Development of Interactive Data Visualization System in Three-Dimensional Immersive Space

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***Abstract*—Today's data-driven environments require innovative tools and methods to analyze and present data. The growth of data across many domains and remarkable technological advances have necessitated a shift from 2D data representations. The rapid growth in dataset scale, variety, and speed has revealed the limitations of conventional charts and graphs. Significant progress has been made in the domain of interactive, three-dimensional data visualizations as a means to address this challenge. The integration of Virtual Reality (VR) and Augmented Reality (AR) technologies enables users to achieve a heightened level of immersion in a simulated environment, where data is transformed into physical and interactive creatures. Recent research in the domain of immersive analytics has provided evidence that virtual reality (VR) and augmented reality (AR) technologies possess the capacity to provide succinct multiple layouts, facilitate collaborative data exploration, enable immersive multiview maps, establish spatial environments, enhance spatial memory, and enable interactions in three dimensions. The primary aim of this research is to design and implement a sophisticated data visualization system that integrates the development of a data pipeline within the Unity 3D framework, with the specific goal of aggregating data. The resulting system will enable the presentation of data from CSV files within a three-dimensional immersive environment. The prospective ramifications of this development have the capacity to yield good effects in diverse domains, including E-commerce analysis, financial services, engineering technology, medical services, data analysis, and interactive data display, among others. The proposed system presents a methodical framework for the development of a 3D data visualization system that integrates virtual reality (VR) technologies, Unity, and Python, with the aim of redefining the process of data exploration within a VR environment. This paper examines the integration of continuous testing methodologies within the context of Python API and virtual reality (VR) environments. It also allows for the creation of an interesting and immersive experience that meets user needs.**

***Keywords*—Immersive space; data visualization; VR system; python API; unity 3D**

I. Introduction

The need for reliable tools and cutting-edge methodologies to analyze, assess, and present datasets has witnessed a substantial increase in the modern era. Technology and the availability of massive data sources across many disciplines enabled the growth. Two-dimensional (2D) charts and graphs are inadequate for revealing intricate patterns and relationships in increasingly large and complex datasets. As the quantity, variety, and speed of data continue to expand at an exponential rate, this constraint becomes more evident.

To address the aforementioned formidable task, significant progress has been made in the field of three-dimensional (3D) interactive data visualization systems. The emergence of these novel technologies has facilitated the ability of researchers, analysts, and other professionals to fully immerse themselves in a domain where data points are converted into tangible entities that can be actively engaged with. The current transformation is helped by the combination of augmented reality (AR) and virtual reality (VR) technologies, which allow individuals to interact with data in a way that is both intuitive and fascinating. Recent studies have shown the significant benefits that virtual reality (VR) and augmented reality (AR) can potentially provide in certain data exploration scenarios, as demonstrated by the existing collection of research in the field of immersive analytics in recent times. The advantages mentioned above encompass a diverse array of subjects, such as the utilization of small multiple layouts [1], the facilitation of collaborative data exploration [2]–[6], the implementation of immersive multiview map systems [4], [7], the provision of boundless spatial environments [1], [7], [8], grouping (clustering) and spatial (dimension reduction) [9], [10], the enhancement of spatial memory retention [11], and the enablement of three-dimensional spatial interactions [3], [10], [12], among various other benefits.

The primary objective of this research endeavor is to introduce and showcase an advanced data visualization system that effectively harnesses the vast capabilities of a three-dimensional immersive environment. This objective is achieved through the integration of computer graphics, data visualization, and human-computer interaction in a mutually advantageous manner. The objective is to provide an extensively interactive setting that facilitates the exploration and analysis of data beyond the limitations imposed by conventional two-dimensional representations. By providing users with the ability to deeply engage with the data, this novel technology aims to exceed the constraints of traditional visualization methods, therefore enhancing users' understanding and facilitating informed decision-making.

The contribution of the research paper can be summarized as follows:

- The proposed system effectively accomplishes the objective of developing a superior user interface within the domain of 3D data visualization, thus attaining excellence in this field. By blending simplicity and accessibility, people of all backgrounds and technological abilities may easily interact with data in an immersive 3D setting. This work serves to enhance the inclusivity and user-friendliness of data visualization.
- The presentation and implementation of advanced visualization techniques tailored for three-dimensional (3D) scenarios have made a significant and noteworthy

contribution. The application of customized visualization methods enhances the representation of complex data relationships and patterns that could otherwise provide difficulties in their recognition. This feature enables users to gain valuable insights from their data within a three-dimensional framework.

- The proposed system facilitates an enhanced level of interactivity by incorporating a wide range of interactive components. This enables users to actively engage with and examine real-time data within a fully immersive 3D setting. The incorporation of functionalities such as data filtering, grouping, and linking facilitates users in effectively managing and analyzing their datasets. The significance of this work resides in the provision of robust tools that enable users to manipulate and explore data effectively within a three-dimensional (3D) spatial context.
- The research work provides a practical contribution by elucidating the process of integrating a Python application programming interface (API) for the purpose of aggregating data into the Unity 3D development environment. This interface enables the smooth conversion of data from a Comma-Separated Values (CSV) file into a three-dimensional (3D) visualization environment, thereby augmenting the level of immersion and engagement. This study focuses on a crucial element of data transmission, aiming to facilitate a seamless and effective transfer from two-dimensional data sources to three-dimensional representation.

The subsequent sections of the document are organized in the following manner: Section II provides an overview and analysis of the existing literature and research studies that are relevant to the topic. The approach adopted is outlined in Section III, while Section IV gives a detailed explanation of the dataset. Section V provides a detailed explanation of the experimental configuration and the methodology employed for interacting with the data. Section VI provides an in-depth look of qualitative results, while Section VII encompasses the concluding remarks.Additionally, Section VIII outlines our upcoming research in this field. The remaining section consists of acknowledgment and references.

II. Related Works

Numerous research inquiries have been conducted in the realm of immersive technologies and data visualization, thereby enhancing our comprehension of the various facets and potentialities of this emerging topic. The comprehensive and innovative research carried out over a prolonged period has greatly clarified the numerous applications of immersive technology and its ramifications across several fields of study. This summary offers a brief outline of the significant contributions made by researchers in these studies, clarifying their primary discoveries and ramifications.

In 2017, Ens, Barret [8] introduced the concept of Situated Analytics Interfaces (SAIs) on Head-Worn Displays (HWDs). Their groundbreaking work clarified the advantages of SAIs over traditional mobile interfaces as well as the implementation difficulties present in this developing field. In 2019, Taehoon K. *et al.* [13] conducted a thorough investigation of the effectiveness of 3D immersive stereoscopic virtual reality technology in producing tactile sensations. Their research produced a significant finding: when compared to the haptic 3D visualization method shown on traditional 3D flat screens, the haptic 3D visualization method presented in a 3D stereoscopic space through headsets displayed superior qualities of intuitiveness, accuracy, and immersion. This result highlighted the immersive technology's transformative potential in boosting sensory engagement with data. Utilizing this knowledge, Alfaro, Luis, *et al.* [14] investigated the state-of-the-art immersive technologies, exploring their significant contributions to the creation of cognitive knowledge. Their research emphasized the potential for immersive technology to completely transform pedagogical methods while illuminating the crucial role it plays in the creation of teaching and learning activities.

Liu *et al.* [1] thorough investigation of the functionality and preferences of various tiny multiples layouts in immersive settings was carried out in the following year of 2020. Their thorough analysis, which covered designs including Flat, Quarter-Circle, and Half-Circle, with a focus on easing combinatorial difficulties through horizontal curvature, yielded insightful results. Their meticulous study did, however, recognize the intricacy of user preferences and performance in immersive tiny multiple visualizations and encourage further investigation of other elements. Simultaneously, Lee *et al.* [2] showed the benefits of utilizing shared surfaces and spaces in the cooperative field of data visualization. Their study emphasized how these collaborative environments create greater spatial awareness, increased collaboration, and improved communication. Lee and colleagues wisely understood the necessity for continued validation and further uses of shared surfaces and spaces in addition to their findings. In-depth research on immersive multiview map systems was conducted by Satriadi, K. A. *et al.* [7], who clarified their potential advantages for tasks including map browsing, search, comparison, and route-planning. While they correctly stressed the need for more study to support their findings and compare the effectiveness of immersive multiview maps to conventional single-view exploration techniques, their observations shed light on the exciting prospects of these systems.

Shifting the focus to navigation strategies in virtual worlds, Yang, Y. *et al.* [15] investigated the effectiveness of two different approaches: overview+detail and zooming in 3D scatterplots. Their comparison investigation, which covered four situations, shed light on the subtle differences between user engagement and comprehension in immersive environments. Yang, Y. *et al.* [3] research on visualization techniques was expanded upon, notably about the use of area-linked data in immersive settings. They gave important insights into the relative efficacy of conventional 2D choropleth maps versus 3D prism maps and colorful prism maps in virtual reality (VR) through thorough controlled tests.

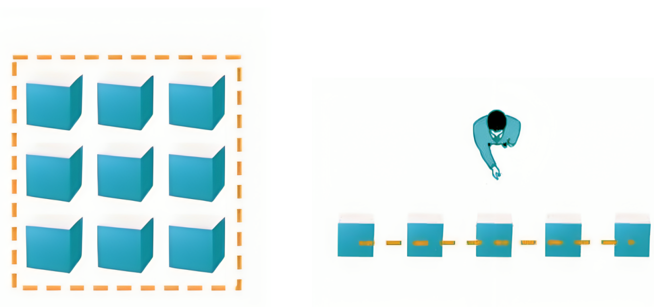
The study of the difficulties in this new field by Ens, B. *et al.* [16] in 2021 was a turning point in the development of immersive analytics. Incorporating visualization, immersive environments, and human-computer interaction, their article covered 17 different difficulties that were categorized into four main categories. These difficulties paved the way for additional research and advancement in the area of immersive analytics. The dynamics of collaboration modes and user position arrangements in a VR learning environment supporting immersive collaborative tasks were investigated concurrently by Chen, L. *et al.* [17] Their findings suggested that in cooperative VR learning settings, shared views and particular user locations could significantly improve task performance and user experience.

Reichherzer *et al.* [11] conducted a study in the field of law to explore the potential applications of immersive virtual reconstructions, particularly virtual reality (VR), in aiding juries during trial hearings. The study unveiled fascinating possibilities for the integration of immersive technology inside the court system. Newbury *et al.* [12] conducted a research investigation on the concept of embodied engagement in immersive maps. Their study shed light on the perceptual intricacies associated with maps as objects in three-dimensional space, as well as the utilization of consistent physical principles during the process of map design.

In the year 2022, Luo, W. *et al.* [18] initiated a scholarly discourse concerning the transformative capacity of augmented reality (AR) in reshaping forthcoming work environments. The researchers conducted a meticulous investigation on the impact of office environments and work practices on the organization of virtual material, specifically about the process of sensemaking using augmented reality. Liu *et al.* [19] conducted a comprehensive examination of immersive approaches for interactive Information Visualization (InfoVis), including diverse data kinds. The user did not provide any text to rewrite. The researchers' findings indicated potential shifts in data browsing behaviors through a comparison of immersive and non-immersive data visualization methods. It is hypothesized that non-immersive approaches may supplant immersive techniques in handling extensive data sets.

The aforementioned collaborative efforts exemplify a diverse array of research initiatives that have contributed to the discourse around immersive technologies and data visualization. These endeavors have yielded valuable insights, shedding light on many aspects of this rapidly evolving field and paving the way for novel avenues of investigation.

III. Methodology



(a) (b)

Fig. 1. (a) 2D DataBlocks and (b) 3D Immersive Space View

The principal methodology adopted in this research involves the development and application of a three-dimensional data visualization system. To address this matter, a block dimension and a layout design have been devised. The chosen configuration for the immersive area depicted in Fig. 1 involves a 2D block dimension and a 3D horizontal layout design. This arrangement aims to expand the possibilities for interactive data exploration and analysis within the dynamic realm of a 3D immersive environment. The aforementioned methodology signifies a fundamental change in our strategies for interacting with and deriving insights from intricate datasets, hence creating a significant impact on the field of data visualization. The system makes use of the Meta Quest 2 virtual reality (VR) headset, which has been specifically created to use the Python API and Unity software in order to provide data in a visually realistic manner.

As depicted in Fig. 2, the methodology is structured into three discrete subsections, each of which centers on a crucial facet of the system's development and implementation. The subsections are the following:

1) Python API: The utilization of a data backend API is used to streamline the process of data processing and retrieval. The Pandas library, which is a powerful tool for manipulating data, is employed to do data processing. The utilization of Flask, a web framework, is incorporated into the codebase to facilitate the transformation of the processed data into an API that can be effectively utilized. JSON (JavaScript Object Notation) is widely regarded as the optimum format for efficient data interchange, particularly for rapid data transportation.

The data frame is imported from a CSV file, serving as the primary data source. The Flask framework hosts two distinct APIs inside a single application. The first API offers a compilation of numeric data columns that may be plotted and are easily accessible. The inclusion of a user-defined column as a route parameter in the second API streamlines the process of user-driven data selection.

Upon completion of the data aggregation process, the selected column becomes linked to the predetermined column labeled "Major Category". The plot data gathered and given consists of aggregated data points, which comprise the necessary index values for constructing a bar plot. The accumulated data is advantageous in determining the relative proportions for pie charts.

The primary objective of these API is to collect and analyze data before transmitting it to the Unity platform to generate graphical representations.

2) Unity Development: Within the Unity environment, the utilization of 3D prefabricated objects is employed to graphically represent bar charts and pie charts in a manner that is highly compatible with the VR context. The prefabricated structures serve as the foundational framework for the representation and interpretation of data within the immersive virtual reality setting. The data acquired from the Python application programming interfaces (APIs) is dynamically integrated into the Unity project at runtime. The process of accessing pertinent data is expedited through the utilization of user-input columns as integral elements within URLs. The data acquired through the application programming interface (API) is associated with the pre-existing objects within the Unity software environment. A dictionary is employed as a data structure to aid the organizing of data by establishing a relationship between columns and their related values. The

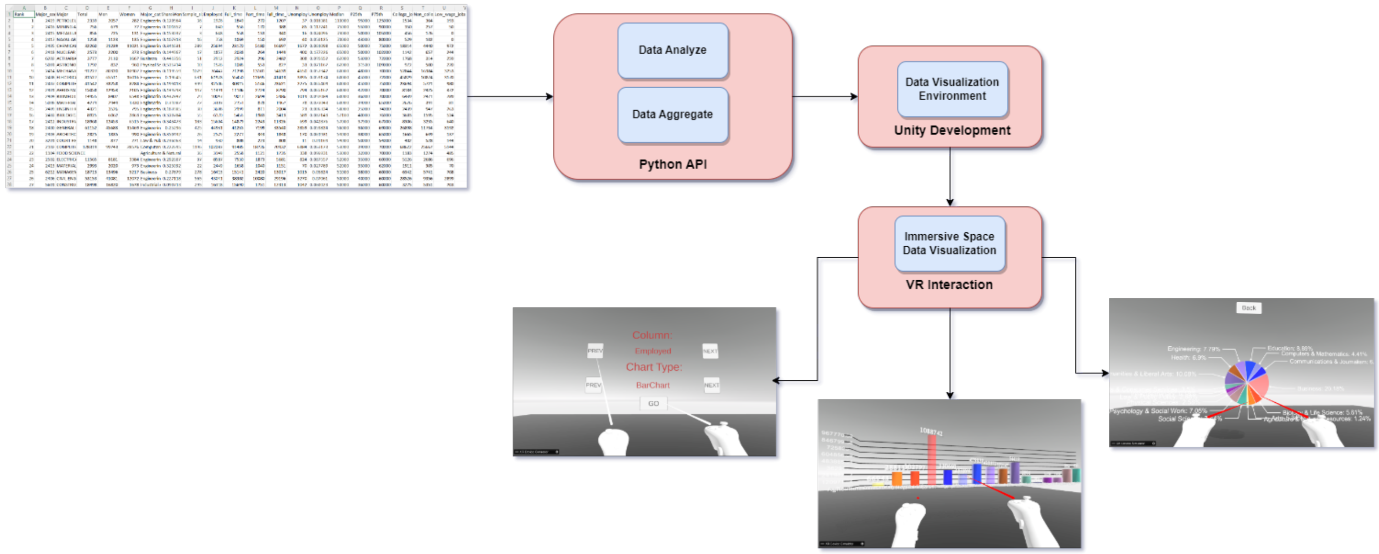


Fig. 2. Proposed data flow and unity visualization model in immersive space.

utilization of data mapping is employed in order to ensure that the preconstructed three-dimensional representations accurately and efficiently display the selected data. Ultimately, this process reaches its completion in the production of the expected data visualizations.

3) VR Interaction: The incorporation of Virtual Reality (VR) technology into the Unity project represents a crucial milestone in the pursuit of creating a fully immersive data visualization experience. The project has been designed to facilitate VR interactions, with a specific emphasis on the Oculus VR platform. The incorporation of VR controllers serves to augment the user's experience within the immersive environment. The XR Interaction Toolkit plays a crucial role in enabling virtual reality interactions and behaviors. The process of continuously testing and gathering feedback from users is of utmost importance in the iterative refinement of a system, as it aids in enhancing its usability and alignment with the desired objectives. The use of the Oculus VR platform is employed for the implementation of the data visualization project that relies on virtual reality technology, guaranteeing compatibility and achieving optimal performance inside the virtual reality environment.

This study presents a systematic approach to developing a 3D data visualization system that effectively combines Python API, Unity, and VR technologies. This methodology aims to offer a new and efficient way of data exploration and presentation inside a virtual reality setting by employing meticulous data processing, dynamic data transmission, and immersive visualization techniques. The process of continuous testing and refining plays a crucial role in ensuring that the system remains in line with user expectations and provides a captivating immersive experience.

IV. Dataset

The dataset included in this study is derived from an article entitled "The Economic Guide to Picking a College Major", accessible on the well-recognized data-centric platform 538. The information under consideration offers significant statistical insights into the median incomes linked with different college degrees. The dataset utilized in this study was carefully selected and retrieved from the previously stated publication. It serves as a solid basis for the empirical analysis conducted in this research. The dataset is supplied in the well-recognized CSV format and was obtained from a publicly accessible GitHub repository[1].

A notable characteristic of this dataset is its specific emphasis on individuals who have just completed their education. The intentional emphasis on individuals who have just completed their education is supplemented by the incorporation of gender-specific data, making it a highly beneficial tool for undertaking a thorough and diverse investigation.

The dataset illustrates the substantial financial disparities that might arise as a result of selecting a certain academic degree. It contains a thorough structure consisting of 21 attributes and 173 rows, providing a wealth of information about the economic aspects of college major choices. The structural complexity of the dataset not only facilitates a comprehensive analysis of median wages but also facilitates the identification of possible patterns and complexities that may arise among different academic disciplines, particularly among those who have just graduated from college.

V. VR Prototype Implementation

The virtual reality prototype that has been constructed in this study serves as a tool for investigating the design aspects of immersive spatial data display.

A. Experimental Setup

In our study, we employed the Oculus Meta Quest 2, a room-scale VR device, together with the Unity version 2021.3.16f1. The prototype operates on a personal computer

[1] https://github.com/fivethirtyeight/data/tree/master/college-majors

running the Windows 10 operating system. The computer is equipped with an Intel(R) Core(TM) i7-7500U CPU, which has a clock speed of 2.70GHz and can reach a maximum speed of 2.90GHz. The prototype also utilizes VRTK XR interaction to enable interactive components.

B. Interacting with the data

The proposed system aims to combine a framework for visualizing three-dimensional data with a virtual reality system. The system provides users with a menu-based interface that allows them to select attributes from a dataset stored in a CSV file. Users can also choose the required chart styles to visualize their data in a personalized manner. The user's input demonstrates a connection between the Python API and a specific attribute called "Major Category".

This feature serves to identify the main fields of study undertaken by graduates. To improve the narrative coherence, it is important to employ a consistent structural element. Based on the provided options, the aggregate data is utilized to generate the required charts.

VI. Result and Discussion

This section presents the findings of this particular research study. Based on the information provided in Section IV, it can be inferred that the dataset under consideration pertains to recent graduates, encompassing 21 attributes and 173 rows. We chose to analyze the qualities of "Employed" and "Full-time" employed among the graduates and represented the data using both a bar chart and a pie chart.

Within this system, the user has the ability to choose a certain column and chart type based on their preferences.

In Fig. 3, the user chooses the "Employed" column and selects the Bar Chart type. This option leads to the creation of a Bar chart plot, as seen in Fig. 4.

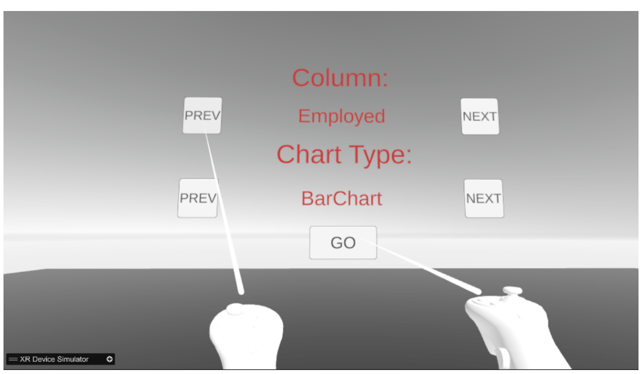


Fig. 3. Selecting employed column and bar chart type.

In Fig. 5, the user opted for the same column as previously and selected a different chart style, namely, a pie chart. Consequently, Fig. 6 displays the final plot in the form of a pie chart.

In Fig. 7, the user opted for the "Full-time" column and picked the Bar Chart type. Subsequently, Fig. 8 displays the outcome in the form of a Bar chart.

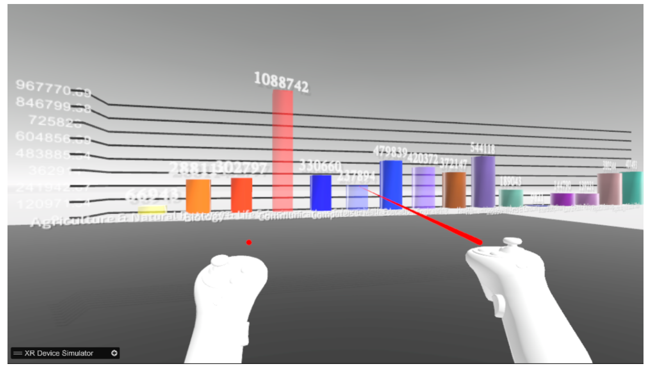


Fig. 4. Bar chart for employed graduates.

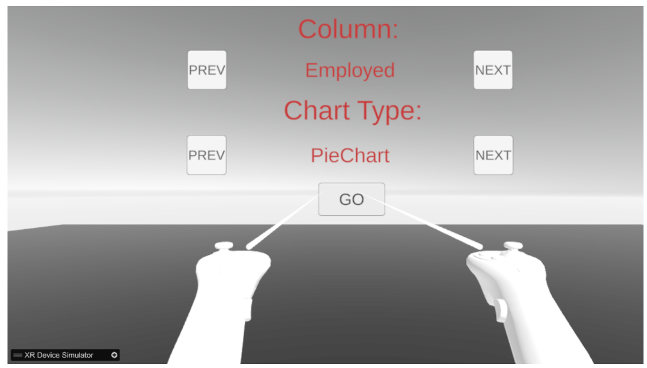


Fig. 5. Selecting "employed" column and pie chart type.

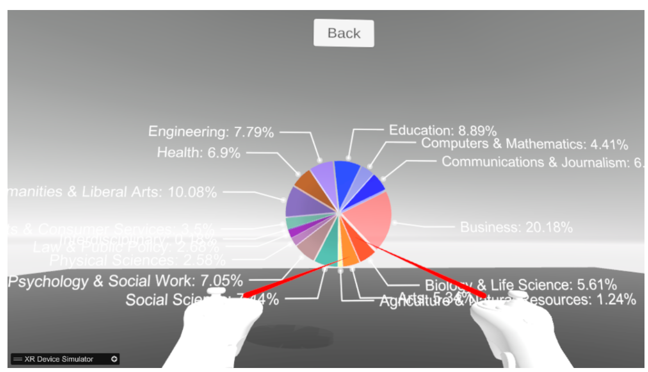


Fig. 6. Pie chart for employed graduates.

In Fig. 9, the user selected the Pie Chart type using the same column as previously. Subsequently, Fig. 10 displays the outcome in the form of a Pie chart.

VII. Conclusion

With the swift progression of technology, our research has effectively made the transition from conventional two-dimensional (2D) data representations to immersive three-dimensional (3D) data visualization. The solution we have developed provides users with an interactive platform, that allows them to access and visualize datasets within a 3D immersive environment using Python APIs. The objectives have been successfully achieved through the expansion of

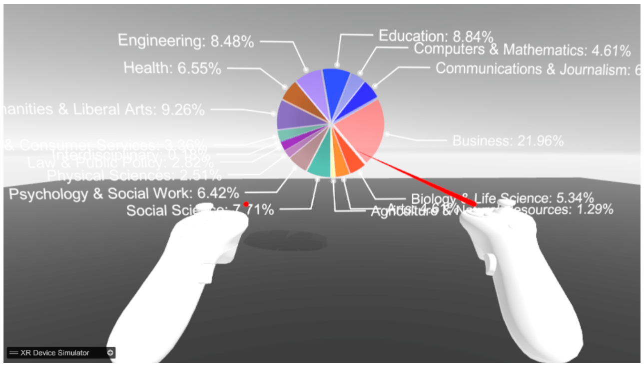


Fig. 10. Pie chart for full-time employed graduates.

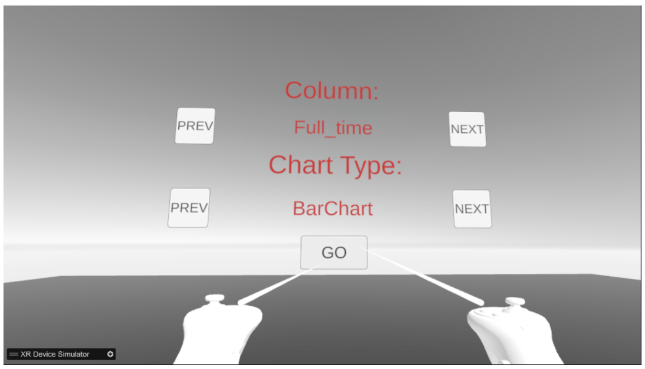


Fig. 7. Selecting "full-time" column and bar chart type.

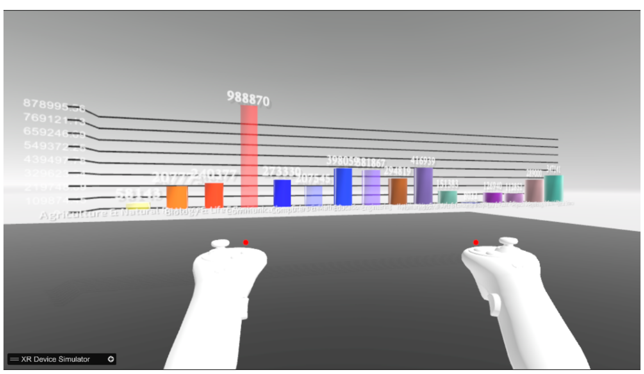


Fig. 8. Bar chart for full-time employed graduates.

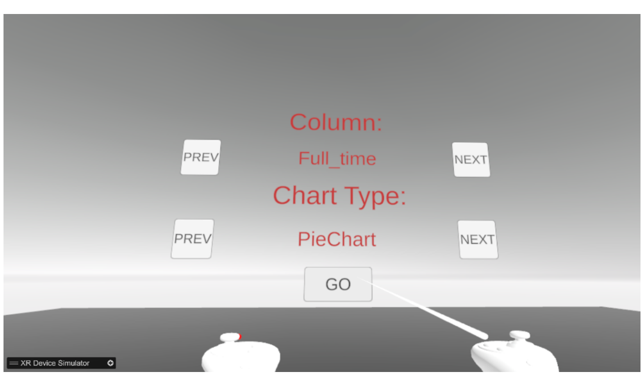


Fig. 9. Selecting "full-time" column and pie chart type.

interactive data exploration opportunities within the dynamic 3D immersive arena.

VIII. Future Work

Our forthcoming study intends to improve the visualization of data by integrating a broader array of interactive chart formats. Furthermore, our objective will be to promote collaboration through the establishment of a communal immersive environment that enables multiple users to engage in data exploration and analysis concurrently.

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