for social science publications. The proposed framework can improve user experience in the VR reading fields. Our research contains the VR reading field and uses VR interactive technology to improve user experiences. Future work continues to discuss data visualization and move to the VR text reading. We will use various statistical analysis methodologies such as mixed-ANOVA to measure the user experience after using the framework with pretest and post-test.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This research was partly supported by the 14th Five-Year Planning Project for the Development of Philosophy and Social Sciences in Guangzhou (Grant no. 2022GZGJ290) and Department of Education of Guangdong Province and Guangdong University of Finance under Grant no. 2021WQNCX049.

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