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Immersive Experience in 3D Data Visualization with Virtual Reality

Bambang Saras Yulistiawan[1], Erly Krisnanik[2*], Catur Nugrahaeni Puspita Dewi[3], I Wayan Rangga Pinastika[4]

[1,2,3,4]*Faculty of Computer Science, Veterans National Development University, Jakarta, Indonesia*

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ABSTRACT

Immersive experiences in 3D data visualization using Virtual Reality (VR) technology are increasingly important in the digital era with an ever-increasing volume of data. VR allows users to interact with data in three dimensions to improve understanding and analysis of complex information. Research shows that interactions in VR environments can speed up the identification of patterns and anomalies, as well as increase user understanding of data by up to 30% compared to traditional methods. This research aims to provide an alternative to the use of immersive technology with VR to provide immersive data visualization. The development of 3D data visualization prototypes using Oculus, Meta Quest 2, and Unity is expected to be an interactive platform for users. Despite the challenges related to ergonomics and comfort, the potential for VR in improving communication and data understanding is enormous. Systematic VR development methods, through planning, design, development, testing, and maintenance steps, are essential to ensure the application is effective and meets the needs of users.

Corresponding Author:

Erly Krisnanik
Information System, Faculty of Computer Science
Universitas Pembangunan Nasional Veteran Jakarta
RS. Fatmawati, Pd. Labu, Cilandak, Jakarta Selatan, Indonesia
Email: erlykrisnanik@upnvj.ac.id

Introduction

The current digital era is an era with such a fast and high volume of data. According to the International Data Corporation (IDC), global data is expected to reach 175 zettabytes by 2025. In this context, data visualization is becoming increasingly important to assist individuals and organizations in understanding and analyzing complex information. One of the latest innovations in the field of data visualization is the direct use of information, making it easier to understand and interpret. Visualizing 3D data using VR not only improves understanding but also allows for better analysis of complex data. Chen said that users who interact with data in a VR environment can identify patterns and anomalies faster compared to traditional visualization methods. This indicates that immersive experiences can increase effectiveness in data-driven decision-making (Chen, Liang, Chen, & Xu, 2021)

Not only does VR technology provide engaging visualization, but the use of VR in data visualization increases users' understanding of complex data by 30% compared to traditional visualization methods. This shows the great potential of VR in increasing the effectiveness of data

communication. Thus, this study aims to explore the immersive experience offered by 3D data visualization using VR technology. (Prendes et al., 2022)

This research contributes to the development of more effective and interactive data visualization methods. The main focus of this research is to explore how immersive experiences in VR can improve data understanding and support better decision-making. In a business context, decisions made based on sound data analysis can improve the company's operational efficiency and competitiveness. Companies that use data for decision-making are more likely to experience a productivity increase of up to 6%.(McKinsey & Company, 2021),

The purpose of this study is to make a significant contribution in the field of data visualization with an immersive approach using VR technology. First, this research will identify and analyze how immersive experiences can affect users' understanding and interaction with data. Where interactive visualizations can increase user engagement, which in turn can speed up the decision-making process. Second, the research also discusses the development of a prototype of 3D data visualization that can be used in a VR environment. Using the Oculus Meta Quest 2 and Unity, the prototype is expected to provide a platform that allows users to interact with data directly, the use of VR in data visualization allows users to experience data in a more in-depth context, thereby improving their understanding of the data being analyzed. (Isenberg et al., 2013) (Saravanos & Curinga, 2023)

VR has enormous benefits, but it cannot be separated from the shortcomings that are challenges in its use. A study mentions that the main challenge in VR development is the issue of ergonomics and user comfort, which needs to be taken into account in order for the immersive experience to go well. (Ramaseri Chandra, El Jamiy, & Reza, 2022) Virtual Reality (VR) is a technology that allows users to experience a fully immersive digital environment. By using hardware such as VR headsets and controllers, users can interact with objects and data in three-dimensional space. According to Statista data, the VR market is expected to reach USD 44.7 billion by 2024, up from USD 15.7 billion in 2020.(Statista, 2024) The visual and audio aspects will play an important role in creating an immersive experience. In 3D data visualization, the use of engaging visual elements and supportive audio can increase user engagementThe use of audio in a VR environment can increase a sense of presence and immersion. Therefore, it is important to consider how these elements can be integrated in data visualization applications. The growth in VR usage shows that more companies and individuals are starting to realize the potential of VR in various fields, including data visualization. (Privitera, Fontana, & Geronazzo, 2024), (Olshannikova Ekaterina, 2015), (Baigabulov & Ipalakova, 2024)

One of the advantages of VR is its ability to present data in a more intuitive context. For example, users can "enter" into visual data and see the relationships between various variables in a way that is not possible with 2D visualization. Some research shows that users who use VR for data visualization have higher information retention rates compared to those who use traditional methods. Thus, VR not only enhances the visual experience but also improves the effectiveness of learning and understanding of data. The line spacing used between the image and the sentence above and below it is 1 (one) blank line. Try to keep the image colorless/black and white (unless the use of color in the image is necessary/unavoidable) and if printed in black and white it can be distinguished. If the image is in the form of a graph, it must be clear the difference between each other by using different types of *lines* and *markers*. Each image must be referred to in writing with the image number and beginning with a capital letter, for example Figure 1. Pemanfaatan big data dalam pengukuran dampak program pengembangan ekonomi pariwisata telah dikaji oleh Sigala et al.(Sigala, Beer, Hodgson, & O'Connor, 2019), yang mengusulkan kerangka proses dan kriteria kualitas dalam penggunaan big data untuk mendukung pengambilan keputusan.

Method

The method used in the research is VR development (VRDLC). This method is a systematic approach to the development of the Multimedia Development Life Cycle (MDLC).

Figure 1. MDLC

A systematic VR development method is essential to ensure that the developed application is effective and meets the needs of the user. One commonly used approach is the VR Development Life Cycle (VRDLC), which consists of seven key steps: 1) Planning stage, where the user's goals and needs are identified. In the context of data visualization, it is important to understand the type of data to be visualized and how users will interact with that data, 2) The design stage, where the application architecture and user experience are designed. This includes the selection of visual elements, interaction, and navigation in a VR environment. Good design can significantly improve the user's experience. At this stage, it is important to consider the ergonomic and comfort aspects of the user, so that they can interact with the data without feeling tired or uncomfortable. (Polcar, Gregor, Horejsi, & Kopecek, 2015), 3) The development stage, where VR applications are built using platforms like Unity. The platform is one of the most popular VR development platforms, as it provides a wide range of features and support for interactive app development. According to Unity Technologies, more than 50% of VR developers use Unity as their primary platform. Developers must ensure that all elements function properly and integrate harmoniously. (Vergara, Rubio, & Lorenzo, 2017), 4) Testing stage. Testing is essential to ensure that the application runs properly and is free of bugs. Testing can be done by engaging users to get feedback on their experience. (Goi, 2024) demonstrate that user testing can identify unexpected issues and provide valuable insights for improvement, 5) implementation, where the VR app is launched and can be used, 6) The maintenance stage, which involves updating and fixing the app based on user feedback, and 7) The evaluation stage, where the effectiveness of the app is evaluated and improvement steps are identified. By following the steps in VRDLC, it is hoped that 3D data visualization applications can be developed effectively and provide a beneficial immersive experience for users (Gronowski et al., 2024) shows that thoroughly tested prototypes can improve the quality of the final application by up to 30%, which shows the importance of this stage in the development process.

This method is used to create effective and efficient VR applications. According to research conducted by user feedback, it is essential in the VR development process, as it can help identify problems and improve the overall user experience. This research will use the Unity platform to develop immersive displays in the form of 3D visualizations assisted by Oculus Meta Quest 2 virtual reality (VR) devices and using datasets in CSV format. (Sumartias et al., 2020)

In the context of this study, emphasis will be placed on the use of Oculus Meta Quest 2 devices and Unity applications as tools to develop 3D data visualization. By utilizing these two technologies, it is hoped that an experience can be created that is not only visually appealing but also informative. (Sun-Ho Kwon1†, 2023) The application of the VRDLC method can improve the quality of VR applications by up to 40%, which shows the importance of a systematic approach in the development of this technology.

Figure 2. Oculus Meta Quest 2

Results and Discussions

Dataset

Datasets are an important component of visualization, and the way the data is presented can affect the user's understanding. In the context of VR, 3D data can provide a more in-depth and interactive perspective compared to 2D visualization. For example, in geospatial data analysis, 3D visualization can help users to understand patterns and trends that may not be visible in a flat format.

In the development of 3D data visualization using VR, the selection of the right dataset is key to creating an informative and engaging experience. The datasets used in this study must be relevant to the purpose of the analysis and be able to provide valuable insights. According to Hullman & Gelman, the quality of the dataset has a major impact on the results of analysis and visualization. Hullman also added that more than 80% of organizations that use 3D data visualization cite improvements in their data understanding. (Afnan et al., 2021; Butcher & Ritsos, 2017; Hullman & Gelman, 2021).

Too large a dataset can cause problems in the performance of a VR application, while a dataset that is too small may not provide enough information. Research shows that complex data visualizations can help users in understanding relationships between variables that may not be apparent at first glance. Data quality is essential for visualization; inaccurate or incomplete data can lead to incorrect conclusions. Therefore, it is important to ensure that the data used in the VR application is valid data and is ready for analysis. (Baigabulov & Ipalakova, 2024)

Proper data processing techniques are also required to ensure that the data can be presented in a way that is easy for users to understand. It's important to pay attention to how we explore and optimize datasets, such as dimension reduction or sampling, to keep them informative without sacrificing application performance. Dimension reduction techniques can help in simplifying data visualization without losing important information.

Immersive Data

Data immersion refers to an experience where users can experience and interact with data in a more immersive and intuitive way. This experience can improve understanding and retention of information. According to research by Privitera et al, users who experience data visualization in VR mention higher levels of satisfaction and feel more involved in the data analysis process. (Prendes et al., 2022; Privitera et al., 2024) Using VR, users can explore data in the form of 3D visualizations that allow them to see the relationships between various variables and make better decisions. (Butcher & Ritsos, 2017).

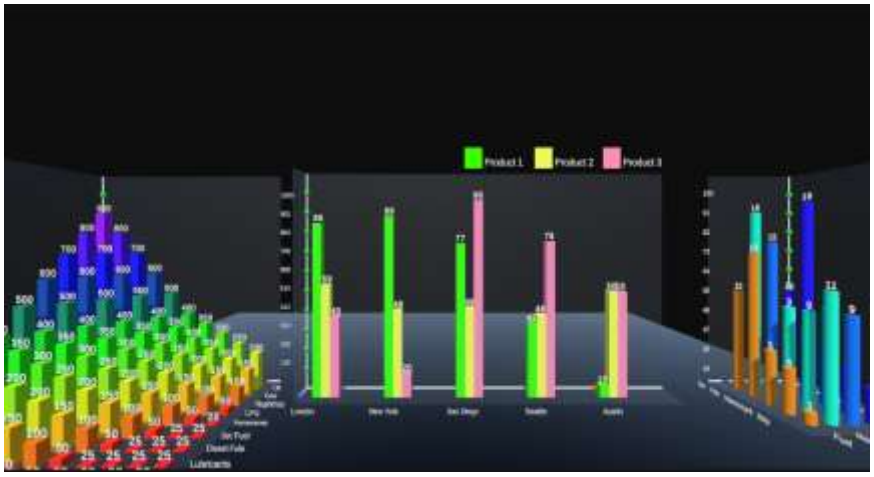

Figure 3. 3D Histogram Visualization on the Unity Dashboard

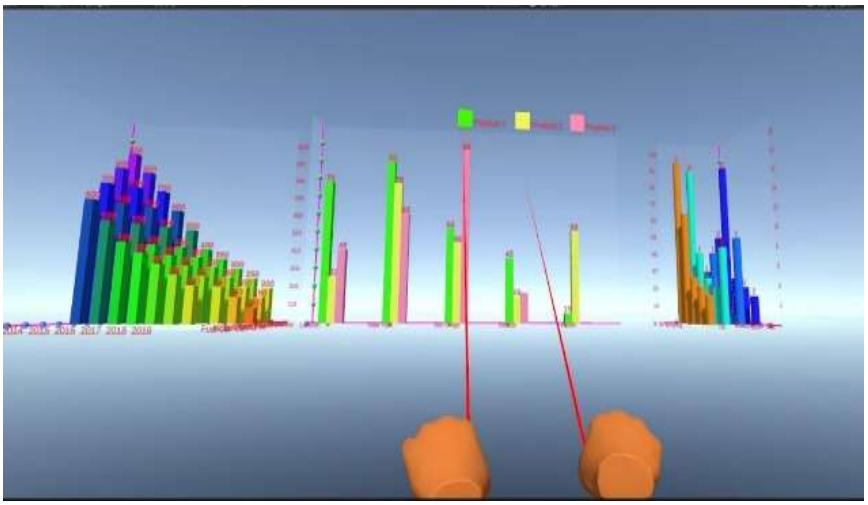

Figure 3. 3D Histogram Visualization with Oculus Meta Quest 2

Figures 3 and 4 show the visualization of histogram data in 3D with virtual reality and use the oculus meta quest 2 so that users can be virtually involved in the visualization to feel and see more details to bring users emotionally in understanding the data visualization.

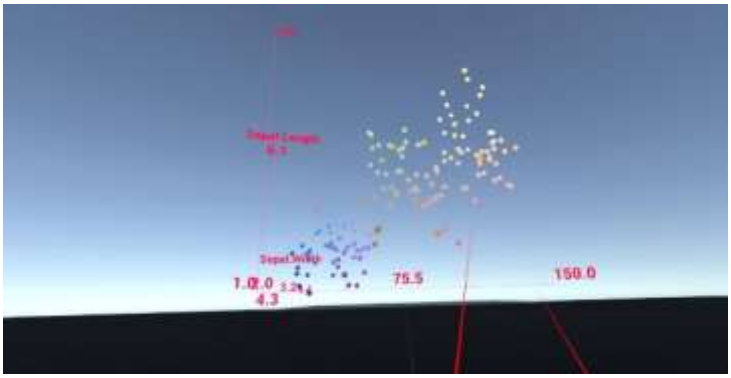

Figure 5. Immersive Visualization of Scatter Plots with Oculus Meta Quest 2

Security Testing Process

Likewise, in figure 6 showing a 3D visualization of scatter plot data with virtual reality and using the oculus meta quest 2, the user will be taken as if in the virtual of the visualization. So that the experience of data conditions will be more profound to be felt. Data immersion in VR not only improves the user experience but also provides deeper insights that can support better decision-making.

Decision Making

Effective decision-making relies heavily on the individual's ability to understand and analyze available data. In this context, VR technology can play an important role in improving the decision-making process. With immersive data visualization, users can explore a variety of scenarios and possible outcomes. (Nugroho, 2023) suggests that the use of VR in decision-making can improve decision speed and accuracy by up to 25%. The use of VR also allows for better collaboration between team members in the decision-making process. Research conducted shows that collaboration in VR can increase creativity and innovation in decision-making, which in turn can provide a competitive advantage for companies. (Saurik, Purwanto, & Hadikusuma, 2019).

Prototype Implementation

This research focuses on the development of a prototype VR application designed to facilitate user interaction with data in a three-dimensional (3D) format. In this study, an example is provided by implementing histogram and scatter plot data visualization. In this implementation, it will be explained how the visualization looks using the Unity platform and using the Oculus Meta Quest 2. The following is an explanation of the steps in the implementation of making the visualization.

Creating Immersive Visualization of Scatter Plots

Importing a standalone scatterplot package into the Unity project, then opening the Example_Scene, seen in figure 6.

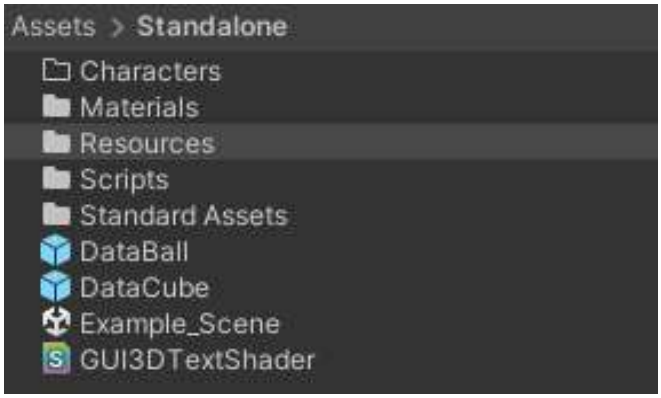

Table 6. ackage Scatterplot Standalone

In the Hierarchy as seen in figure 7, select GameObject Plotter to change the data you want to create in the inspector.

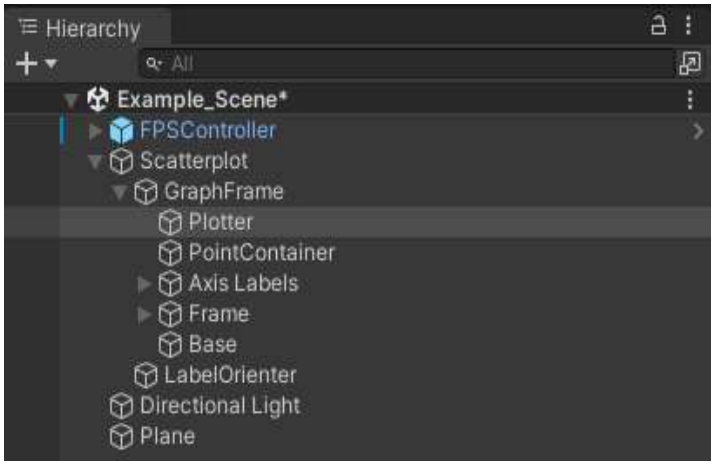

Figure 1. Hierarchy

In scatter plots, technical features have been provided to improve the user experience, including a) Render Point Prefabs: Allows users to see the nodes that make up the scatter plot, b) Particles: Displays particles derived from scatter plot data, and c) Render Prefabs with Color: Adds color variations to nodes to make it easier to understand visually.

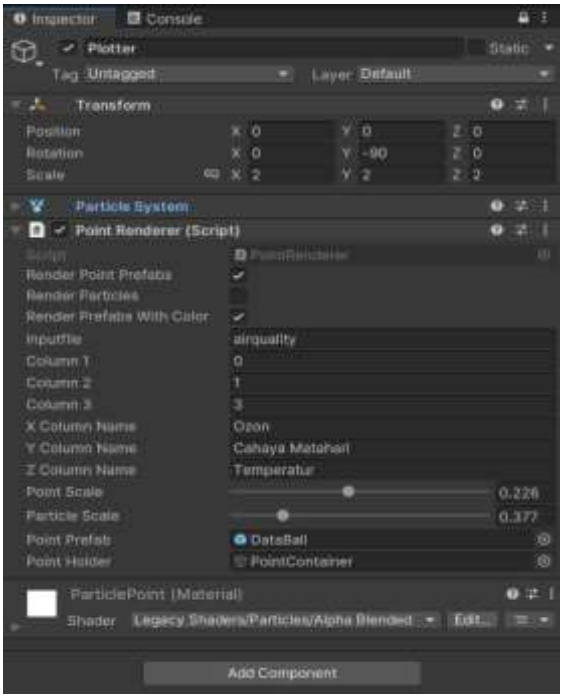

Figure 8. Functions to display data

In the GameObject Plotter there is a function/script called Point Renderer as shown in Figure 8. In this function the user can select the dataset via "Inputfile". Then users can also select columns from the dataset that will be displayed on the scatterplot in addition, users can label each axis using "X Column Name", "Y Column Name", and "Z Column Name". Users also have control over the size of nodes and particles through Point Scale and Particle Scale and can choose which prefab to use as nodes with "Point Prefab". Finally, the "Point Holder" allows the user to specify the GameObject that will store the scatter plot nodes, making the application very flexible and interactive in 3D data analysis.

Creation of Histogram Immersive Visualization

Import the 3D Interactive Bar Chart package from the Asset Store and then open one of the scenes in the Scenes folder.

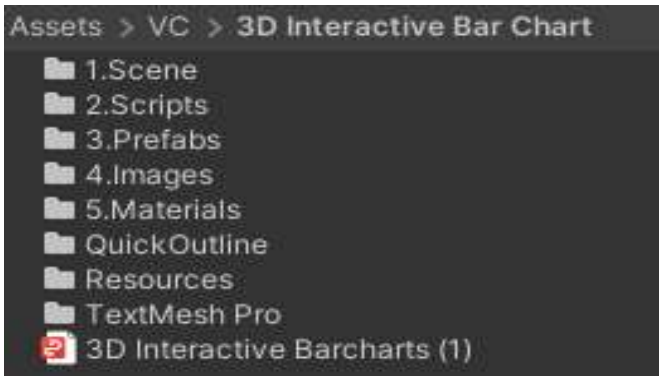

Figure 9. Package 3D Interactive Bar Chart

To create a new Histogram, on the toolbar, select ViitorCloud then select BarGraph and continue to select Create BarGraph. This will create a new GameObject BarGraph in the Hierarchy. Then select the BarGraph in the hierarchy as shown in figure 10.

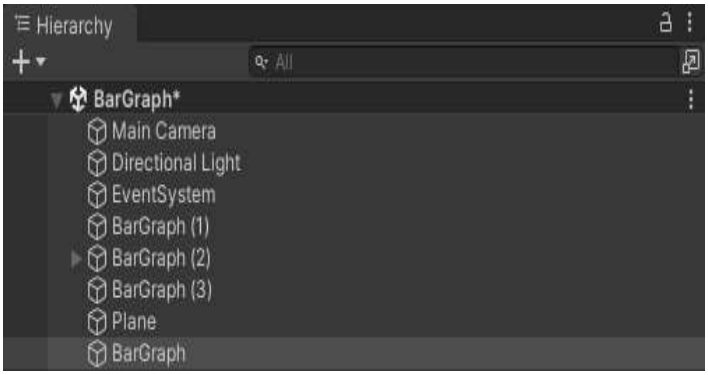

Figure 10. Tombol Membuat BarGraph Baru

In the GameObject BarGraph there is a Bar Graph Example function / script which is a function to call the dataset you want to use such as figure 11. To set the shape of the graph you can use the inputs from the Graph Generator (Script). Set the maximum height of the chart with "Max Height". Set the starting value of each axis with "X Start", "Y Start", and "Z Start". Set the number of segments of each axis with "Segment Size On axis". Set the distance of each axis with "Offset Between Row". Adjust the animation starting from the animation speed and the type of animation used. Set the shape of the graph bar with the prefab and its color. Finally, set up custom events that can be set by yourself with the available event system.

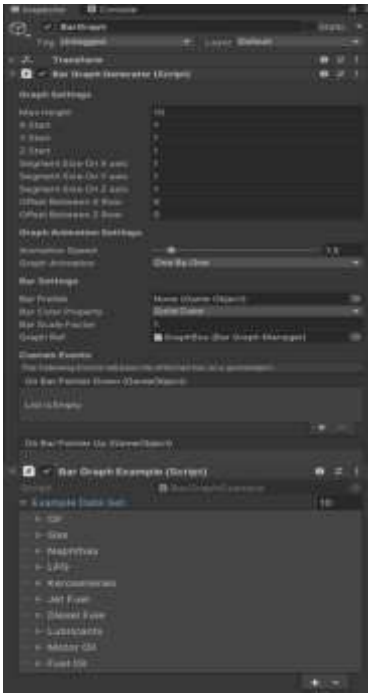

Figure 10. Fungsi Membuat Histogram

The process starts by removing all the bars inside the panel to ensure the graph is always clean before generating a new graph. Then, this class specifies the maximum value from the list to adjust the bar scale to be proportional. Using loops, it will instantiate the prefab bars for each value, set the bar scale based on values relative to the maximum, and set the bar position to line up neatly. Positioning is done by calculating the distance between the bars, which makes the graph easier to read. Through this implementation, the application can effectively present data in an intuitive and informative visual format.

Conclusions

This research shows that the use of Virtual Reality (VR) technology in 3D data visualization can increase user understanding and engagement with complex data. With a structured VR Development Life Cycle (VRDLC) method, data visualization applications were developed using the Unity platform and Oculus Meta Quest 2 devices. The results of the research in the form of immersive visualization through histograms and 3D scatter plots allow users to interact directly with the data, accelerate pattern identification, improve information retention, and support faster and more accurate decision-making up to 30%. Challenges such as ergonomics and user comfort remain important concerns in the development of this application. This research has implemented a prototype application that enriches the user experience through interactivity and audio-visual integration in a VR environment. The use of relevant datasets and data processing techniques such as dimension reduction ensures visualizations remain informative without sacrificing application performance. Thus, this approach not only drives the effectiveness of data communication but also opens new opportunities for the development of VR-based data visualization systems in various industry sectors, supporting a more effective and competitive digital transformation. This research contributes to the innovation of modern data visualization methods that are more effective, interactive, and support the improvement of productivity and competitiveness of data-driven decision-making organizations

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