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VR Data visualization experience

Bachelor's degree in Video Game Design
and Development

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Abstract

During these recent years we have seen a massive increase in the use of Virtual Reality technologies and its multiple uses in different fields, from video games to medicine, engineering or art.

In this project we will create a virtual reality project focused on the data visualization field. We will look at how to adapt data from a database into a data visualization experience that's adapted to virtual reality and where the users will be able to immerse themselves and have a different and more interactive approach to data and data visualization.

Throughout this project we will go through the whole development of the project from the conceptualization and design of it to the coding and implementation of all the features that the experience will have. We will also be able to see how data visualization technologies can be implemented into virtual reality and we will go through how the current state of art is to this day.

Key Words

Virtual Reality, data visualization, Unity, programming, experience design, data communication, Meta Quest 2

List of Contents

List of Figures.....	7
List of Tables.....	8
Glossary.....	9
1. Preface.....	10
1.1 Motivation.....	10
1.2 The Problem.....	11
1.3 Main Goals.....	12
1.4 Specific Goals.....	12
1.5 Project Range.....	13
2. State of the art.....	14
2.1 VR headsets.....	14
2.1.1 Standalone headsets.....	14
2.1.2 PC Powered headsets.....	15
2.1.3 Hybrid headsets.....	16
2.1.4 Special-purpose headsets.....	17
2.2 Data visualization.....	18
2.2.1 What is data visualization?.....	18
2.2.2 How do we create good data visualization?.....	19
2.2.3 Data visualization common mistakes.....	25
2.2.4 Great data visualization.....	27
2.3 VR Data visualization tools.....	30
2.3 Interactive data communication.....	34
2.4 Where do we go from here?.....	37
3. Planification.....	38
3.1 SWOT Analysis.....	40

3.2 Risks and Contingency Plans	41
3.2.1 Programming	41
3.2.2 Design.....	42
3.2.3 Art.....	42
3.3 Initial Cost Analysis	43
3.4 Management tools	43
4. Methodology.....	44
4.1 Monitoring Tools.....	46
4.2 Evaluation tools	47
5. Development.....	48
5.1 Tools, technology and devices	48
5.1.1 Devices	49
5.1.2 Technology and tools	49
5.2 Preproduction	52
5.2.1 Concept Idea	52
5.2.2 Design.....	53
5.3 Production.....	54
5.3.1 Unity project Setup.....	54
5.3.2 Meta Quest 2 in Unity	55
5.3.3 Earth	57
5.3.4 Data Set	59
5.3.5 Data into Unity	61
5.3.6 Interaction.....	63
5.3.7 User Interface	64
6. Conclusions and Future Work	66
7. Bibliography	67
8. Download the prototype	68

List of Figures

Figure 1. Oculus Go Standalone Headset.....	14
Figure 2. Valve Index PC-powered Headset.....	15
Figure 3. Oculus Quest 2 Hybrid Headset.....	16
Figure 4. PS VR Special Headset.....	17
Figure 5. VIVE Flow Special Headset.....	18
Figure 6. Principle of figure-ground.....	20
Figure 7. Principle of Similarity.....	21
Figure 8. Principle of proximity.....	21
Figure 9. Principle of common region.....	22
Figure 10. Principle of continuity.....	22
Figure 11. Principle of closure.....	23
Figure 12. Principle of focal point.....	23
Figure 13. Data visualization pillars.....	24
Figure 14. ESPN visualization, bad design.....	25
Figure 15. ESPN visualization, bad design.....	26
Figure 16. Average female height visualization, bad design.....	27
Figure 17. Cell towers in the world by OpenCellID.....	28
Figure 18. Covid-19 vaccination tracker by reuters.....	29
Figure 19. Stolen Paintings by La Lettura.....	30
Figure 20. Brexit - Google Labs.....	31
Figure 21. Reddit's "Place".....	31
Figure 22. Reddit's "Place" VR data visualization tool.....	32
Figure 23. 21 years of the Nasdaq.....	33
Figure 24. 6x9 - The Guardian.....	34
Figure 25. Titans of Space.....	35
Figure 26. War Remains.....	36
Figure 27. Gantt diagram part 1.....	38
Figure 28. Gantt diagram part 2.....	39

Figure 29. HacknPlan Project.....	44
Figure 30. Scrum methodology diagram.....	45
Figure 31. Waterfall Methodology diagram.....	46
Figure 32. GitHub Interface.....	47
Figure 33. Unity game engine.....	50
Figure 34. Audacity Audio editor.....	51
Figure 35. Photoshop.....	51
Figure 36. Blender Modelling software.....	52
Figure 37. Unity Project Creation.....	55
Figure 38. Oculus Integration SDK.....	56
Figure 39. Earth Shader in the Amplify shader tool.....	57
Figure 40. Earth Model With the shader applied.....	58
Figure 41. Earth Political Map Version.....	59
Figure 42. The World Bank Website.....	60
Figure 43. Sorted Data in Excel.....	60
Figure 44. Country Base Class.....	61
Figure 45. Csv Data Parse.....	62
Figure 46. Rescale Function.....	62
Figure 47. Country Color Functions.....	63
Figure 48. Ray Interactor Component.....	63
Figure 49. Ray interactable Component.....	64
Figure 50. Meta Quest 2 Controllers.....	64
Figure 51. Curved Canvas.....	65

List of Tables

Table 1 Swot Analysis.....	40
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Glossary

VR: Virtual Reality, the use of computer technology to create a simulated environment.

Data visualization: Interdisciplinary field that deals with the graphic representation of data.

Game engine: Software framework primarily designed for the development of video games.

Unity: Game engine used to develop games and other interactive software.

Bug: Error in the code that crashes or prevents the software from working as expected.

Game object: The fundamental objects in Unity that represent characters, props and scenery. They do not accomplish much by themselves, but they act as containers for components that implement the real functionality.

Shader: User-defined program designed to run on some stage of a graphics processor. Shaders provide the code for certain programmable stages of the rendering pipeline.

Data set: Collection of related sets of information that is composed of separate elements but can be manipulated as a unit by a computer.

Scene: Where you work with content in Unity. They are assets that contain all or part of a game or application.

1. Preface

1.1 Motivation

Data visualization and data analysis is a big part of our society nowadays. We use it to track lots of information, which helps us make better decisions and understand why things happen in the way they happen. Nowadays, we use it in lots of different fields, such as physics, economics, business management, medicine, computer science, etc. This has always attracted me, and it still amazes me how using graphs, charts and other types of data visualization helps us understand such big chunks of data in a simple and visually appealing way that people can interpret and understand easily.

On the other hand, creating an experience for data perception is more than just showing the users a representation of a data set. An experience lets me create a project where we can take the user on a journey to connect them with the data we are using, it makes the work of immersing the user in the world of the data we will be showing to them and take part in it.

Finally, using virtual reality in the project has also been a big part of the decision to take part in this project. Since I started thinking about the final degree project, I have been thinking about projects where I could use virtual reality. It's a topic that since the start of this project I have had no knowledge about, and it really appealed to me. I have always been kind to get involved in a project that uses VR, and when Lasse proposed to make this topic, I thought it was a great project to get involved in and start my journey in the virtual reality field.

1.2 The Problem

Nowadays, with all the information we receive, it's very hard for us to retain everything we get told and explained. Every day we receive tons of input and new information, and without an adequate environment and experience, it is very hard for people to remember everything. On the other hand, information and data understood without emotions is always easily forgotten. In order to reach people and make them understand, the VR experience has to appeal to the users and connect the data with their emotions and their knowledge.

As the data expert Brent Dykes says in a Forbes article, “The need for more data storytellers is only going to increase in the future. With the shift towards more self-service capabilities in analytics and business intelligence, the pool of people generating insights will expand beyond just analysts and data scientists. This new breed of data tools will make it easier for people across business functions to access and explore the data on their own. As a result, we're going to see an unprecedented number of insights being generated within companies, more than ever before. However, unless we can improve the communication of these insights, we will also see a poorer insight-to-value conversion rate. If an insight isn't understood and isn't compelling, no one will act on it and no change will occur.” (Dykes, 2016) . The need to not just show data to people but to communicate it in a meaningful way to them is rapidly becoming a necessity nowadays because not only experts have access to data but everyone has access to lots of information ,and without an accessible way of showing it, it can be hard to interpret and understand what we are seeing. Data visualization expert Stephen Few said, “Numbers have an important story to tell. They rely on you to give them a clear and convincing voice.” (Dykes, 2016a).

That's why data storytelling is important nowadays and it's something that isn't being explored as much as it should be. There are great data visualization storytelling experiences and it's something that has been getting more attention in recent years, but with the rise of new technologies such as virtual reality, there is still a lot of room to explore and innovate in this field. Although there are some data visualization experiences in VR, such as the *6x9 virtual experience of solitary confinement* or *Titans of Space*, I think we have to keep going and exploring in order to see how these tools can help us narrate and understand data.

1.3 Main Goals

The main objective of this TFG is to take a set of data and, through data visualization, create an experience where the users, through their virtual reality glasses, are capable of having a better understanding of what the data scale and meaning really is. The objective is that the users can understand and have a closer look at what a data set can really mean more than some numbers or information on a screen throughout the mechanics and all the design behind the project and using data visualization.

1.4 Specific Goals

To perform this project, we have set some objectives that we will take into account during the development:

1. Find a topic with enough data and interest to be used to create an experience from it.
2. Design an experience that lets the user understand how the data changes with their interactions.
3. Adapt and implement real data to take part in the virtual reality experience.
4. Implement all the necessary mechanics of the project.
5. Create and implement a cohesive and consistent art style through the experience.
6. The last goal to accomplish is to educate, as education is really important and data visualization is a really powerful tool to help teach people more about the world we live in.

1.5 Project Range

This project is aimed at helping people see that data can be understood if it's presented in an easier and more accessible way, through narrative and interaction. That's why this project is aimed at everyone who is interested in having an experience in data visualization. On the other hand, there are also some limitations for people to have this experience, as not everyone has a VR headset at home to try out the experience and not everyone is used to virtual reality technologies. Our objective is to make the project as accessible as possible to people to make them connect with what data can mean through an experience. That's why the project has to help the people that haven't got any experience in virtual reality so they can have the same experience as those that have more experience using VR hardware.

After this, we can conclude that the project is meant to be used by people who own VR hardware that's compatible with the experience and are interested in having that experience and learning about it.

2. State of the art

2.1 VR headsets

Before discussing the different types of games and experiences that use VR and data visualization nowadays it's important to notice that there are different types of hardware used for virtual reality in the market and it's important to know and see the differences between them before deciding which is the one that suits better and it's going to be used in the project.

2.1.1 Standalone headsets

These headsets are capable of working by themselves without the need to use any type of computer or phone attached to them. They have an integrated PC that runs everything they need in order to work.

The prices for these devices can normally range from 199€ to 599€.

An example of this type of headset is the Oculus Go:<https://www.oculus.com/go/>



Figure 1. Oculus Go Standalone Headset.

[URL : <https://m.media-amazon.com/images/I/51SLSQfATKL.AC.SL1379.jpg>]

2.1.2 PC Powered headsets

PC powered headsets are devices that are not meant to work by themselves, they need another device that powers them in order to work. Most of these devices can be connected to a PC, but there are some that also work with mobile phones.

Normally they are wired to the PC in order to work, but nowadays we can start to see some options that work wirelessly and can be connected through Wi-Fi or Bluetooth.

Prices for PC powered headsets can normally range from 100€ -1000€.

An example of this type of headset is the Valve Index :

<https://store.steampowered.com/sub/354231/>



Figure 2. Valve Index PC-powered Headset

[URL : https://m.media-amazon.com/images/I/61QWPgRS0S._SL1500_.jpg]

2.1.3 Hybrid headsets

The third type of headset we can find are hybrid headsets. These types of devices can work as both standalone and PC-powered headsets, so you are able to use them by connecting them to another device which will power them, and they also have an integrated PC in them that can run by itself without the need of any other device.

There are different prices for these devices, but the most popular round form is 200 to 500 euros.

An example of a hybrid VR headset is the Meta (Oculus) Quest 2:

<https://www.oculus.com/quest-2/>



Figure 3. Oculus Quest 2 Hybrid Headset

[URL : <https://m.media-amazon.com/images/I/615YaAiA-ML. SL1500 .jpg>]

2.1.4 Special-purpose headsets

The last type of headset we can find are the special-purpose headsets. These types of headsets are made in order to fulfill concrete purposes. Some years ago, these types of headsets weren't really frequent as the VR technology was really recent, but nowadays that virtual reality is more common, we can start to see more niche devices that fulfill more concrete purposes.

We can find different examples like the PS VR, which is a headset dedicated to gaming with a PlayStation console:

<https://www.playstation.com/es-es/ps-vr/>



Figure 4. PS VR Special Headset

[URL : <https://www.desconsolados.com/wp-content/uploads/2021/03/PSVR-708x398.jpg>]

Another great example of this is the VIVE Flow VR headset, which is dedicated to wellness and meditation:

<https://www.vive.com/us/product/vive-flow/overview/>



Figure 5. VIVE Flow Special Headset

[URL : <https://www.muycomputer.com/wp-content/uploads/2021/10/HTC-VIVE-Flow-2.jpg>]

2.2 Data visualization

2.2.1 What is data visualization?

Before starting to look at how data visualization is nowadays, I think its important to have some context about what data visualization is and what makes good data visualization.

Data visualization is the graphical representation of information and data by using visual elements like charts, graphs, maps and other techniques. Data visualization tools provide an accessible way to see and understand trends, outliers and patterns in data.

In the world of Big Data, data visualization tools and technologies are essential to analyze massive amounts of information and make data-driven decisions. (What Is Data Visualization? Definition & Examples | Tableau, n.d.)

From here we can understand why data visualization is important and how it can help us in the world of data analysis as it creates a visual representation of data which for us humans it can be really difficult to put into perspective some times just from rough information. Data visualization is a tool that helps us put into perspective the data we are trying to analyze, and if its well done it can help us understand it better and take better decisions from it.

2.2.2 How do we create good data visualization?

Now that we have a rough knowledge of what data visualization is and how it can help us, we can ask another question: what makes good data visualization?

When creating some data visualization for our data, it's important to understand that not everything works and that even though data visualization can help us have a better understanding of what we are analyzing, a badly driven and badly focused data visualization can also make us have a wrong understanding of the data we are analyzing.

In order to avoid having a bad perception of what we are analyzing, what can we do?

Matt David, who is a data analyst expert, gives us some best practices for creating compelling and reliable data visualization.

The first thing he suggests is to define "why." To keep yourself on track throughout the data visualization process, think about your core motivation behind visualizing your data as a plain-English sentence. "This definition of "why" is the seed that will grow into the story you tell with your data." (David, 2020) he says.

We can differentiate the motivations into 3 different categories: ad hoc, strategic planning, and decision support.

Ad hoc is for when you need to explore data quickly and roughly in order to find a fast answer or clarify your own thinking. The audience is often you or a knowledgeable teammate.

Strategic planning is when data visualization is meant to inform decision-making behind large projects. The audience here is broad, from executives who need to provide approval to the employees who have to put the plan into action. Strategic planning visualizations often rely on historical data and should be well thought out because they play a central role in both the planning and the process of carrying out that plan.

Decision support data visualizations help with ongoing decision-making. The audience is usually composed of business leaders but can also be any employee who has to make data-based decisions. These data visualizations here should be well-thought-out, like

strategic planning visualizations, but highly iterative, like ad hoc visualizations (David, 2020).

The second practice he advises is to keep it simple. After having answered the "why", we can start to think about the options we have to visualize the data. But going for fancy options is not always the answer, as our main objective is not to create a beautiful visualization but to be clear and succinct.

As a third piece of advice, he gives us is to cluster but don't clutter. As we have said before, we have to keep it simple to have good visualization and data can normally be complex, so it can be easy to try to simplify it to the point where what we are trying to show or explain with the data starts to change.

In order to avoid that, we can use techniques like the gestalt principles of visual perception, which are some principles mainly used in the field of design and which state different rules to follow in order to have clear and coherent designs. These principles help us understand how the human brain interprets different shapes and colors when put together and help us see what's easier for humans to understand.

There are seven main principles:

The figure-ground principle, which states that we can instinctively interpret objects that are in the foreground or the background. Which means that they can stand out prominently in the front or the background of the figure.



Figure 6. Principle of figure-ground

[URL https://www.cormacmaher.com/wp-content/uploads/2018/02/figure_ground_reverse_by_zentatsu-d593xs7.jpg/]

The principle of similarity, which states that things similar to each other are instinctively grouped together, and we tend to think that they have the same function.

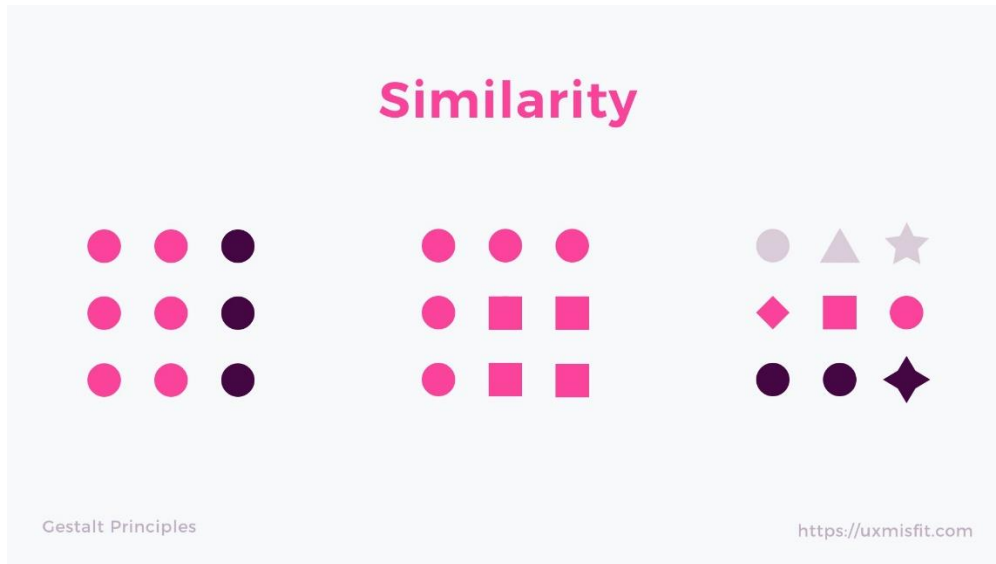


Figure 7. Principle of Similarity

[URL : <https://uxmisfit.com/wp-content/uploads/2019/04/similarity.jpg/>]

The principle of proximity, which states that things that we tend to relate things those that are closer together than those that are further apart.

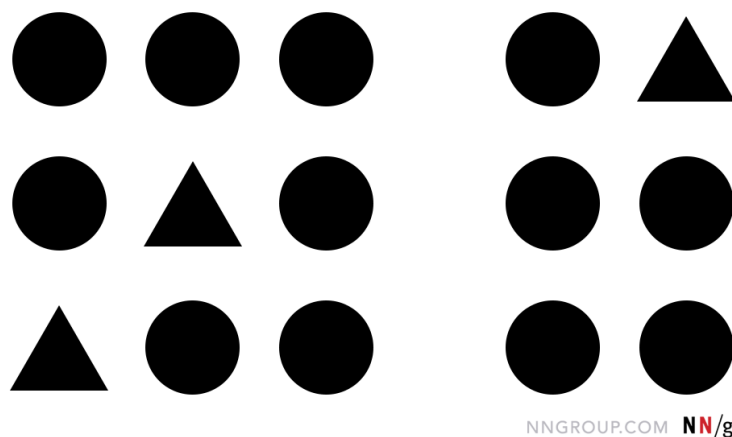


Figure 8. Principle of proximity

[URL https://media.nngroup.com/media/editor/2020/07/02/proximity-withdifferentshapes.png_]

The principle of common region, which states that when objects are enclosed in the same region, they are perceived as a group.

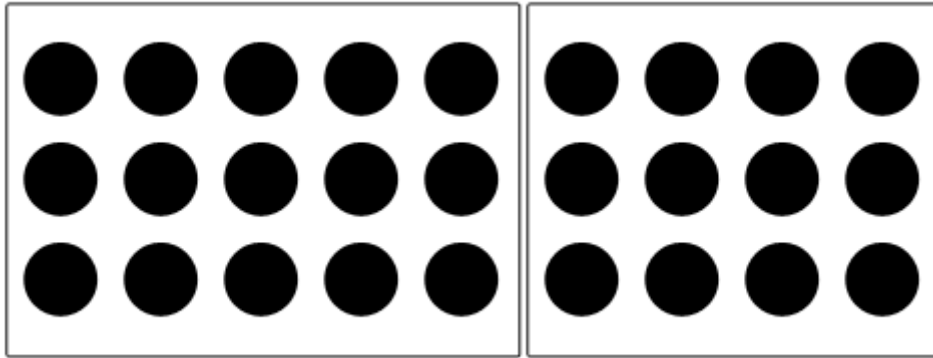


Figure 9. Principle of common region

[URL https://www.usertesting.com/sites/default/files/inline-images/common-regions_0.png]

The principle of continuity, which states that elements arranged on a line or curve are perceived to be more related than other elements outside the line or curve.

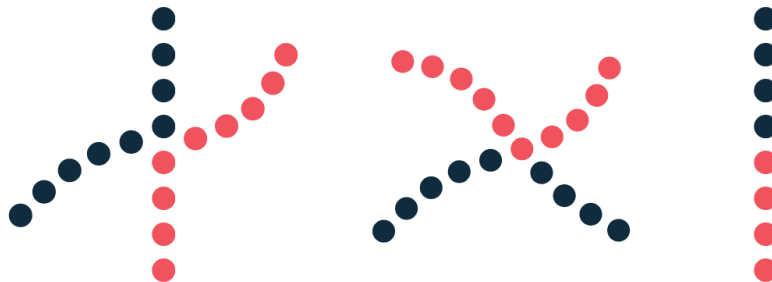


Figure 10. Principle of continuity

[URL https://miro.medium.com/max/1400/1*Nn5jdN0G69T6ROTSAJEEfw.png]

The principle of closure, which states that when we look at complex patterns of shapes and elements, we instinctively try to look for a single recognizable pattern.

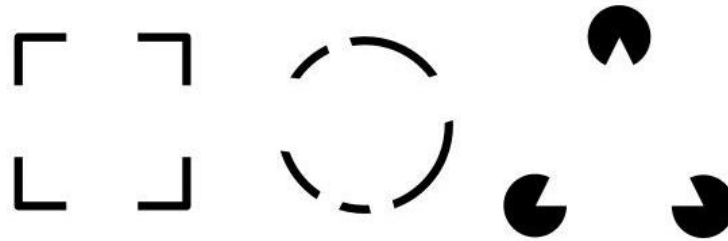


Figure 11. Principle of closure

[URL <https://i.pinimg.com/originals/ee/55/72/ee5572bcec1a90f2f76ecbabe0549ca5.jpg>]

For the last principle, we have the principle of focal point, which states that if an element stands out, it will instinctively capture the user's attention before other elements.

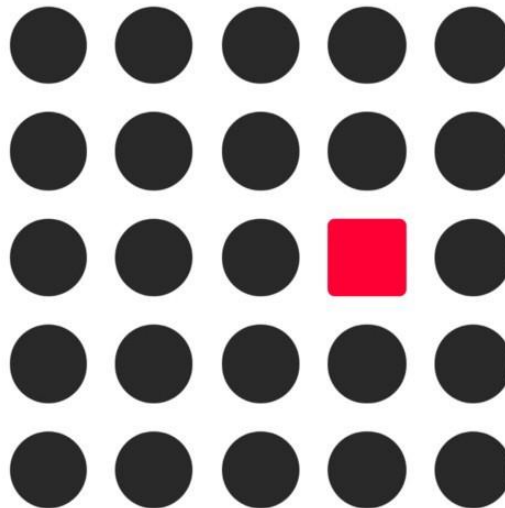


Figure 12. Principle of focal point

[URL https://miro.medium.com/max/1400/1*jnYC88PBMXmfLL2GHbFgFA.jpeg]

The last piece of advice David gives us is to have a story to tell. This means that it is important not only to convey useful data but to resonate with the audience we are trying to approach. It's important to prioritize the audience first, to know what the audience needs, and to prioritize it over other things like what you want to achieve, for example.

Another thing, to take into account when creating visualizations is identifying accepted thresholds for each variable. Doing so provides a benchmark against past performance and can provide guidance on how to avoid displaying misleading differences between categories. So, for a line chart showing how a digital ad performed over time, you may

want to show how previous campaigns fared to help the team decide if the campaign is worth repeating or if the results can be built up.

Label bar charts with numbers, but not to the extent that the details become overwhelming. Long numbers are usually hard to read. Use a shorthand recognizable to the team when accuracy to the nth degree isn't important. For example, the value “10,523” can be shown as “10K” on a bar graph.

Where possible, sort data by value to emphasize scale, but be careful not to distort the difference between categories. (DeBois, 2020).

To understand better the pillars of good data visualization, we can take a look at the data visualization created by the expert David McCandless, shown in the next figure.

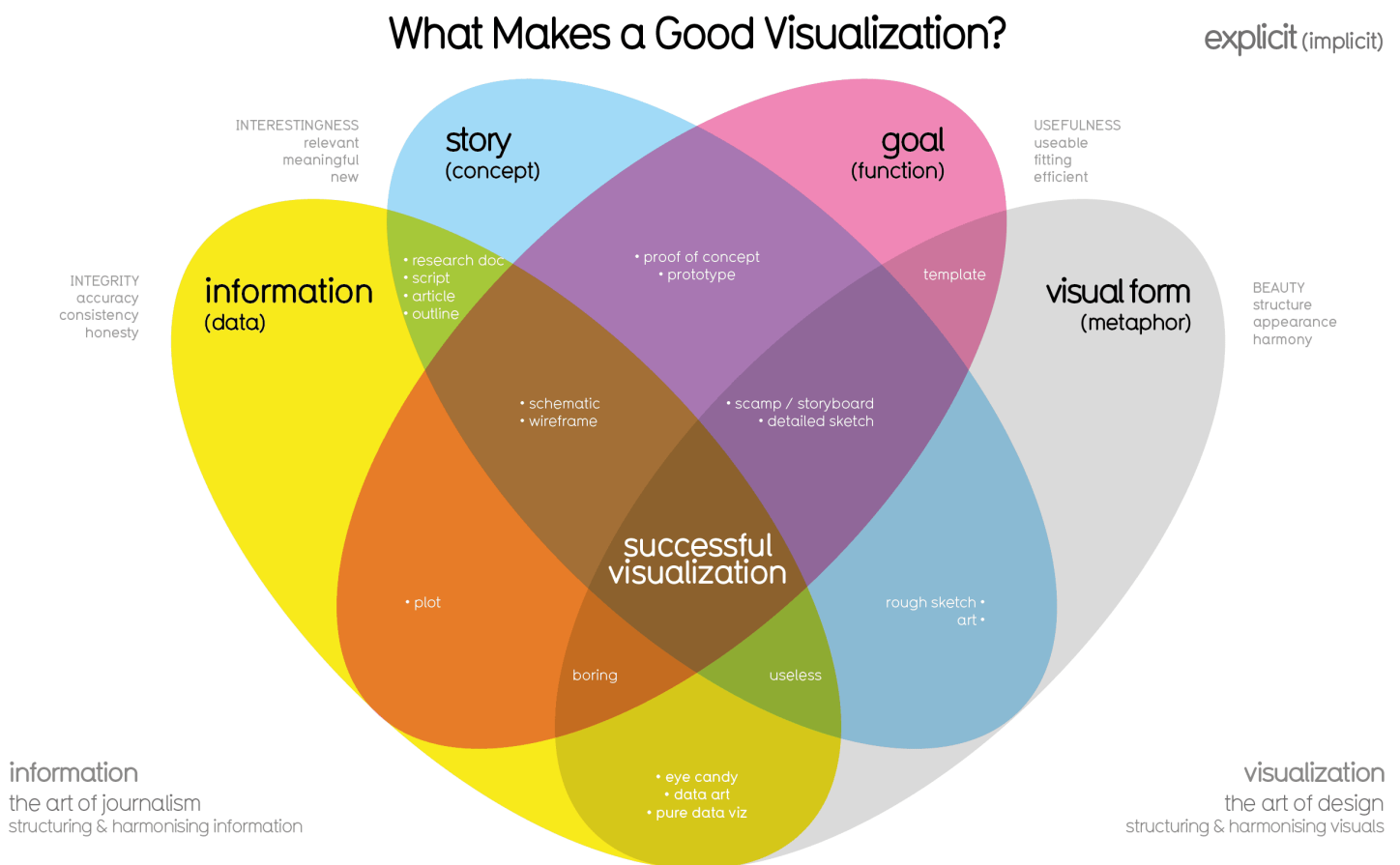


Figure 13. Data visualization pillars

[URL https://infobeautiful4.s3.amazonaws.com/2015/05/2552_What-Makes-a-Good-Infoviz-frame02.png]

As we can see in the data visualization, the four main pillars we need to take into account to create a successful data visualization are information, which refers to the data we are

using, the story which represents the concept of what we are trying to say and how we say it, the goal which is the function of what our visualization is made for and the visual form which is a metaphor we use to represent the data and give a visual coherence to it.

What is also great about this visualization is that we can also see what happens when we don't take into account some of those pillars. For instance, if we create a concept without the story, we are going to create a boring visualization, and if we don't take into account the goal of what we are making, we are probably going to end up with a useless visualization.

2.2.3 Data visualization common mistakes

Missing one of those pillars can be a crucial mistake, but it's not the only way to have confusing or badly designed visualizations. To see other ways visualizations can go wrong, we will take a look at some bad visualizations and analyze why they don't work as they should be.



Figure 14. ESPN visualization, bad design

[URL <https://www.espnricinfo.com/story/which-top-cricket-city-would-win-the-world-cup-1196522>]

As we can see in this figure above, the graphic adds no value to what we are trying to explain. There is a dense text on top which needs to be read to be understood. If using different sizes for bars is bad enough, using different shapes for each bar can be even

more confusing too. Also having two types of information being represented in the graph makes it confusing as to what the bars are trying to show.

This example helps us see why we have to keep it simple, as having complex designs for visualizations can end up messing with the information we are trying to give.

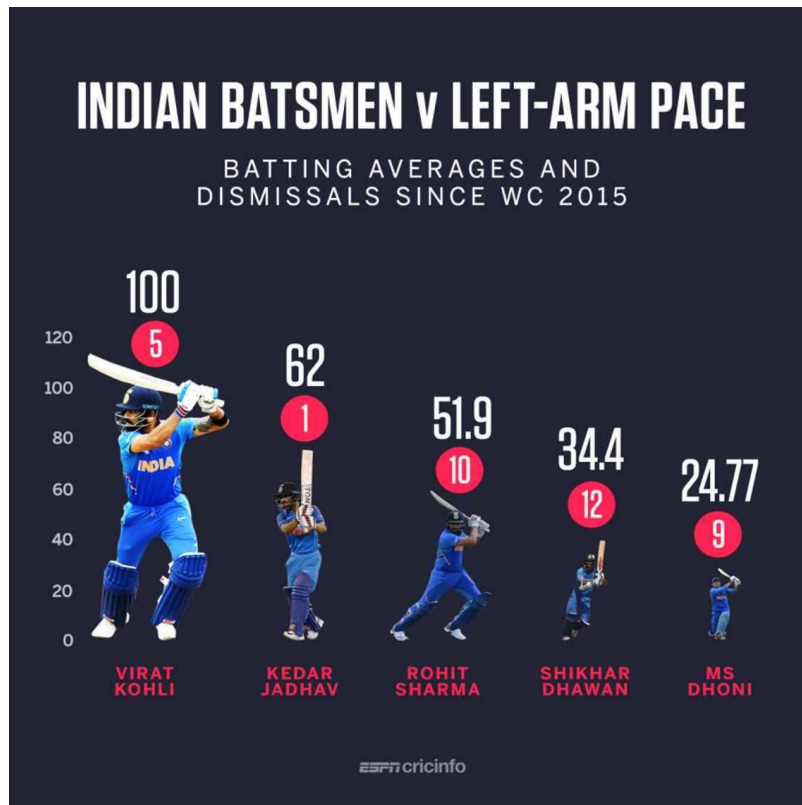


Figure 15. ESPN visualization, bad design

[URL <https://www.espn-cricinfo.com/story/tactics-board-how-india-can-beat-australia-1187863>]

In this second example, we can see how, again, the use of different shapes can be confusing. We can also see from this that the scale at the left is useless as it doesn't help us have a precise vision of what the visualization is telling us as we have the exact number at the top. Finally, the numbers in the red circles above the players do not have context, and it's hard to understand what they mean without more information.

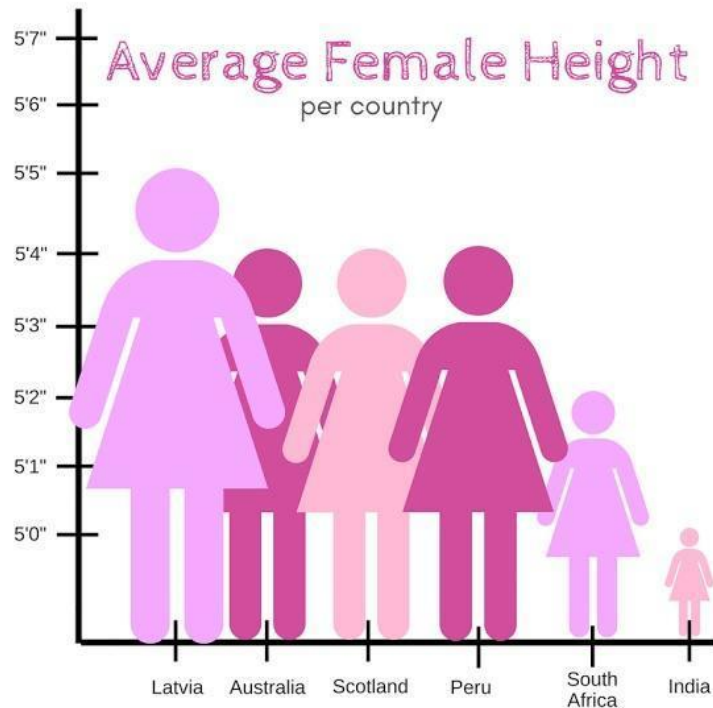


Figure 16. Average female height visualization, bad design

[URL <https://badvisualisations.tumblr.com/image/184828044636>]

In this last example, we can see we have a problem of scale. This visualization makes it seem that Indian women are a fifth of the height of Latvian women, and that is because the y axis of the graph doesn't start at 0. As a rule, the y axis should always start at 0. If the y axis had started at 0 instead of 5'0" we would be able to see that the difference in height between all the bars is not that radical.

2.2.4 Great data visualization

After having a better understanding of what data visualization is and what is considered a good visualization and what's not, let's take a look at some good examples of visualizations to see how the industry is nowadays and where we have got to.

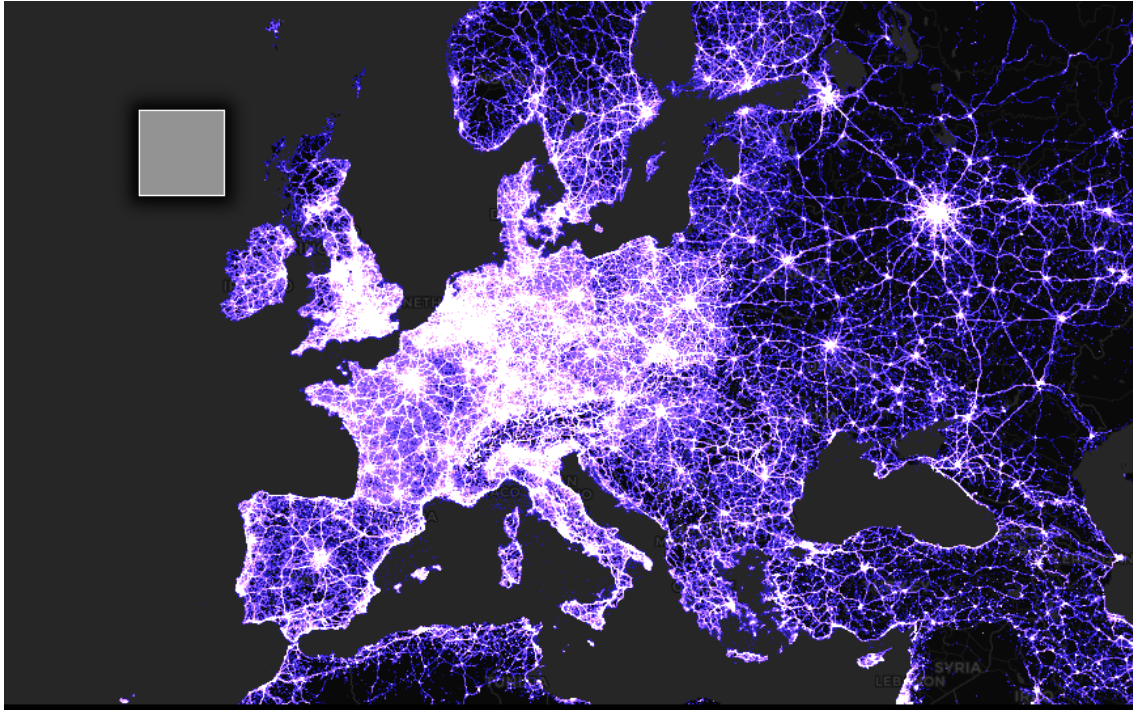


Figure 17. Cell towers in the world by OpenCellID

[URL <https://alpercinar.com/open-cell-id/>]

This visualization, created by OpenCellID, lets us see all the tower cells that are active around the globe, giving us a clear perspective of the density and position of the tower cells everywhere in the world. This visualization is not only visually appealing but is also really clear and is interactable. Anyone who wants can get into the website and move around the map of the globe looking and focusing on different areas, and it even tells us how many towers of each type there are in that enclosed area we are looking at.



Figure 18. Covid-19 vaccination tracker by reuters

[URL <https://graphics.reuters.com/world-coronavirus-tracker-and-maps/vaccination-rollout-and-access/>]

In this second example, the visualization lets us see the percentage of people vaccinated against COVID-19 per country, all around the world. It's a really clean implementation that lets us see right away which countries have a higher percentage of vaccinations and which ones have a lower one with their color difference. It is also interactable, so people can move around the globe and explore all the countries. If a country is selected, it shows extra information about it.

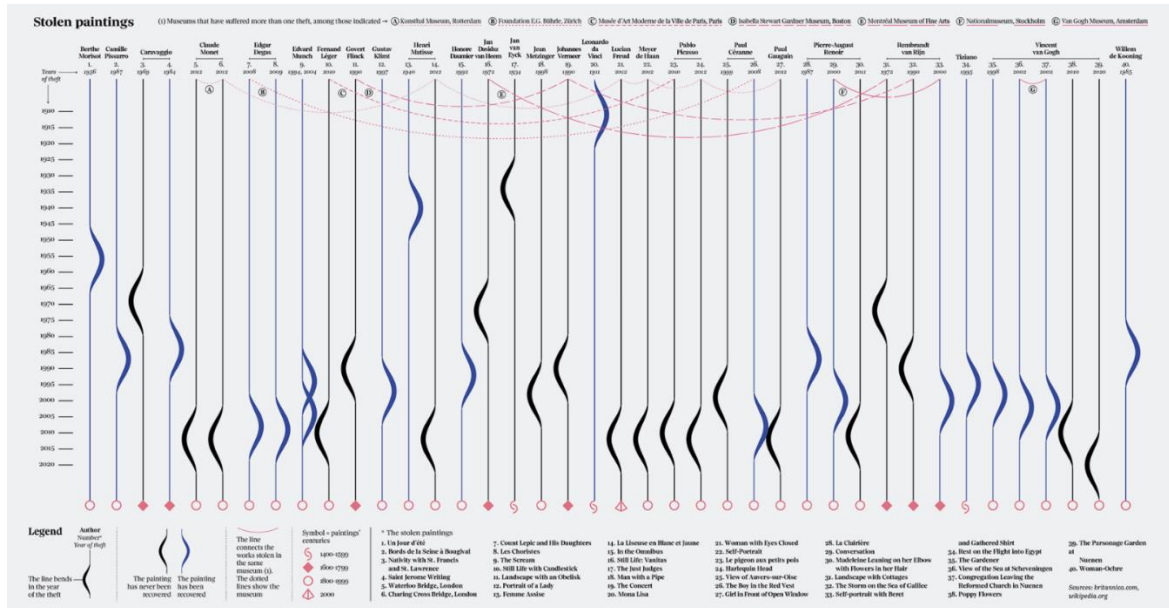


Figure 19. Stolen Paintings by La Lettura

[URL <https://www.behance.net/gallery/110024405/Stolen-paintings/>]

This last example is an infographic that shows us 40 important stolen paintings since 1900. The infographic shows us several details about each painting, such as the year it was stolen, the artist, the century when it was made, and the name of it. This infographic is not only clear but really appealing to the eyes.

2.3 VR Data visualization tools

A great way to start to see what virtual reality has to offer us in data visualization is to have a look at what tools and software are nowadays being used and sold on the market. Those might not be experiences with great data communication, but they allow us to see how far data visualization has gone in terms of virtual reality.

Brexit – Google Labs



Figure 20. Brexit - Google Labs

[URL :<http://news-lab-brexit.appspot.com/images/social.png>]

<http://news-lab-brexit.appspot.com/vr/>

This tool created by Google lets you see, while interacting with it, what the most searched questions are from all over Europe about Brexit, which is the withdrawal of the United Kingdom from the European Union.

With this tool, we are able to look around and point to the different countries in the UE to see what the most searched questions are about the topic.

Reddit's "Place" VR data visualization tool



Figure 21. Reddit's "Place"

[URL: <https://i.ytimg.com/vi/CbCr4SZOV00/maxresdefault.jpg>]

Video with explanation from the creator of the tool :

<https://www.youtube.com/watch?v=bkPAJ8aP89U>

Project website: <https://github.com/GregBahm/PlaceViewer>

Reddit's Place was a social experiment done on the social network of Reddit where a blank canvas of 1000x1000 pixel squares was presented to Reddit users. During 72 hours, users were able to change pixels one by one by choosing between a 16-color palette, and after changing a single pixel, a timer between 5 and 20 minutes was set up for the user, which wouldn't let him change more pixels.

During these 72 hours, communities from the social network fought to have a space on the canvas where they could create and maintain their artwork.

In the next URL you will be able to find a video timelapse of how Reddit's Place changed during the course of these 72 hours.

<https://www.youtube.com/watch?v=XnRCZK3KjUY>

After the experiment ended, Greg Bahm decided to create a tool that, using virtual reality, would be able to see different information and data from the Place experiment. This tool lets you see the hit of the different pixels through time to see which were the most changed pixels and at what time. It lets you see all the transformations of the pixels through time and have a look at what they looked like throughout history and many other tools that Greg Bahm created and other collaborators added to it later on.

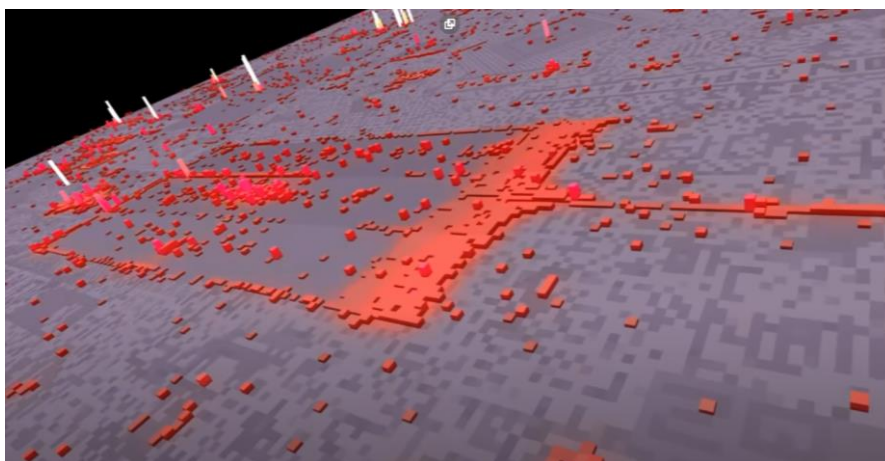


Figure 22. Reddit's "Place" VR data visualization tool

[URL: <https://www.youtube.com/watch?v=bkPAJ8aP89U>]

21 years of the Nasdaq – Wall Street Journal

This project, created by the Wall Street Journal, lets the users have another perspective on the last 21 years of the Nasdaq, or National Association of Securities Dealers Automated Quotation, which is an American stock market. This tool lets you see all the ups and downs that the stock market has gone through, marking all the important events at the time.

Project URL: <http://graphics.wsj.com/3d-nasdaq/>

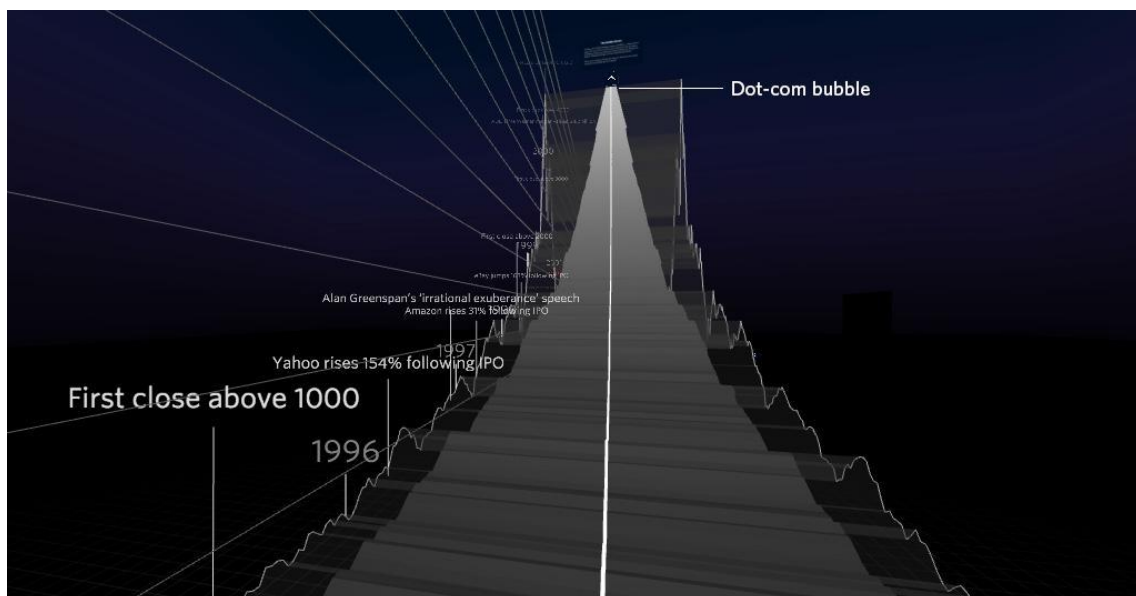


Figure 23. 21 years of the Nasdaq

[URL: <http://graphics.wsj.com/3d-nasdaq/img/promo-facebook.jpg>]

2.3 Interactive data communication

Now that we have taken a look at some data visualization tools, we also have to take into account that there are other types of virtual reality experiences that not only help to represent data and show it to the users but also try to take them on a journey, to immerse them in a more sophisticated experience. Those experiences are important because not only do they show the data to people but also give meaning to it.

6x9 a virtual experience of solitary confinement



Figure 24. 6x9 - The Guardian

[URL: <https://www.realovirtual.com/files/images/4001-5000/4085/5bc6eafaa42b9.jpeg>]

URL to the project:

<https://www.theguardian.com/world/ng-interactive/2016/apr/27/6x9-a-virtual-experience-of-solitary-confinement>

In this virtual reality experience created by The Guardian the user gets on the skin of a prisoner and its life and gets to experience what it's like to live in confinement 23 hours a day. It's interesting how this experience tries to show you not only how it is to live in confinement but also what it feels like to live like that for long periods of time and how this has an effect on people.

Titans of Space

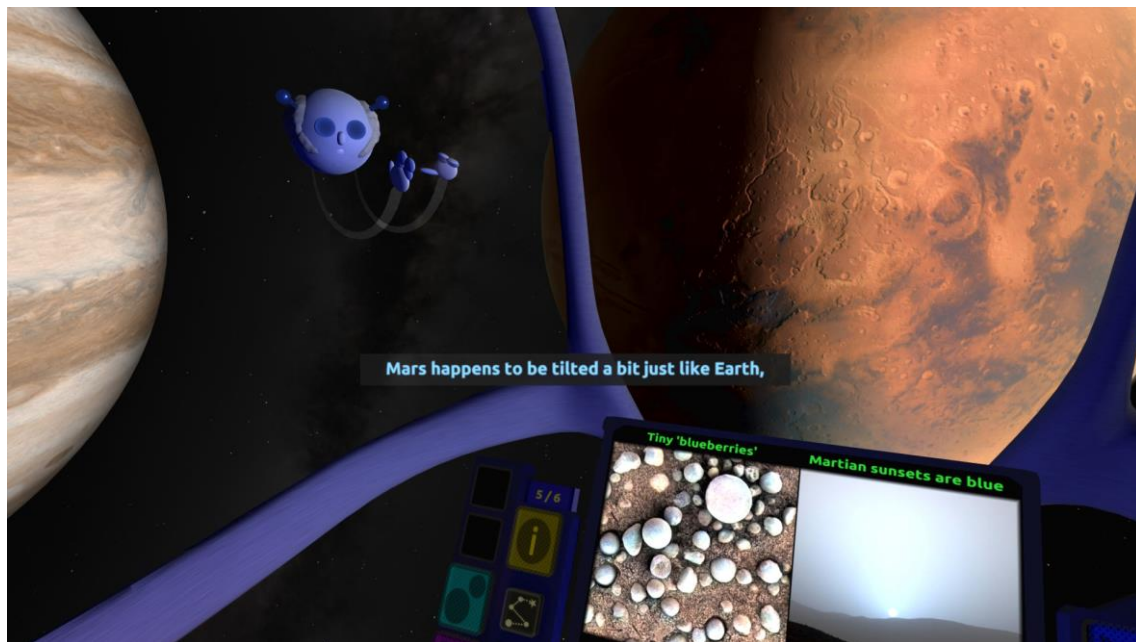


Figure 25. Titans of Space

[URL:

https://cdn.cloudflare.com/steam/apps/468820/ss_acac82dde7df6f7383e606cd61d3fd4476bfec8.1920x1080.jpg?t=1586980270]

URL to the project:

<http://titansofspacevr.com/titansofspace.html>

Gameplay video:

<https://www.youtube.com/watch?v=o9QxVHOVNWs>

Titans of Space is a virtual reality experience where you get to explore our solar system and all its planets, including some of the biggest known stars. This game takes you on a journey where the user gets to see, discover, and learn about all these planets and stars. This project is not only educational and can help kids and people learn more about our universe, but also offers an immersive experience and lets people interact with the planets and stars to get a better sense of scale.

War Remains



Figure 26. War Remains

[URL: https://cdn.akamai.steamstatic.com/steam/apps/1198050/capsule_616x353.jpg?t=1618925224]

Experience URL:

https://store.steampowered.com/app/1198050/War_Remains_Dan_Carlin_Presents_an_Immersive_Memory/

Gameplay:

<https://www.youtube.com/watch?v=tXTPmFecs8U>

War Remains is an experience that transports the users to the western front of the First World War, and from the point of view of a soldier, it lets them get a feeling of how wars were seen by soldiers. The importance of this experience is not as much from an educational point of view but more of an experience that tries to connect the users with the soldiers and the people that lived throughout this war and let them experience what it felt like.

2.4 Where do we go from here?

As we have seen in the state of the art, data visualization is not a new technique and has been around for many years, but in these past years, due to the new technologies and the boom in computer science, we are capable of creating and exploring much more of the field than we could have done before. Nowadays, with the rise of Big Data and software, we are able to create impressive work that before it would have been really difficult to do. The implementation of data analysis in lots of different fields and the accessibility of the software and tools to develop data visualization has improved a lot and has made this field expand.

On the other hand, virtual reality is a pretty recent technology, and although it's becoming more mainstream recently, it's still not as explored as other technologies. As we have seen, there are several data visualization experiences in virtual reality, but there is still a lot of room to explore and investigate how virtual reality can help us with data analysis and data visualization.

As we have seen, the business in VR and data visualization is really big nowadays and a lot has already been done, so where does this project come in in this context and what can this project contribute nowadays?

This project is meant to create a prototype of a data visualization experience that could be marketable in the current market. There are lots of projects done for different businesses, from art galleries, museums, schools, private businesses, and also independent projects similar to this one, and the objective of this project is to end up with an experience that could fit into a marketable project nowadays.

3. Planification

There is a lot of work that will have to be done throughout the development of this project, so it's important to have a solid plan before starting to work. Having a planification done before the project allows us to have an idea of what's going to happen and how much time and effort each part of the development will cost, and helps us have a clear vision of what's possible and what is not within the limits of time and resources we can use.

The development of the project can be divided into different sections. The first section will be the work done before starting the development of the experience itself, where there will be research in the state of art to have a clear vision of what has been done to that day and what's the actual status of the VR and data visualization industry. This way, we will be able to see what the actual needs are in those fields in order to develop a good experience. In the next figure, you will be able to observe the Gantt diagram used for the first part of the development of the project.

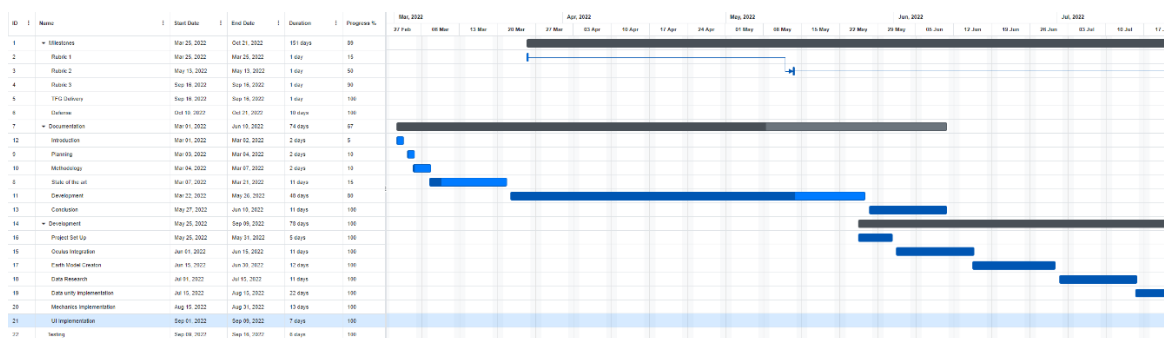


Figure 27. Gantt diagram part 1

On the other hand, for the second part of the project, all the resources will be focused on developing the VR experience and all that comes with it, from creating the visual part, the programming of the features, finding and solving bugs, etc. In the next figure, you will be able to observe the Gantt diagram used for the second part of the development of the project.

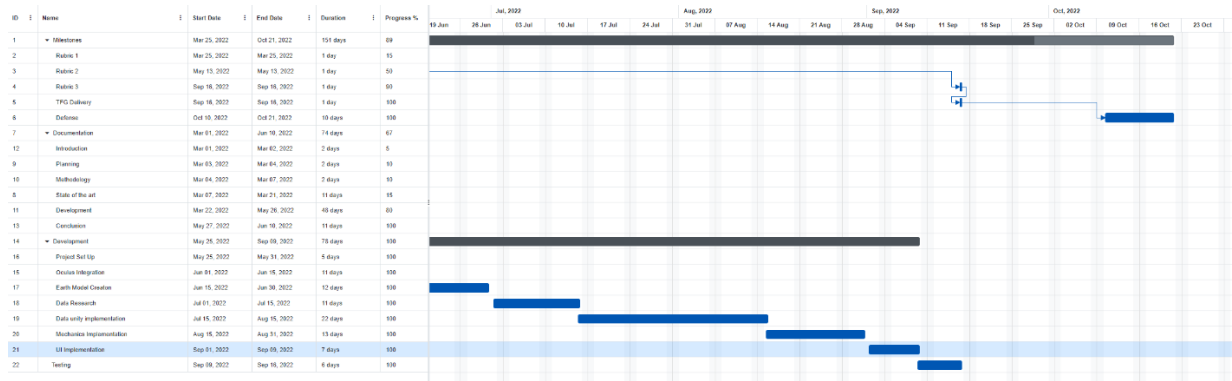


Figure 28. Gantt diagram part 2

3.1 SWOT Analysis

We will use the SWOT analysis in order to evaluate the project’s strengths, weaknesses, opportunities, and threats. With this analysis, we can consider everything that gives us an advantage in developing this project and everything that could potentially make the project fail or not have the success we were looking for.

Table 1 Swot Analysis

	Positive	Negative
Internal	<p>Strengths</p> <ul style="list-style-type: none"> - Experience in project management and task time estimation. - Experience with game engines and programming. 	<p>Weaknesses</p> <ul style="list-style-type: none"> - Little experience with data analysis and data visualization. - No experience developing with Virtual Reality. - First time managing a project by myself.
External	<p>Opportunities</p> <ul style="list-style-type: none"> - Virtual reality is a pretty new technology and it’s still very unexplored. - There are not many data visualization experiences in virtual reality. 	<p>Threats</p> <ul style="list-style-type: none"> - The time given to develop the experience is short. - As it’s a virtual reality game, there are some requirements needed. The experience has to run at least at 90 FPS so it doesn’t cause dizziness.

3.2 Risks and Contingency Plans

Considering that the project has a lot of work to do, the main risk of it is not being able to do all the tasks on time and not finishing and accomplishing the full project. This project has never been done before, and there can be problems when doing some of the tasks, which can lead to taking more time than expected to finish them or solve the problems that are involved. One of the solutions found to avoid this happening is to plan each task with more time than expected so there is a margin for each task and also to consider which tasks are more prone to problems and try to prioritize the time on these tasks.

We can also divide the project into different fields to see what risks we can find in each of those fields and how we can try to avoid them.

3.2.1 Programming

Most of the risks related to programming will come from the nature of programming a game or an experience itself. The problem is that many of the tasks that might seem easy when planning at the beginning can become harder and present unexpected problems because when dealing with big software systems, at the end, there are too many things to take into account in order to not have any problems. Furthermore, in software development, bugs are a normal thing that any developer can escape from, so it's important to have this in mind when planning and developing a project.

As mentioned before, most of these problems can be solved by giving more time than what is actually expected to do the task itself. Giving a margin will help us when problems appear and will make us able to not go short in time at the end of the project development.

Another important aspect to avoid problems like that is to have a part of the development only focused on testing and fixing errors that might appear, as if we don't try our software and try to find possible errors and bugs, there will probably be bugs which we are not aware of.

3.2.2 Design

The main goal of the project is to develop an experience, so one of the most important things when taking care of the development of the project will be its design. It's important that when the users try out the experience, we are trying to create something that they feel is accessible, easy to use, that appeals to them, makes them want to keep on playing with it, and that evokes the feelings and makes them understand what we are trying to show them.

Some of the risks that can arise from that are the user not understanding how the experience works, how a mechanic works, what the objectives of the experience are, or not understanding what we are trying to evoke in the user. In order to avoid those risks, we will need to have a solid and robust design. One of the keys to doing that is to start with simple and powerful mechanics and ideas and try to elaborate on those little by little. The main idea is that simpler and more powerful designs tend to be better than more complex design systems, which are harder to control and to work with. By starting with a simple design, you can take the time to ensure that everything is working as it should, and you can always change and add more content later on if it's needed.

Playtesting is also an important part of ensuring everything works correctly and that the users have the intended experience. When testing the prototypes, we can all fail to consider that if we have developed the experience, it will be easier for us to understand everything when testing it, but for the users that might not be the case, as the first time they try to play with it they will not have any knowledge about it. That's why playtesting with other people rather than the developers helps to find errors in the design and lets the developers see what they are missing.

3.2.3 Art

For the art field, it's very important that the experience has compact and clear visuals and that it's appealing and helpful for the user. The visual style has to have coherence too.

For this aspect, there are many risks as we don't have much experience in this field and it's not the strongest field in the development of this project.

To solve that, there are many asset packs and tools for game engines that are sold on various platforms that can help us overcome these difficulties in an easier way.

3.3 Initial Cost Analysis

This project is not aimed at making any profit. The development will be conducted over the course of eight months and will be developed by a single person working from home, so there won't be many expenses related to materials, offices, or supplies. Most of the costs will come from human expenses and resources. On the other hand, we will also have to use some hardware, such as a PC with its peripherals and a VR headset to test out the project. From the software perspective, we won't need to spend much as there are tons of free software that we can use to develop each part of the project, such as Unity, Gimp, Visual Studio, etc.

To calculate human expenses, the salary will take as reference a high-paid junior software developer's salary from Spain.

Concept	Cost (€)
PC	100€/month
Mouse	4€/month
Keyboard	10€/month
Headset	11 €/month
VR Headset	20€/month
Mousepad	1,5€/month
Google Drive	0 €
GitHub	0 €
Blender	0 €
Unity	0 €
Gimp	0 €
HacknPlan	0 €
OnlineGantt.com	0 €
Countries 3D Models	47.80 €
Salary	1675 €/month
Water and Electricity	75 €/ month
Internet	25 €/ month
Total	15.419,80€

3.4 Management tools

To organize all the tasks that must be done during the development of the project, we will use HacknPlan, which allows us to create a Kanban board for the project. HacknPlan will be a perfect complement to the Gantt diagram, where we will be able to check the progress on the tasks and compare it to the Gantt diagram. We will also be able to track in which

state every task is, if it needs to have a review, if there are bugs that need to be solved, etc.

Another important feature that we will use in the HacknPlan project are the tags. HacknPlan allows us to have different tags for each task to know what is required for it. We can also add an estimated time for each task and log the time we have spent on that task. That gives us an idea of what the difference between the time estimated and what we really worked, which can help us reorganize the project for the future and have a better understanding of what takes time. HacknPlan also lets us create different boards for each sprint which helps us with the agile technique that we want to use to develop the project.

The HacknPlan board also lets us bucket the tasks into different lists to track our progress:

Planned: Here there will be all the tasks that are yet to be done.

In Progress: All the tasks that have been started but haven't been finished yet.

Testing: Tasks that have already been done but have to be tested before they are finished.

Completed: Tasks that have been finished.

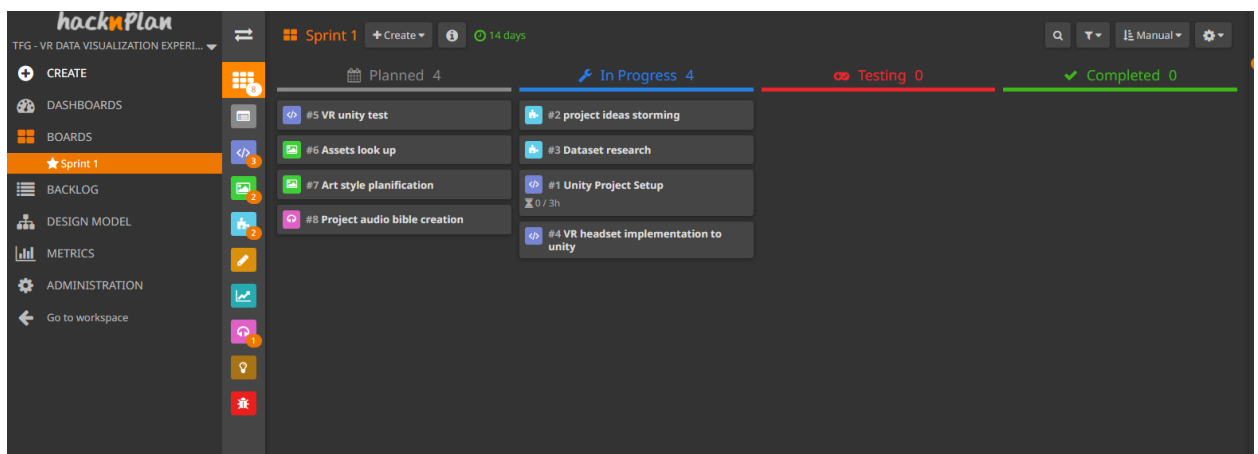


Figure 29. HacknPlan Project

4. Methodology

To develop this project, we will be using Scrum agile methodology but a bit adapted for a single-person project. The development will be done in sprints where there will be a minimum shippable product at the end of them. With the HacknPlan we will be able to

have a Kanban board to use it to keep track of the backlog, and at the end of each sprint we will be able to have a sprint review and see what needs to be addressed and changed, as well as what else needs to be done.

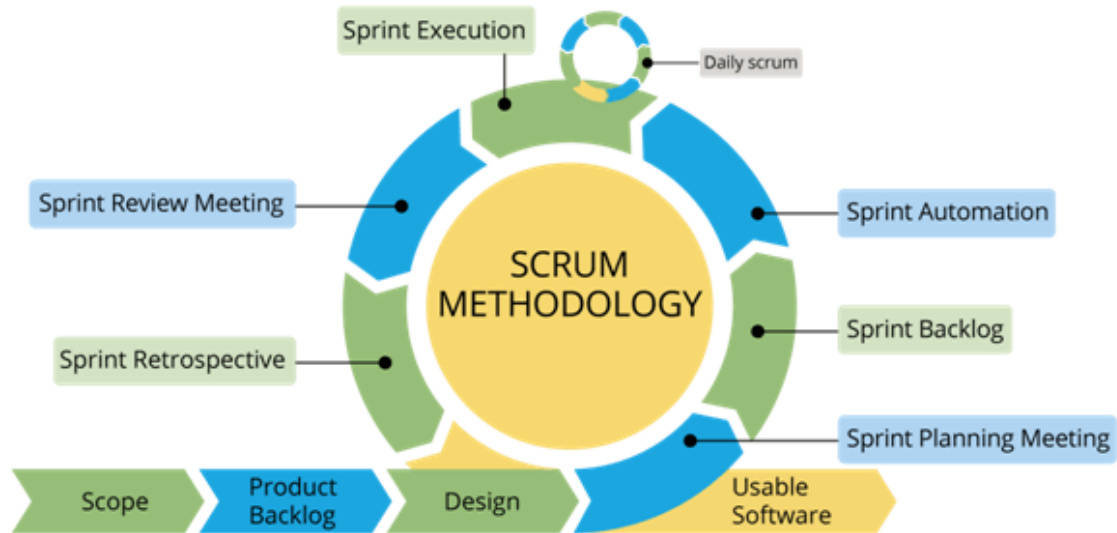


Figure 30. Scrum methodology diagram

Besides Scrum methodology, a waterfall methodology was also considered for this project, which was a methodology that seemed easier for a one-person project, but after analyzing it, we saw it brought some problems with it. The problem with the waterfall methodology is that it's not really flexible to changes during development, and everything that has to be changed can create problems if it's not addressed really early. On the other hand, with the sprints of the scrum methodology, we will be able to adapt to every situation easily and at the end of every sprint we will be able to look at what the projects' current necessities are and adapt better to them.

WATERFALL

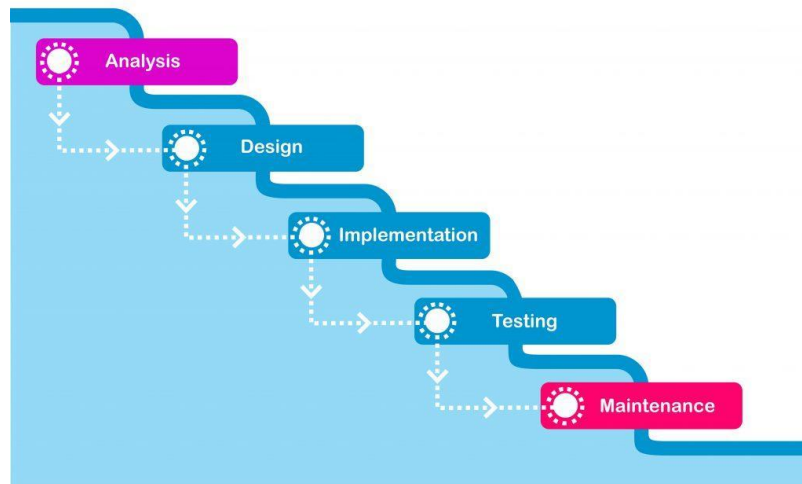


Figure 31. Waterfall Methodology diagram

4.1 Monitoring Tools

The monitoring tool that will be used during the course of the project will be GitHub. GitHub is a tool that lets you store projects and keep track of them, helping developers with file updates, version control, bug tracking, task management, continuous integration, and it even lets you create wikis to document the projects you are working on. It's a great

tool to use when developing software, and it centralizes and provides many features that help developers with day-to-day tasks.

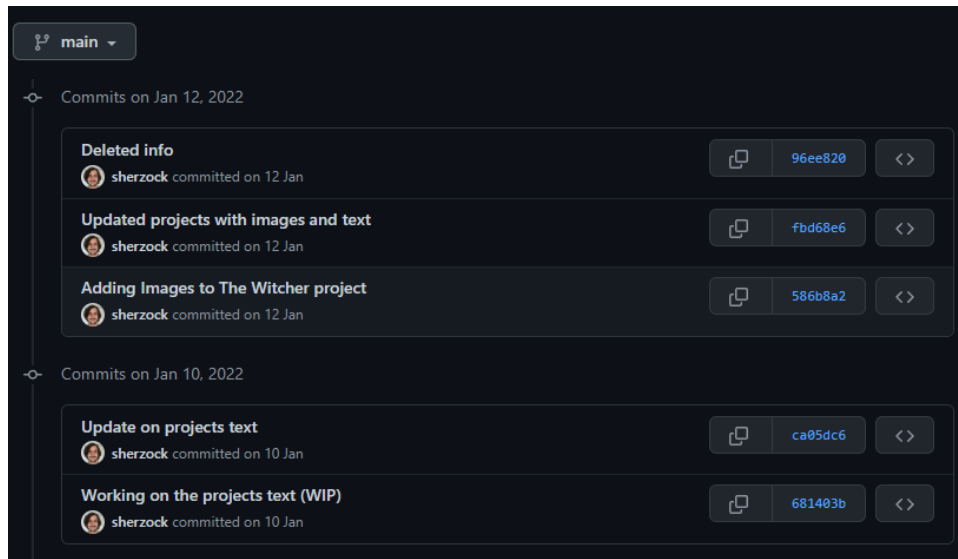


Figure 32. GitHub Interface

Besides the Kanban board that will be used to have a backlog of all the tasks, a great addition to it is the feature that GitHub offers called GitHub Issues, which is a ticketing system that lets us track all current bugs that are going on in the project and helps to keep track of them, and even lets you add tags to them to sort them out, so it's easier for the developers to know the importance or urgency of solving them or what type of bug they are.

4.2 Evaluation tools

The main evaluation tool that's going to be used for the project is playtesting sessions. Playtesting sessions will consist of inviting some people to try out the VR experience, giving them some basic explanations beforehand, explaining to them what they are expected to do in the playtest session. That way, we will be able to see how users without previous knowledge of the project will react and interact with it .

In these playtesting sessions, we will be looking at how real users who didn't have any contact with the development or the experience beforehand react when trying it out. We will be looking at errors that the experience might have in all types of senses, from technical issues and bugs that might have been created from the code or the implementation in the game engine to other types of errors that have to do more with the design of the experience. It's important to test if the users behave the way the experience

is intended to, if everything is accessible when using it, if it's coherent and the users don't feel lost using it, if the users enjoy the experience or get bored while trying it out. The whole experience has to be appealing to them, so it's important to test all of this in these playtest sessions.

After the playtests, the users will be given some tests to perform and answer in order to have some answers about how they felt while in the experience and what they noticed when playing. These tests will be important in order to see how the experience works and what we can do to improve it. Most of the questions will be focused on understanding how the user felt during the experience from different fields, from engagement to understanding of what happened or accessibility of the experience.

The tests that the play testers will do will focus on different parts of the experience, starting from how they felt when trying it out, how it felt, if they were bored or felt lost at some point. Then they will have other questions about what they understood from the experience. They will be asked questions about the narrative and the intention of the experience to see if they really understood what they were doing.

For the last part of the test, they will be given the freedom to give us feedback from what they think could be done better or should be changed and they will also be able to tell us if they found any bug or error.

5. Development

In this section we will go through the development of the project from the preproduction and design part to the implementation and more technical part of the project going through everything that has been done in order to obtain the virtual reality experience.

5.1 Tools, technology and devices

Before starting to explain how everything works and how it is being developed, we have to take into account which tools and devices we are going to use for this project because it can make a big difference when developing software to have a clear insight of how we are going to develop it and for what device it is intended.

5.1.1 Devices

In order to develop the experience, we will need to use a virtual reality headset in order to ship the product, test it out and have a target for the project. In this case, we are going to use the Meta Quest 2 headset and controllers.

The idea to develop the experience on the Meta Quest 2 is not arbitrary, there are several things that have been taken into account in order to make that decision. The first one is popularity; Meta Quest 2 is a pretty popular VR headset which competes with Valve Index and Vive too. Choosing a popular headset was an important decision for the project, as we want to make the experience accessible for as many people as possible, and nowadays, not everyone has a VR headset and the experience can't be compatible with all the different operating systems of all headsets.

Meta Quest 2 is also not really expensive compared to its direct competitors such as Valve Index, as its price rounds to 339 euros, and that also helps make it more accessible to people.

The Quest 2 VR headset also provides us with 2 controllers, which work really well and help create an interactive experience with them. The controllers are really intuitive to use and work really well. When using them, it feels like an extension of your hand in a virtual world.

The last thing that Meta Quest 2 offers is a quite easy implementation of our game engine, as it offers a sdk (software development kit) which is pretty easy to install and use. It also has a big community behind it, so it's easier to find information about it on the internet and in forums.

5.1.2 Technology and tools

It's important to mention how we are going to develop our project, which is the software that we are going to use and which are the tools that will help us develop the VR experience.

In the first place, we are going to be using Unity as our game engine. Unity is really popular amongst indie developers as it's a very versatile tool that gives the opportunity to develop all kinds of games and experiences. Although there might be other more

sophisticated game engines which, in the end, can give better performance and obtain better results, Unity provides us with a free engine to use with a lot of documentation and facilities to work on small projects, and it is also prepared to support virtual reality experiences.

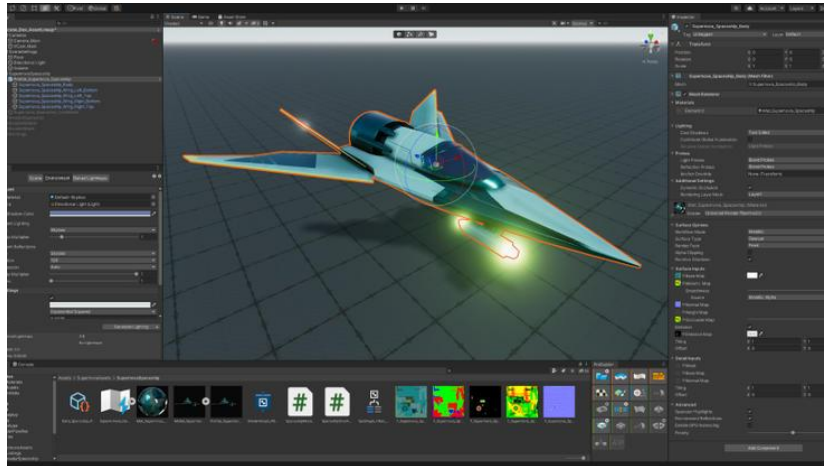


Figure 33. Unity game engine

[URL: https://unity.com/sites/default/files/styles/cards_16_9/public/2021-03/roadmap-editor-810x455%401x.jpg?itok=122IzhFT/]

We could have also used other really popular engines such as Unreal Engine, but at the end of the day, the results won't change as much from one engine to another, and I feel more comfortable using Unity as I've got more experience than in other engines.

The last thing that made me choose Unity over other engines was its community. As of all the engines, Unity has the biggest community, which is great when you are trying to develop software, as you can find lots of information.

For the audio of the experience, I will be using an audio editor in order to achieve the sound effects and music I will use for the engine. The audio editor I will be using is Audacity, which is free software that is pretty powerful and has more than enough features that I need to edit the audio for the game.

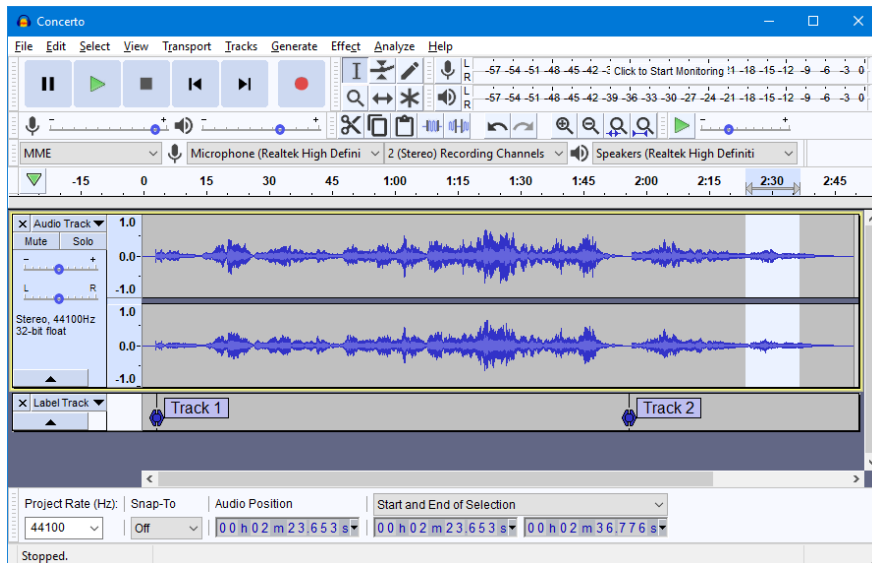


Figure 34. Audacity Audio editor

[URL: <https://files.soniccdn.com/files/2021/03/18/audacity%203.png>]

For the visuals of the game, I will be using Adobe Photoshop and Illustrator in order to create the needed 2D props and textures for the experience.

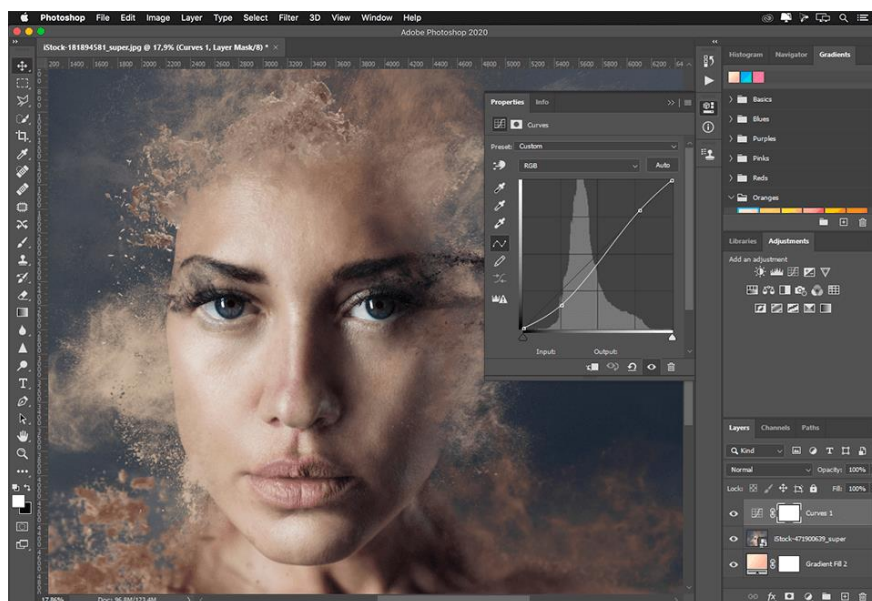


Figure 35. Photoshop

[URL: https://hotmart.s3.amazonaws.com/product_contents/9a67bf54-34db-44ec-af78-8189b84779f9/Photoshop.png]

On the other hand, for the 3D models, if I need to model anything, I will do it on Blender as it's the only modeling software I know and I feel comfortable enough to use.

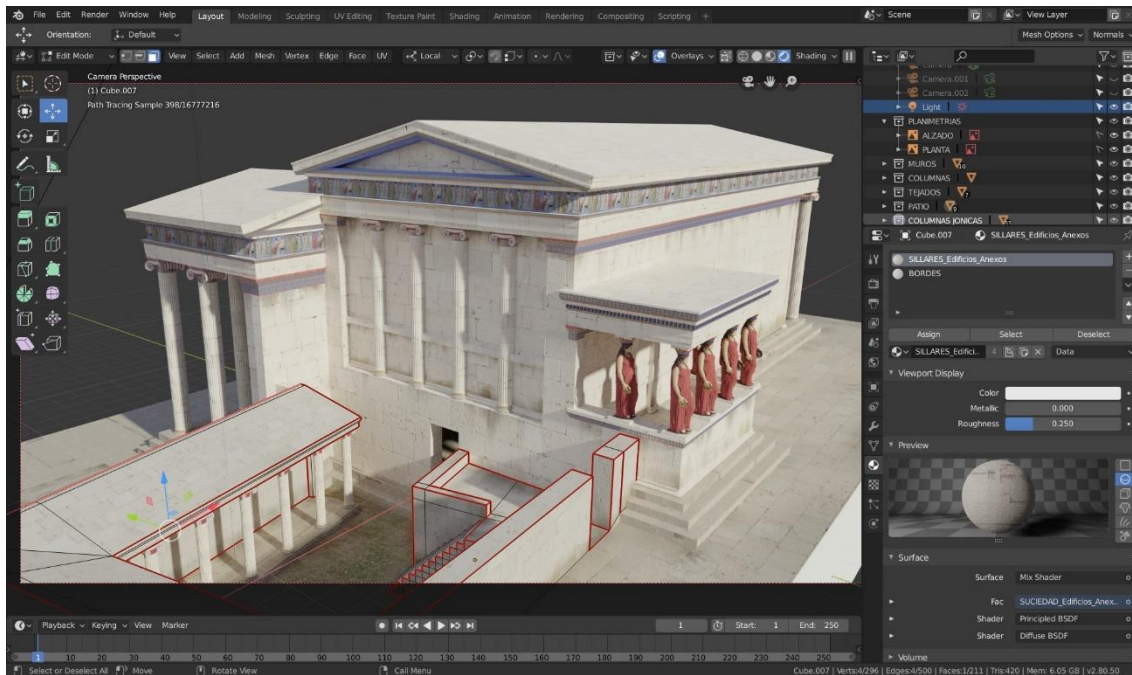


Figure 36. Blender Modelling software

[URL: <https://latermicamalaga.com/wp-content/uploads/2020/04/escenario-blender.jpg/>]

5.2 Preproduction

Before getting into the production of the project itself, we will be going through the preproduction of the experience, from the creation of the concept idea of the project to the design of the mechanics and the experience.

5.2.1 Concept Idea

The first thing I did in order to come up with an idea for the project was a brainstorming of the different themes and topics that were suitable for it. To do so, we did a lot of research on different experiences and games, which inspired and gave us ideas to implement into a virtual reality experience.

Once that was done, there was another aspect to take into account when deciding the main topic of the project, and that was the data that was going to be used, as the main idea of the project was to create a data visualization using real data.

In order to solve that, we did some research of available data sets on different topics in order to see which topics from the brainstorming done could fit for the application.

With all that information researched, we came to the conclusion that the topic we wanted to work with was the migration of people throughout the world. It was a pretty dense topic

that had given us enough freedom to work with, and it also had lots of data on it and related to it.

With the topic in mind, we started to think about different ways to play with the data and how to bring this topic to people.

The first idea that came to my mind was to put the user in the shoes of different migrants from different countries and guide the user through the topic using a story with different characters, but in the end, we discarded the idea as it was getting too ambitious for the resources and time we had for the project.

After that, my idea for the project changed, and I decided to focus on creating a simpler experience that worked well and could be expanded later on instead of trying to create a big project that would be really hard to finish.

In the end, we ended up with the idea of creating an earth model, as we realized while researching for data visualization examples to get ideas, that we were stumbling across many visualizations based on political maps of the world, and we thought it would be a great idea to make an experience based on this concept for a VR application.

5.2.2 Design

With a basic idea in mind, we could now start working on how we could adapt a simple data visualization to an interactive experience in virtual reality. The first thing to take into account was what benefits virtual reality gives us and what constraints it imposes on us. The first thing that VR can help us with is immersion when using a VR headset. The feeling of having all the vision focused on a recreation of a 3D space instantly gives the user a better feeling of being transported out of the room or the space where they physically are to get into a virtual space.

The second aspect to take into account was that using VR headsets can be tiring and can make the user dizzy when used for long periods of time with high-action applications. To prevent that from happening, the experience should have a relaxed feeling where the user should feel comfortable using it without many distractions that would get the user confused or tired when using the application.

With those ideas in mind, we designed the experience where the user would be side-by-side with a model of the earth and where the player would be able to see different data

from every country and compare it to the rest of the countries. To do that, the idea would be to have a scale of color between the maximum and the minimum values in order to see where every country is placed and to easily compare it with the other countries nearby. The user would also have the option to select a country and see the exact value for a country and compare the value shown with the values that the same country has had in other years. Also, to have an easier task, the player would have to be able to move and rotate the earth as preferred.

Finally, it would also be great to have a mode of showing the earth not just as a political map but also as a real view of how the earth looks from space, to captivate the attention of the users and let them have a more realistic view to compare.

5.3 Production

5.3.1 Unity project Setup

To start developing the project, the first thing to be done is to set up the Unity project, which will be the game engine in which most of the work will be done during the production phase. For this project, we will use the 3D URP (Universal Render Pipeline) template to start with, which is the most suitable template for this project.

We could also use the HDRP (High-Definition Render Pipeline), which can achieve incredible results on the graphic aspect, but for a project this size it would take too much time to optimize and create something that would take advantage of the HDRP. That's why the option chosen for the project is the URP instead.

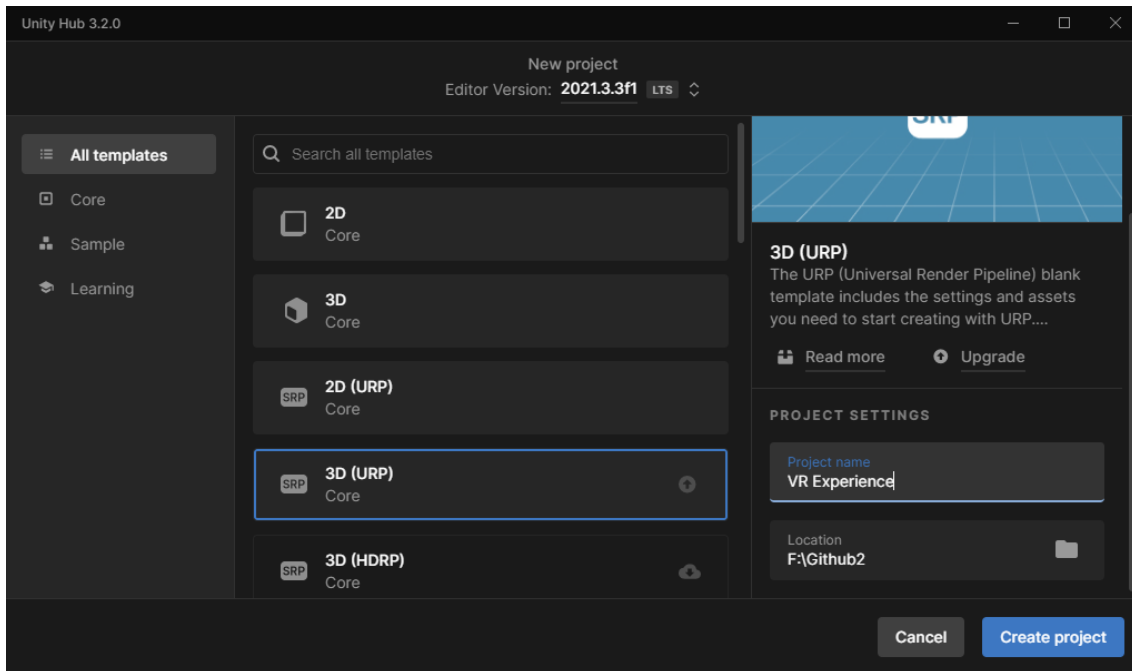


Figure 37. Unity Project Creation

5.3.2 Meta Quest 2 in Unity

The next step, once we have the Unity project created, is to implement the Meta Quest 2. As our main goal is to create an experience that will end up running on a Meta Quest 2 headset, it's not as simple as creating a Unity project as you would do when creating a project for a PC or other consoles.

As Quest 2 works on Android, the first thing we have to do is change the project to build on Android.

We also have to add the XR plugin management to the project, and finally, the most important part is to also add the Oculus Integration SDK package.

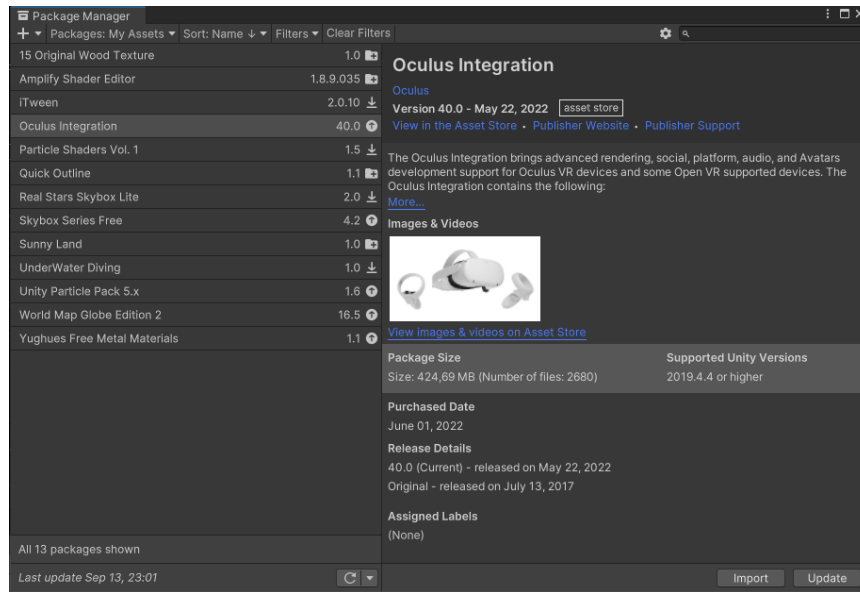


Figure 38. Oculus Integration SDK

The Oculus package includes lots of features and assets that are needed in order for the Meta Quest 2 to work properly.

From there, we can start to work by adding a camera rig that works with the headset.

To add the controllers, we can choose from different options available. The first option is to use the main Oculus controllers, which will have the appearance of controllers inside the experience, with a 3D model that is identical to the real controllers. The second option is to add the same controllers but with the appearance of hand models that adopt different poses depending on which buttons are pressed or touched on the controller. The third and last option we have is to use our own hands as controllers, as the Meta Quest 2 has a tracking system which is capable of translating the position and gesture of your own hands by using a set of cameras in front of the headset.

In the project we will be using a combination of the first and the third option, as the idea is that the user will be able to use the controllers, but when the controllers are not being used, the headset will be able to detect them and switch to the hand tracking mode.

We could also use normal controllers such as the Xbox controller or even a keyboard and mouse, but these aren't suitable options as the Oculus controllers are more immersive for experiences like this one.

5.3.3 Earth

After the basic Meta Quest 2 assets are settled on the screen, we can start to work on the experience itself. The first thing we have to do is to create a model of the earth that represents the real earth as accurately as possible.

The first part for the creation of the earth is to have a sphere model where the UV's are ready to support earth textures. To do so, we can do it using a blender.

Once we have the model, we can import it into Unity and start to work on the material, which will create the appearance of the earth.

The material will be based on a shader that will use different textures from the earth, such as a daytime earth map, a nighttime earth map, a specular map, a normal map, and a cloud texture.

The textures will be taken from <https://www.solarsystemscope.com/textures/>. which provides us with high resolution textures of the earth which are free to use based on Nasa's elevation and imagery data.

By using the Amplify shader editor asset, which is a node-based shader creation tool, we are able to merge these textures, and with a bit of tweaking and adding, we are able to create a material that represents the earth pretty accurately. Although Unity now offers a node base shader editor too by default which is called Shader Graph, I opted to use this one because I am more used to work with it and the results are mostly the same.



Figure 39. Earth Shader in the Amplify shader tool



Figure 40. Earth Model With the shader applied

This earth representation is great for an introduction to the experience, but with a non-political map representation of the earth, it will be really difficult to plot any data on it to visualize. In order to plot the data, we will be creating another render mode which will have a political view of the world.

For that second visualization mode, we need to have a way to represent all the countries of the world on earth. For that, there are many possible solutions for doing so.

The first idea is to use a ".geojson" file, which is a type of ".json" file which is adapted to store geodata. The "geojson" we need should have all the coordinates of every vertex of the borders of every country in the world. From there we would be able to load this file into unity and create a script which can read it, and translate every world coordinate into a UV coordinate of the earth model. Then we would have to use that information to plot all the countries of the world on it. The problem with that is that the "geojson" only gives us the points of the borders, but trying to create an interactable country with colliders makes it harder than it should be.

The second idea is to use a political map of the world as a texture and, through a shader, read it in order to create a visual representation of the different countries. The problem is that going from a texture to different interactable game objects makes the task much more

difficult. Furthermore, the political maps available are really poor and low quality, which makes the creation of a high-quality representation difficult.

The third and final option we have is to use 3D models of the different countries shaped to be used on a globe. This option might require more resources as it's harder to render all these different models than to use some text data, but it will have a good quality result and it is more versatile than the other two options.

Even though it uses more resources to do it this way, it won't affect the final result in terms of performance as the experience we are developing won't use all the power that the Meta Quest 2 provides us.

With that in mind, we used the last option to develop the other version of the Earth model.

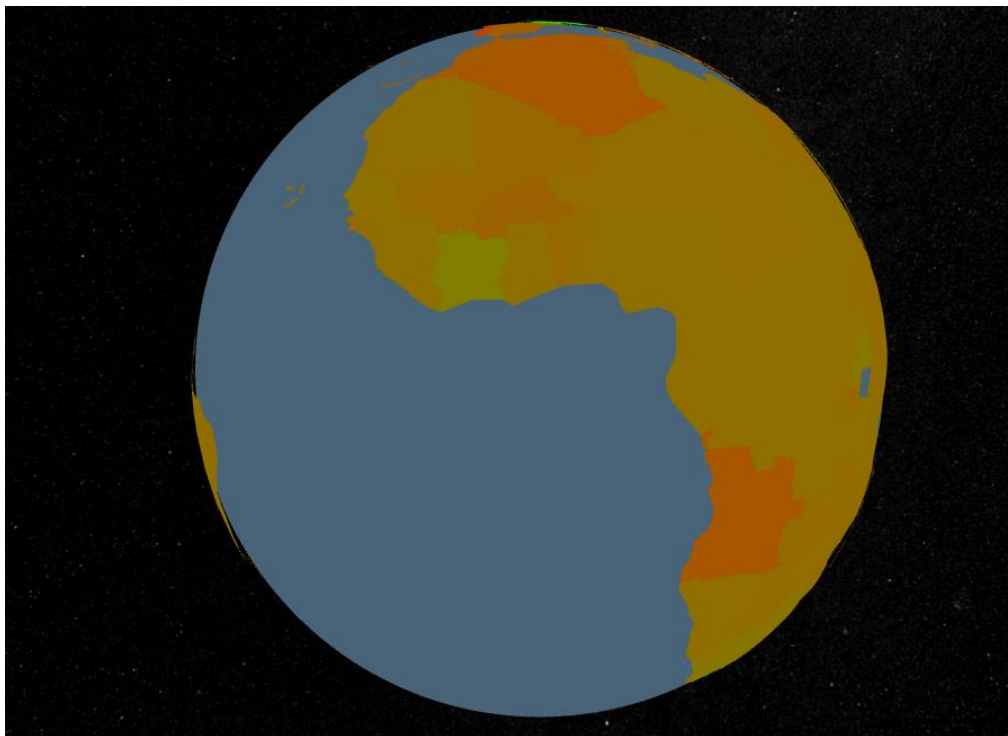


Figure 41. Earth Political Map Version

5.3.4 Data Set

Before using the data sets in our unity project, we have to choose what data we are going to use and prepare it so it's easier to load into unity.

For the project, we will be using a data set extracted from the World Bank Group (<https://www.worldbank.org>), which is an organization with 189 member countries. The World Bank Group is a unique global partnership where five institutions work for

sustainable solutions that reduce poverty and build shared prosperity in developing countries.

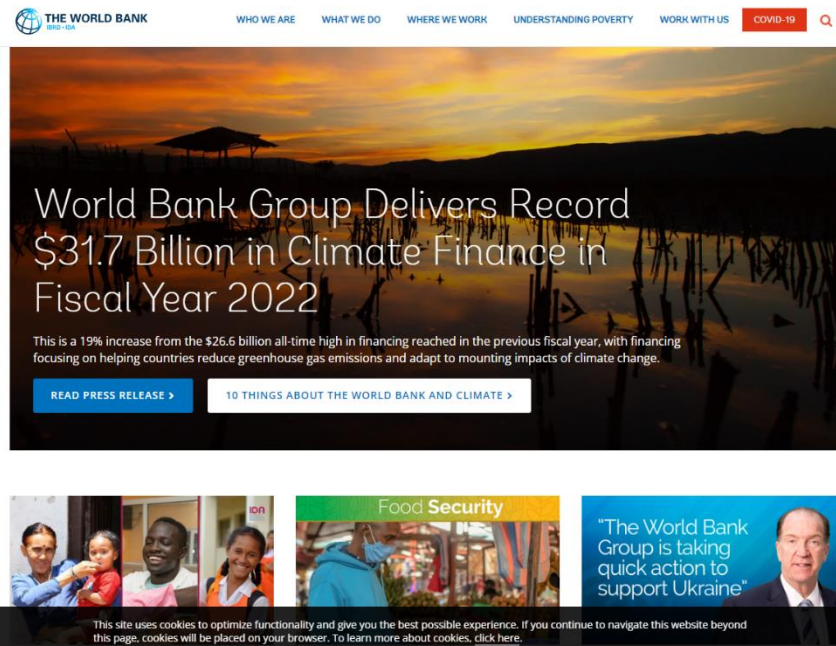


Figure 42. The World Bank Website

To prepare the data, we will take the different data sets in Excel files and merge them into a single file in order to make it easier to import into Unity.

Country Name	1962	1967	1972	1977	1982	1987	1992	1997	2002	2007	2012	2017	
Aruba		-4323	-4275	-3537	-5470	-1921	-5194	14218	6926	6263	-441	1253	1004
Afghanistan		-20000	-20000	-20000	-1153959	-3345095	-1525351	3076383	-867540	744193	-1046361	521769	-314602
Angola		-296717	-587286	199800	199800	234148	188491	142812	199800	261100	357301	166267	32066
Albania		-99	-99	-99	-99	-99	-99	-443212	-179606	-176774	-217358	-136590	-69998
United Arab Emirates		37882	53823	260488	372430	184159	256638	368126	498394	1189616	3592436	270000	200000
Argentina		122000	130000	142000	-230000	140000	160000	-105000	-128000	-125000	-120000	30000	24000
Armenia		70335	103399	86404	17214	-51230	-67528	-496288	-223873	-160521	-183361	-30535	-24989
Antigua and Barbuda		-1880	-1202	-7018	-4428	-3763	-2890	2231	2469	252	1887	943	0
Australia		384343	806193	259531	235744	453572	654209	351078	388419	589282	1210802	989375	791229
Austria		15996	50401	82001	5502	18002	110999	227841	65082	178117	153763	267172	324998
Azerbaijan		0	-40000	-50466	-50466	-101568	-161568	-115116	-111849	36523	53579	8499	6002
Burundi		-84989	-57900	-266496	-150290	-139146	-180004	-320001	-455304	-24721	30004	-70001	10003
Belgium		38304	47288	70980	73523	18478	42556	106947	50870	219560	294270	258672	240000
Benin		-24295	-23742	-24845	-19393	-10848	-8723	68259	-2851	25005	-48776	-42268	-10000
Burkina Faso		-144723	-144723	-170263	-217400	-217400	-183699	-150001	-137499	-125000	-125000	-125000	-125000
Bangladesh		-142378	-161822	-3045287	-1137344	-793826	-219363	-813794	-719899	-1492537	-3254778	-2306839	-1847503
Bulgaria		-1437	-6423	-43396	-94868	-22346	-184143	-356464	-133824	-85500	-83742	-24472	-24001
Bahrain		-4195	-8033	19123	48962	3234	12899	5480	39180	155500	272000	42000	299000
Bahamas, The		13873	13929	949	2981	646	-811	-322	-3001	11877	14536	4999	4999
Bosnia and Herzegovina		-50002	-96958	-82247	-74132	-29999	-134587	-740715	-159283	-6000	-59246	-258529	-107926
Belarus		-125387	65585	37146	38298	47114	-23021	-63057	56146	-6382	63933	72123	43648
Belize		-2418	-2957	-10665	-13542	-5332	-5404	-9011	11909	5797	8722	7594	6000
Bolivia		-20760	-23150	-26620	-40130	-73670	-64260	-51670	-64330	-77720	-67700	-57620	-47520
Brazil		0	0	0	0	0	0	0	0	0	0	15924	106000
Barbados		-17960	-13677	-6934	-5548	-7856	-6311	-5393	-3643	-3188	-249	-397	-397
Brunei Darussalam		6422	10843	10886	8293	3622	3684	4770	4188	422	-2257	-901	0
Bhutan		5000	10000	10001	10016	797	1595	-58565	143	6171	-10971	300	1600
Botswana		-22436	-24198	3992	17744	5203	46821	24296	36443	26928	26928	-73138	14999
Central African Republic		11930	13145	-50000	-1000	40000	-80000	50000	30000	-24405	-125614	-396129	-200000
Canada		178691	611117	758104	420633	373939	859217	690555	783535	1052013	1326431	1241416	1210159
Switzerland		277152	92978	25185	-135365	81040	130857	247406	65218	186125	344872	397267	259999
Channel Islands		2934	3880	4250	1726	5380	6085	1170	2291	1513	5970	3570	6754
Chile		-146900	-196500	-161260	-148300	-154520	-68650	3610	19340	42330	107169	163730	558539
China		-1125727	-160002	-1105479	-47004	-200000	-431651	-779982	-382999	-1965578	-2178385	-1552209	-1741996

Figure 43. Sorted Data in Excel

5.3.4.1 Net Migration

The dataset we will be using is the net migration of the countries. This data set contains information that shows the difference between the immigrants and emigrants of a country per year. The dataset contains data for most of the countries in the world from 1962 to 2017 every five years.

We chose to use this data set before others because the net migration dataset lets us show where people want to migrate the most, as it doesn't only take the emigrants that go away from the country or just the immigrants that enter the country. With the difference, we can actually see if people want to go live in a country or if most people want to migrate to other countries. It gives us a perspective of where people want to live and also, adapting it to a VR experience, lets us investigate more into the geographical areas and not only into single countries, as sometimes there are events which affect certain areas more than others, or there are poorer countries which are close together where people want to leave for a better future. It's a really great dataset to get a first glance of what's happening in our world.

5.3.5 Data into Unity

With the data ready, we have to create a system to load all the data and save it in unity, so we can show it to our users.

The first thing we have to do is to create a class for every country where we will store the necessary data of that country in order to later on use it in the experience.

```
public class Country
{
    public string name;

    // 1962/1967/1972/1977/1982/1987/1992/1997/2002/2007/2012/2017
    public int[] NetMigration = new int[11];
    public float[] NetMigrationColor = new float[11];

    public GameObject capital;
    public GameObject meshMat;
}
```

Figure 44. Country Base Class

Once we have the base class created, we can now start loading the information into it.

The first thing we have to do is to create an array of countries and fill it with every country we will need.

And once we have the array completed, we can start to go through our “.csv” file and, for every country, fill in the necessary data we will need.

```
string[] data = CsvFile.text.Split(new string[] { ";", "\n" }, System.StringSplitOptions.None);
tableSize = data.Length / 13 - 1;

for (int i = 0; i < tableSize; i++)
{
    for (int j = 0; j < CountriesSize; j++)
    {
        if (countries.country[j].name == data[13 * (i + 1)])
        {
            for (int k = 0; k < 11; k++)
            {
                countries.country[j].NetMigration[k] = int.Parse(data[13 * (i + 1) + k + 1]);
                if (countries.NetMigrationMin[k] > int.Parse(data[13 * (i + 1) + k + 1]))
                    countries.NetMigrationMin[k] = int.Parse(data[13 * (i + 1) + k + 1]);
                if (countries.NetMigrationMax[k] < int.Parse(data[13 * (i + 1) + k + 1]))
                    countries.NetMigrationMax[k] = int.Parse(data[13 * (i + 1) + k + 1]);
            }
        }
    }
}
```

Figure 45. Csv Data Parse

After that, we will have the data fully loaded into Unity. Now what we have to do is plot it into the globe model we have done before. To do so, we will have to play with the material applied to each country. By changing the material color of the countries depending on the value each country has, we can actually visualize what the data for every country is with respect to other countries.

The first thing we have to do is to rescale the data we have and apply it as a color. We have to search for the maximum and minimum value, and from there we can create a scale in order to have a range of color which will go from 0 to 1.

```
public float ReScaleValue(float OldMin, float OldMax, float NewMin, float NewMax, float OldValue)
{
    float OldRange = (OldMax - OldMin);
    float NewRange = (NewMax - NewMin);
    float NewValue = (((OldValue - OldMin) * NewRange) / OldRange) + NewMin;

    return (NewValue);
}
```

Figure 46. Rescale Function

With that done now, we only have to apply the color to the material of every country model.

```
void CreateColorToCountry()
{
    for (int i = 0; i < CountriesSize; i++)
    {
        for (int j = 0; j < 11; j++)
        {
            countries.country[i].NetMigrationColor[j] = ReScaleValue(countries.NetMigrationMin[j],
            countries.NetMigrationMax[j], 0f, 1f, countries.country[i].NetMigration[j]);
        }
    }
}

2 referencias
public void ApplyColorCountry(int yearArrayPos)
{
    for(int i = 0; i < CountriesSize; i++)
    {
        countries.country[i].meshMat.GetComponent<MeshRenderer>().material.color = Color.Lerp(Color.red, Color.green,
        countries.country[i].NetMigrationColor[yearArrayPos]);
    }
}
```

Figure 47. Country Color Functions

5.3.6 Interaction

Now that we have the data visualization working, we can look at how the users will interact. As explained before, at this point the project has basic hands and controllers working, but they are not prepared to interact with anything in the main scene of the project. One thing that is important is that we want to be able to interact with the model no matter how far it is from the user, so it's easier to manipulate from anywhere. To achieve that, the Oculus integration package comes with a feature that will be really helpful, which is the Ray interaction.

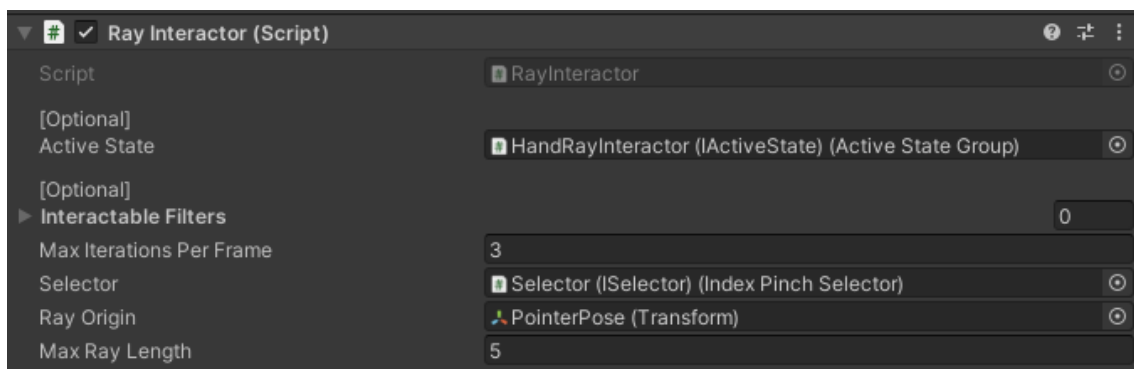


Figure 48. Ray Interactor Component

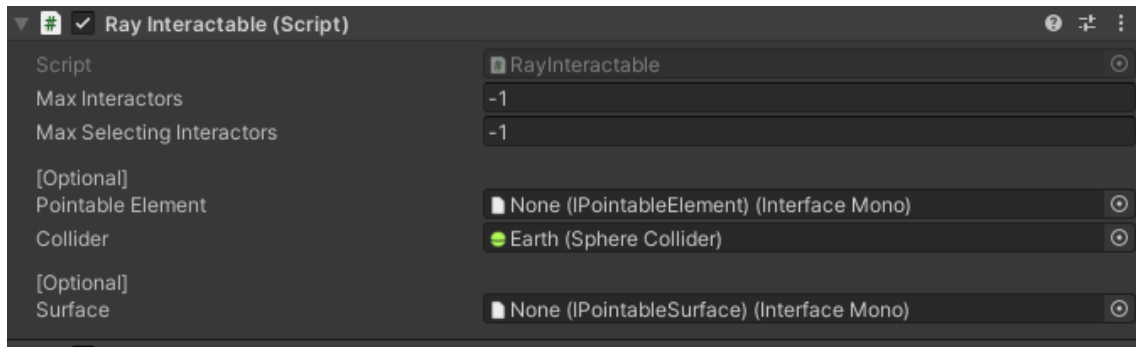


Figure 49. Ray interactable Component

This feature allows us to generate a ray cast from our controllers or hands and interact with any game object that has a Ray interactable component.

We can use that in order to select the different countries where we want to look in depth.

With our controllers, we will also implement some methods that will allow the player to rotate the earth model in order to see whatever part they want by using the joystick on the controller.

Using the other joystick of the other controller, the user will be able to move the earth and have a better position of the earth. Finally, with the hand triggers, they will be able to control the height at which the earth is.

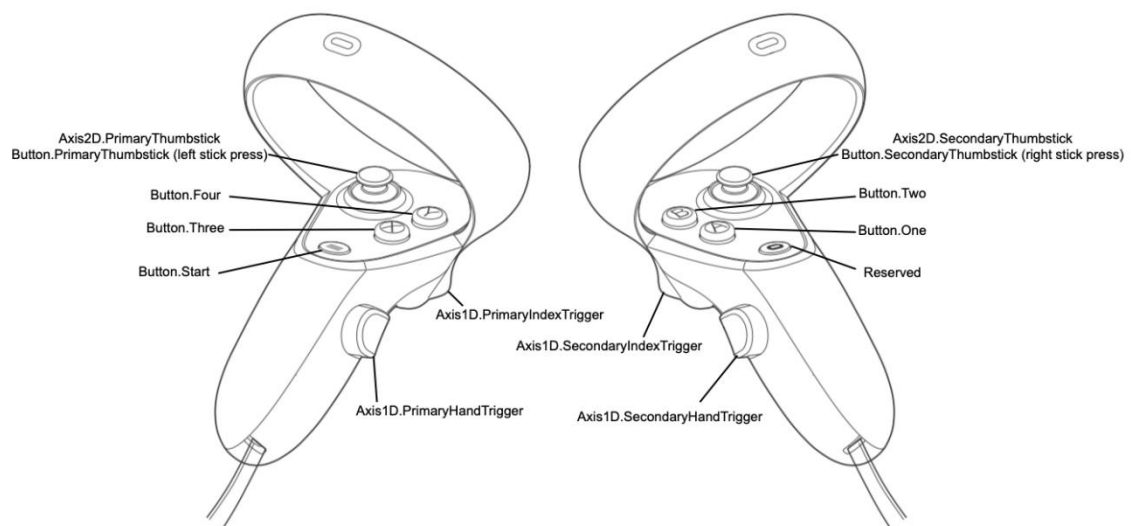


Figure 50. Meta Quest 2 Controllers

[URL <https://developer.oculus.com/documentation/unity/unity-ovrinput/>]

5.3.7 User Interface

As it's a data visualization experience, we will add some user interface so the user can set up the experience as they feel more comfortable with, and also to show more exact data of the desired countries, they will be able to select them. To do that, we will use a curved canvas that will allow us to create text, buttons, sliders, etc. The user will be able to interact with this canvas with the technique explained before, which is the ray cast interaction.

As having a canvas can be very intrusive, the users will have a button to close it down in order to have a better view and be less disturbed, and they will be able to open the menu up again if they need to by pressing the "x" or the "a" button on their controllers.

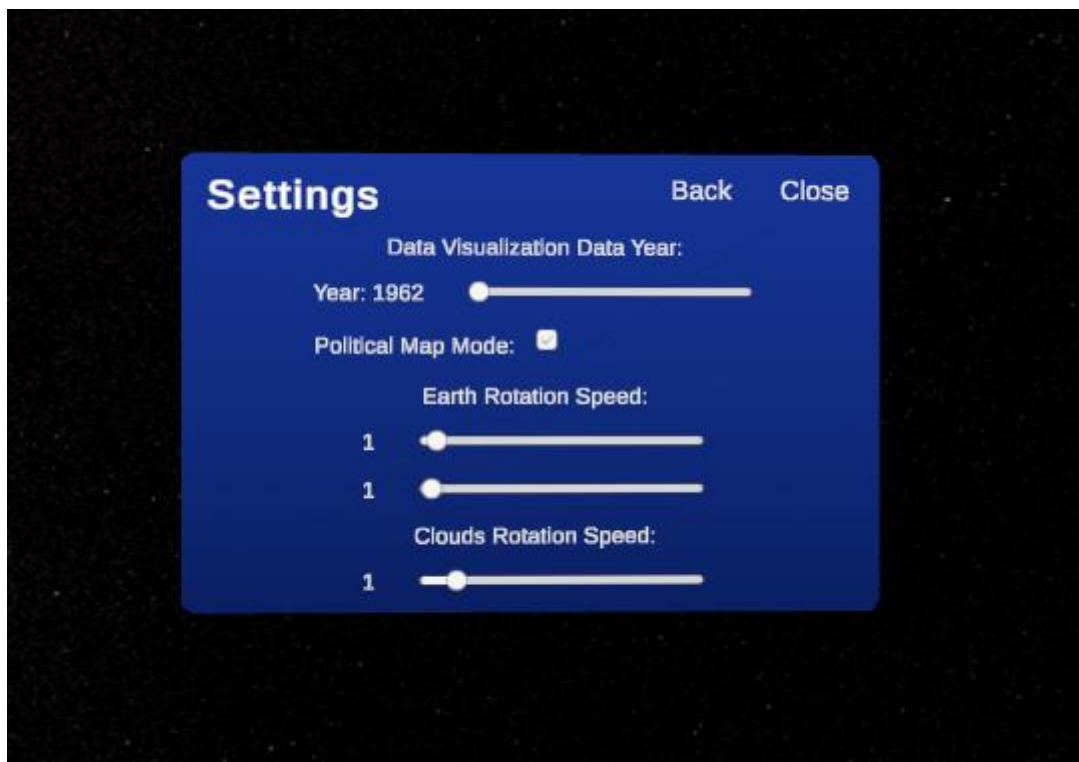


Figure 51. Curved Canvas

6. Conclusions and Future Work

Keeping track of my initial objectives for this project, I have been able to fulfill all of them, although the project's final result is different from what I wanted to create from the beginning of the project. At the beginning of the project, I had the idea of creating a project that was closer to the development of a game with data visualization in it than a data visualization tool. Throughout the first stages of the production of this project, I saw that maybe it was a project that was too ambitious to create now and redirected the project into a more straightforward data visualization experience.

During the production of the experience, I had many problems working with the Meta Quest 2 headset, which made working on the project really tedious and slow.

When I decided to use that headset and bought it, I didn't think about if it was going to be compatible with the hardware of the PC I have, as I thought that being a standalone headset would always run everything from the headset itself. To my surprise, when I started working with unity and the headset, I saw I had lots of trouble connecting the headset to the PC, and that was because the graphics card I had on my PC was not supported by the Meta Quest 2. That meant that every time I wanted to test the project on the headset, I had to do several tries, restarting my PC every time until it worked.

Even though I had these problems during the development and that the final result is different from my initial idea of the project, I am really proud of the results achieved. I think the VR experience created lets the users immerse and see the data from a different perspective than what we are used to. I think it's a great project that can be improved and extended in many different ways in the future, such as creating a more extended data visualization tool where people can load and see the data they want portrayed on the earth globe. Also, many customization settings for the project could be added, which would help people have a more customized experience.

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8. Download the prototype

Project Github repository:

<https://github.com/sherzock/Virtual-Reality-Experience>

Final prototype download:

<https://github.com/sherzock/Virtual-Reality-Experience/releases/tag/1.0>