Visualizing historical data with virtual reality

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Report of internship

Master of digital humanities

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Visualizing historical data with virtual reality

From the 15th of March to the 15th of August 2021

At the Luxembourg Centre for Contemporary and Digital History (C2DH)

Mojtaba MOSAVAT

Internship supervisor: Dr Lars Wienke – Head of DRI at the C2DH

Academic advisor: Dr Elena Pierazzo – Head of Digital Humanities department

Acknowledgements:

Since starting my master's degree, I always wanted to do my internship in another European country in order to have a unique experience with different people. As I'm passionate about contemporary history of Europe, I searched for infrastructures who work on digital history or digital re-creation of artefacts. I had the chance to find the C2DH, which is a dedicated Center for digital history of contemporary European history.

Therefore, I would like to thank my supervisor at the C2DH, Dr. Lars Wieneke who was always present during the internship and he was always encouraging me on our project. I would also like to thank Aida Horaniat, a PhD candidate in digital humanities with an engineering background at the University of Luxembourg who had helped me during the internship with her advice and clarifications despite her studies and paper submissions.

I should also thank my colleagues who helped me to integrate myself quickly into the working environment, and they did their best to help me while I needed them.

At the end I appreciate all the efforts and patience of my academic advisor Dr. Elena Pierazzo who helped us to continue our studies and even to do international internships despite the worldwide covid pandemic.

List of acronyms and abbreviations:

3D: three dimensions

APK: Android application package

AR: Augmented reality

C2DH: Luxembourg Centre for Contemporary and Digital History

DRI: Digital research infrastructure

glTF: Graphics Language Transmission Format

HMD: Head mounted device

OSM: Open Street Map

PBR: Physically based rendering

SDK: Software development kit

STATEC: Institut national de la statistique et des études économiques

VR: Virtual reality

XR: Extended Reality

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Introduction:

During 5 months, I had the chance to do my internship at the C2DH of the University of Luxembourg (Figure 1) which is located in the city of Esch-sur-Alzette in Luxembourg. During this internship I gained lots of experiences in a research infrastructure, and I developed my technical and research skills.

Moreover, I managed to work with new tools that I have never worked before which was somehow challenging for me. These challenges have helped me to get to know and to appreciate the possibilities that advanced skills in programming could offer to me in terms of finding future job opportunities.

My internship took place entirely remotely due to covid pandemic but this situation didn't affect my internship to function properly. During my internship I focused mostly on development of an interface to navigate geo-temporal datasets with an adding value of virtual reality.

This internship was an opportunity for me to have my first professional experience in a research infrastructure which aims to promote an interdisciplinary approach between digital tools and history.

This report aims to represent my experience which is gained throughout the tasks that I undertook as well as multiple discussions with my supervisor and my colleagues. Moreover, some series of workshops have also helped me to discover the research world.

Therefore, I'll start this report by presenting my hosting institute. Secondly, I will describe in detail my daily tasks and some difficulties that I have encountered. Then, I will represent our initial idea about creation of geo-spatial data visualization by using virtual reality.

1 Hosting institution:

1.1 C2DH (Luxembourg Centre for contemporary and digital history):

Luxembourg centre for contemporary and digital history (C2DH) is one of the three interdisciplinary centres of University of Luxembourg which is working on study, analysis and public dissemination of contemporary Luxembourgish and European history. This centre has an interdisciplinary approach which is mostly focused on new digital tools for historical teaching and research[1].

The Centre was established in October 2016 and was officially launched in May 2017. It has around 130 staff members who work on different interdisciplinary projects.

1.1.1 Missions:

The centre aims to have a major key in three fields of interest. The first domain is the role of the centre as a national reference in fields of study and research related to Luxembourgish history. The second mission is to be an international research centre for reflection on the challenges of history in digital ages. The last mission of the centre is to promote digital literacy in academic research and teaching at the University of Luxembourg.

Therefore, the centre is largely focused on the use of digital tools for historical research. It also has an interest for the new forms of digital tools which engage the people in a different way and specially on a large scale.

1.1.2 Research:

The research infrastructure in C2DH is focused on the history of Luxembourg, European history and digital historiography which are all explored with interdisciplinary approaches.

[1] https://www.c2dh.uni.lu/

1.1.2.1 Contemporary history of Luxembourg:

Research and studies on the contemporary history of Luxembourg consist of political, economic, cultural and social history of Luxembourg in the 20th and 21st centuries.

The research's field of interest is to produce new knowledge based on events and phenomena which has largely affected Luxembourgish history or whose values are shared between other nations. These fields include the two world wars and its occupation, resistance and collaboration, the transition of economy from steel production to manufacturing and services, the emergence of the migratory region with its social and political impacts and responses and the development of Luxembourg as a welfare nation within the framework of Europe and the worldwide globalization.

1.1.2.2 Contemporary European history:

As the term of Europe is defined in multiple or contradictory ways, the study in fields of European history is in constant evolution between borders and boundaries which can be geographical, political or societal.
General topics of interest are the different phases of industrialization, the development of transnational infrastructure and the "hidden integration" of Europe, political conflicts and crises, cultural circulation between European nations and the project of Europeanisation of Europe to extend a high standard of living and cultural values in European countries.

1.1.2.3 Digital history & historians:

This field of study aims to combine digital tools with pure historical research in order to increase public engagement and online spread of research results for both historians and the larger public.
The research area on histography and history covers topics like digitization and preservation of digital data, data management and metadata description, the use of tools for data visualization and text mining and public history and crowdsourcing.

1.2 Digital research infrastructure:

My internship was held at the Digital research infrastructure (DRI) at the C2DH. This team was mostly formed by colleagues who have excellent skills on digital tools who work on different projects. Inside the infrastructure multiple teams exist as well. For example, the interface team or the development team which is formed by staff members who are mostly oriented to a specific technical aspect which is at the same time complementary for other colleagues.

The head of this infrastructure is Dr. Lars Wieneke who coordinates all the projects and he manages intrapersonal relations between colleagues.

1.3 Hierarchy:

In order to represent the hierarchy of the roles in C2DH, I'll present the people who were involved in my internship directly or logistically.

Members of C²DH Management:

- Andreas Fickers: Director of C2DH
- Lars Wieneke: Head of digital infrastructure
- Denis Scuto: Head of Luxembourgish history
- Brigitte Melchior: Personal Assistant to the Director & Leader of C²DH secretariat

Members of C²DH Communication office:

- Vanessa Napolitano: Communication officer

Other members:

- Aida Horaniet Ibanez: Phd student
- Robert Beța: IT system administrator
- Maxime Derian: Research associate
- Elisabeth Guerard: IT application developer
- Christopher Morse: PhD student

We also had a cooperation with the department of the engineering for the laser scanning of the "Rumelange[2]" mine in Luxembourg:

- Felix Norman Teferle: Full professor in Geodesy
- Addisu Hunegnaw: Postdoctoral researcher

A complete list of working staff members can be found on the official web page of C2Dh.[3]

[2] https://www.visitluxembourg.com/fr/adresse/museum/musee-mines-rumelange
[3] https://www.c2dh.uni.lu/people

2 Internship's environment:

In order to give a detailed overview of what I have performed during my internship I will start by explaining my first days at C2DH and the welcome day that was organized upon my arrival. Then, I will continue to explain the working environment.

2.1 Welcome day:

Few days before my internship, I received a welcome mail from Ms. Melchior of the secretariat office. In this document all the details were explained to me: showing me my office, getting my badge and getting IT credentials.

As I agreed with my supervisor to work remotely from France due to covid restrictions, the meeting with the secretariat team was postponed to another time.

I received a welcome pack document explaining everything an intern would like to know. I found lots of information about the C2DH and the staff members: a campus map, where to go on the first day of internship, explanations about IT credentials, C2DH's values, different labs and useful links.

2.2 15th of March 2021: First day of Internship

On the first day of internship, I had my first meeting with my supervisor as well as Ms. Horaniet and Dr. Maxime Derian. During this discussion we talked about different possibilities around the project, and they sent me multiple links to articles and conferences in order to do the literature study of our project before going into the development phase.
We agreed that I would search for articles about 3D data visualization and virtual reality for two weeks.

2.3 Daily meetings:

In order to be in touch with other colleagues during remote working, a series of daily meetings were already put in place by Dr. Wieneke. I was also invited to this daily meeting on the second day. These meetings took place every working day from 9:30 to 10 o'clock.
Each person has his/her time to talk about what he/she is doing and what he/she is going to do.

On Tuesday 16th of March, I had my first daily meeting where I saw my colleagues of DRI (digital research infrastructure) for the first time and I did a brief presentation of myself and other colleagues were presented to me as well.

2.4 Meeting with Christopher Morse:

On Monday 17th of March, I had a meeting with Christopher Morse who is a doctoral researcher specializing in experience design for museum technologies and virtual reality.
During our meeting he explained to me his works and his fields of interests which is mostly user interface design. We have talked about gamification and storytelling in data visualization and the VR experience.

2.5 Monthly plenary sessions:

Every Wednesday of the second week of each month we had a plenary session with the director of the C2DH Dr. Andreas Fickers and all the staff members. For my first plenary session I was asked to present myself to other colleagues and I was warmly welcomed by the team.
Each plenary session was a chance to get to know other colleagues and to be informed of the future workshops or conferences.

2.6 Follow up meetings:

Every Monday of the week, I had a follow up meeting just after the daily meeting at 10:30 with my supervisor and Ms. Ibanez. During these meetings I used to present what I did during the last week, and I shared my screen to show the progress of the project. Then, we had a discussion about the project.

If there were any concerns, I could directly ask my supervisor for some advices and he responds very quickly.

2.7 Communication tools:

In order to communicate during remote working, multiple options were put in place to be in touch with each other.

2.7.1 Slack:

We used the slack[4] software in order to inform each other quickly and to be in touch easily. Most of my communication with my supervisor and other colleagues was through slack. We had multiple channels for each purpose. For example, a channel for the internship, a general channel and even a channel for asking programming solutions in case someone has a technical issue or a question.

2.7.2 Webex (by Cisco):

We have used the Webex[5] software for all our meetings, seminars, workshops and all other sorts of communications. Despite the huge number of people using the Webex software, we have never encountered a problem during our communications.

2.7.3 University email address:

From the first day of internship, an email address of the University of Luxembourg has attributed to me to communicate easily with my colleagues. A short presentation of me was sent from the secretariat to all the C2DH's staff and lots of working staff sent me a welcome message separately.

[4] https://slack.com/
[5] https://www.webex.com/

2.8 Internal and external workshops:

During my internship, I had the chance to participate in different workshops inside the C2Dh. One of the first conferences that I attended was the presentation of Frédéric Clavert's project called "UNSURE" which is trying to resort to digitally born archives of newsgroups to analyze the discussions on Europe in the 1990s-2000s, to shed light on the opposition to the European integration outside of mass media.

I also attended the presentations for the assistant prof position where I listened to interesting projects around digital humanities and especially digital history.

Moreover, I had enrolled in a workshop about Nodegoat which was held by Kaspar Gubler of the University of Bern in Switzerland. I have participated in four sessions, each of them three hours. I learned how to use the Nodegoat platform for data modeling, data creation and exploration and data visualization.

2.9 Working hours:

Working hours in Luxembourg are longer than in France and they work 40 hours per week compared to France which is 35 hours.

Therefore, I had 8 hours of working hours from Monday to Friday. My daily work would start at 9 o'clock. At 9:30 I used to have my daily meeting and right after the meeting I used to work on the project until 12:30. After one and a half hours of break for lunch, I would return to work until 18:30.

2.10 My office:

My office was already prepared with a desk and a computer in a shared room with other colleagues. Unfortunately, due to covid restrictions It was not possible for me to move to Luxembourg and to use my office.

With the new guideline of the director of the C2DH, I had the possibility to work in the office from June but due to lack of time to organize a possible move to Luxembourg at the end of my internship and with the permission of my supervisor, I continued to work remotely from France.

3 Intern's tasks:

In order to explain in detail, the task that I have undertaken, I would start by briefly explaining my project at C2DH.

3.1 VR data visualization Project:

With advice of my supervisor, I had a discussion with Ms. Ibanez who has already started her PhD in University of Luxembourg where she is working on the "LuxTIMEMachine"[6], and we decided to work together on my VR project prototyping.

This project is gathering three different fields: eco-hydrology, medicine and history.
LuxTIME is using a local case of industrialization of the Belval/Minette region in Luxembourg in order to define the impacts of environmental changes on the health of the local population in the long term.

3.1.1 First use case of VR – VR map of Belval region with statistical dataset:

After long discussions and brainstorming with my supervisor and Ms. Ibanez, we agreed to create a large map of Luxembourg, to put a walking person inside the map, to load the map in VR and put some statistical data related to the Belval region.

We decided to create a prototype of the population of Canton of Esch-sur-Alzette in Luxembourg in VR. In order to do the prototype, I started to do some research about different tools, and I came up with the idea of using Unity engine[7] as the VR framework for the development of VR experience as well as Mapbox[8] which is an open-source online map which is free to use up to 25,000 active users and it is sufficient for our project.

[6] https://www.timemachine.eu/ltm-projects/luxtime/
[7] https://unity.com/
[8] https://www.mapbox.com/

3.1.2 Second use case of VR – VR visit of the Rumelange mine in Luxembourg:

In parallel with the first project, we reached out to Dr. Felix Norman Teferle of the Department of Engineering of the University with whom the C2Dh had already done another project.

We managed to have a discussion with Dr. Teferle and his team for a possible laser scanning of Mine. After multiple discussions between our team and the engineering team, they agreed to scan the mine and send us the point clouds of inside of the mine.

As soon as we received the laser scanning, I started to work on point clouds in Meshlab[9] and Cloud Compare[10] to create the 3D meshes. We used the Three.js library of Java script to create the 3D environment.

3.2 Missions:

3.2.1 Literature study:

One of the most important and preliminary phases of a research work is the state of art. During the first two weeks of my internship, I was asked to work on different articles related to the fields of data visualization, VR, AR, and 3D visualization. I watched multiple seminars, presentations and I read many articles.

In order to keep a record and share these articles with my supervisor and Ms. Ibanez, we used Zotero[11] software and we created a shared folder to see at the same time and in one place, all the articles and useful links.

We discussed my findings after the first week at C2DH in our weekly follow up sessions on two following Mondays.

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[9] https://www.meshlab.net/
[10] https://www.danielgm.net/cc/
[11] https://www.zotero.org/

After two sessions of discussion, we came up with the idea of loading a map of Luxembourg with a third person character walking through the map who can interact with statistical data such as population or steel production in the Belval region.

3.2.2 First use case of VR – VR map of Belval region in Luxembourg:

3.2.2.1 Choosing the tools for implementing the VR map:

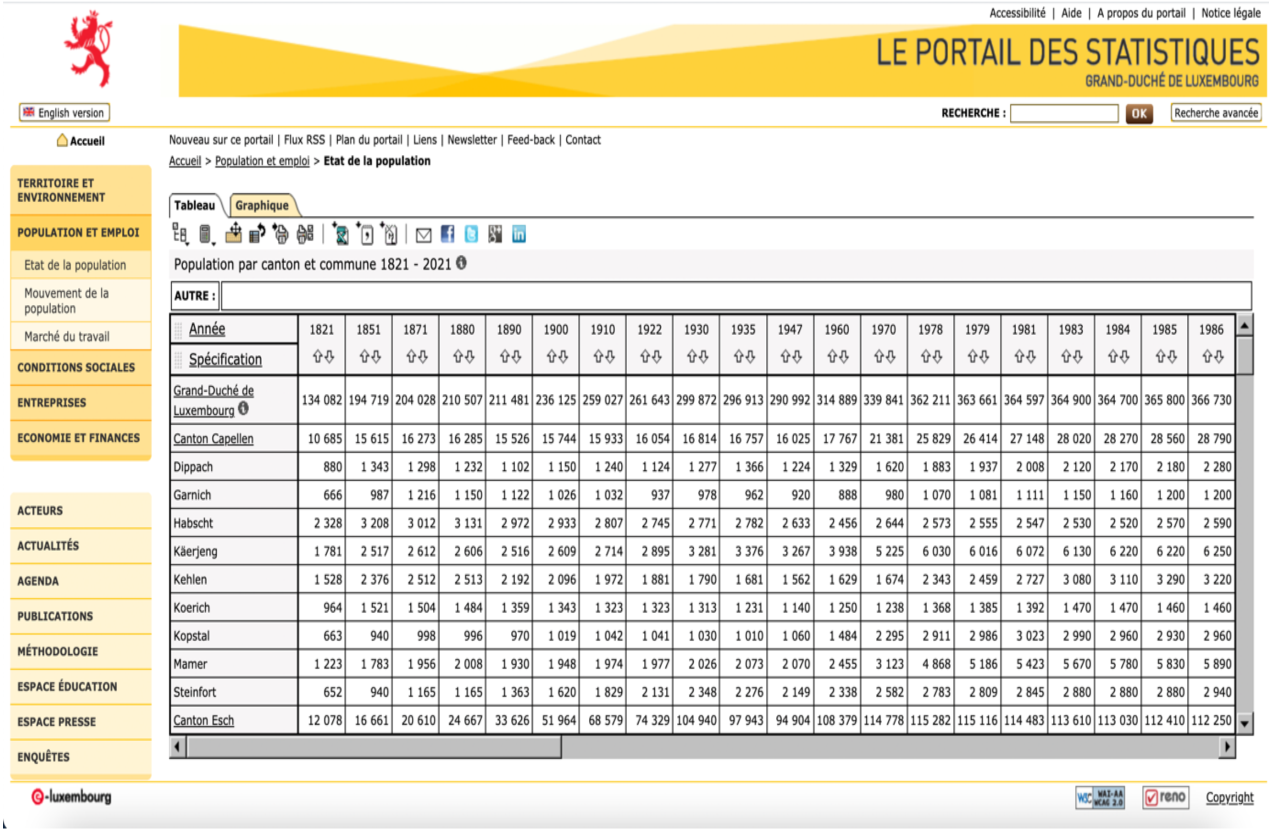
After working two weeks on the literature study, my supervisor proposed me different frameworks for VR development like A-frame[12] and Three.js[13]. As I didn't have so much experience in these frameworks I proposed to work on Unity because we already had some courses about 3D environment in Unity engine in the second year of Master's degree.

In order to implement the map, one of the most interesting options that we found was Mapbox which provides multiple visualization options.

3.2.2.2 Data collection:

In order to find the population statistics, the best option was to use the STATEC's[14] (officially in French: Institut national de la statistique et des études économiques) detailed statistics which cover almost all the social sectors. The data are downloadable in different formats: csv, excel and xml. Our preference here was to download the data in excel and csv in order to add geographical locations.

[12] https://aframe.io/
[13] https://threejs.org/
[14] https://statistiques.public.lu/fr/acteurs/statec/index.html



Population par canton et commune 1821 - 2021

Année / Spécification	1821	1851	1871	1880	1890	1900	1910	1922	1930	1935	1947	1960	1970	1978	1979	1981	1983	1984	1985	1986
Grand-Duché de Luxembourg	134 082	194 719	204 028	210 507	211 481	236 125	259 027	261 643	299 872	296 913	290 992	314 889	339 841	362 211	363 661	364 597	364 900	364 700	365 800	366 730
Canton Capellen	10 685	15 615	16 273	16 285	15 526	15 744	15 933	16 054	16 814	16 757	16 025	17 767	21 381	25 829	26 414	27 148	28 020	28 270	28 560	28 790
Dippach	880	1 343	1 298	1 232	1 102	1 150	1 240	1 124	1 277	1 366	1 224	1 329	1 620	1 883	1 937	2 008	2 120	2 170	2 180	2 280
Garnich	666	987	1 216	1 150	1 122	1 026	1 032	937	978	962	920	888	980	1 070	1 081	1 111	1 150	1 160	1 200	1 200
Habscht	2 328	3 208	3 012	3 131	2 972	2 933	2 807	2 745	2 771	2 782	2 633	2 456	2 644	2 573	2 555	2 547	2 530	2 520	2 570	2 590
Käerjeng	1 781	2 517	2 612	2 606	2 516	2 609	2 714	2 895	3 281	3 376	3 267	3 938	5 225	6 030	6 016	6 072	6 130	6 220	6 220	6 250
Kehlen	1 528	2 376	2 512	2 513	2 192	2 096	1 972	1 881	1 790	1 681	1 562	1 629	1 674	2 343	2 459	2 727	3 080	3 110	3 290	3 220
Koerich	964	1 521	1 504	1 484	1 359	1 343	1 323	1 323	1 313	1 231	1 140	1 250	1 238	1 368	1 385	1 392	1 470	1 470	1 460	1 460
Kopstal	663	940	998	996	970	1 019	1 042	1 041	1 030	1 010	1 060	1 484	2 295	2 911	2 986	3 023	2 990	2 960	2 930	2 960
Mamer	1 223	1 783	1 956	2 008	1 930	1 948	1 974	1 977	2 026	2 073	2 070	2 455	3 123	4 868	5 186	5 423	5 670	5 780	5 830	5 890
Steinfort	652	940	1 165	1 165	1 363	1 620	1 829	2 131	2 348	2 276	2 149	2 338	2 582	2 783	2 809	2 845	2 880	2 880	2 880	2 940
Canton Esch	12 078	16 661	20 610	24 667	33 626	51 964	68 579	74 329	104 940	97 943	94 904	108 379	114 778	115 282	115 116	114 483	113 610	113 030	112 410	112 250

Figure 1 Population table of STATEC

3.2.2.3 Data processing:

In order to prepare the statistical information to be imported to the Mapbox studio, we need to have whether latitude and longitude (two points) or polygons (multiple points).

As the polygons are so long with a lot of lines, I added the latitude and longitude of each city to the csv file. Once the csv file is completed, it is ready to be uploaded to the Mapbox studio.

3.2.2.4 Importing csv file into Mapbox studio:

In the Mapbox studio, we can create a new dataset by drawing polygons, lines or points. As we had already created our file, I imported the population data into Mapbox studio. After importing the csv file, all the cities appear on the map. As we have already mentioned, the polygons are to be added instead of latitude and longitude.

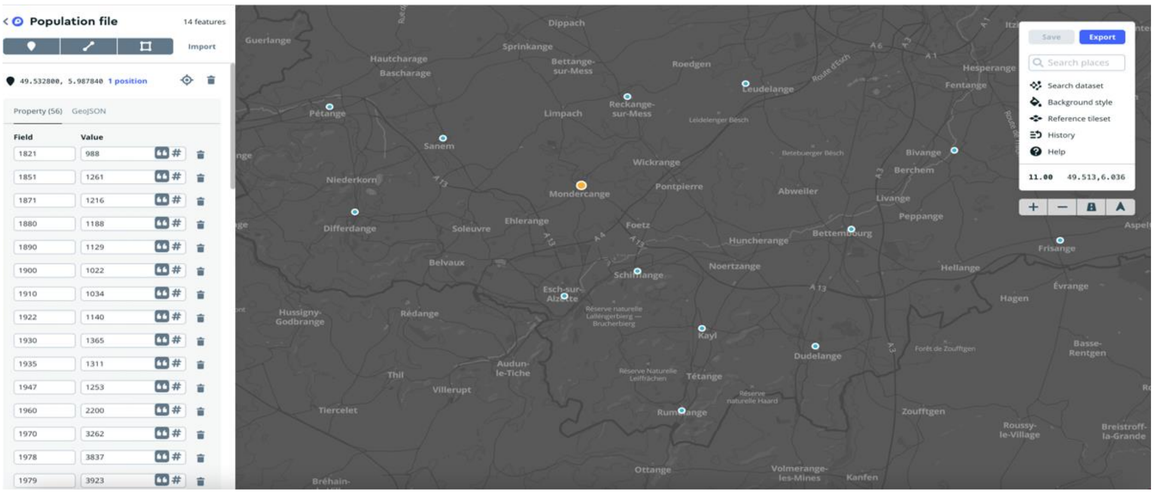
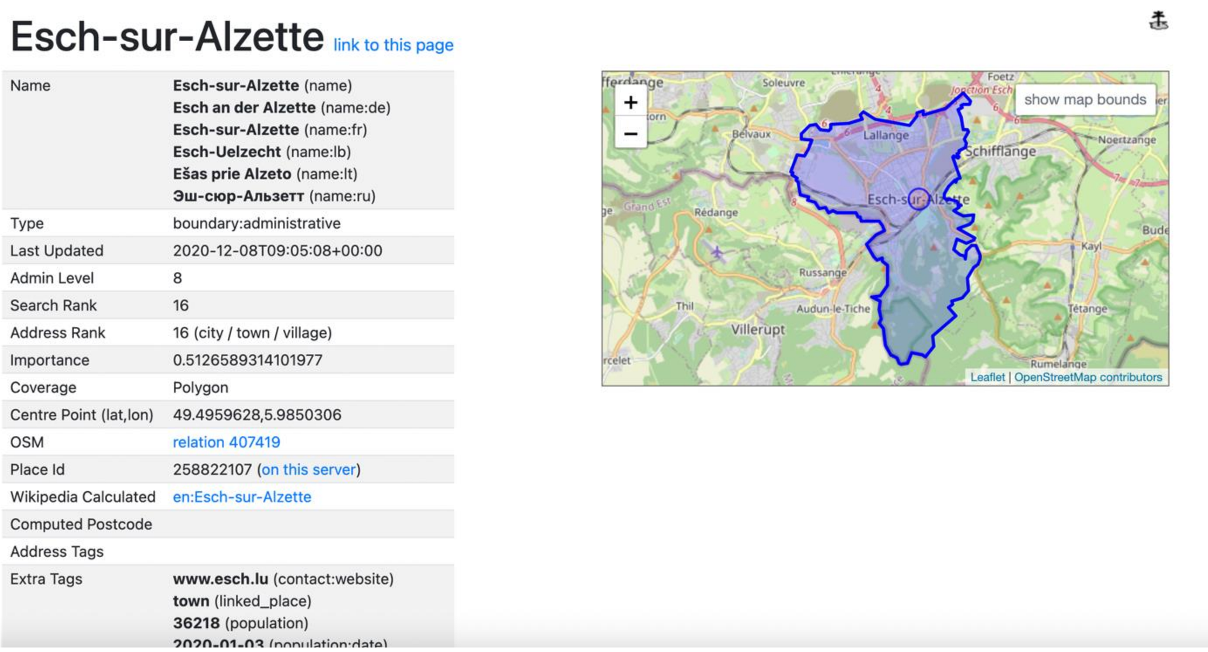


Figure 2 Imported population file

3.2.2.5 Open Street Map (OSM) API:

Open Street Map[15] is a free editable geographic database of the world. The Open Street Map is used in this project in order to get the OSM Id of each commune of Esch-sur-Alzette Canton. After entering the city's name, we copy the OSM relation Id in order to get the exact polygons points.



Esch-sur-Alzette link to this page

Name	**Esch-sur-Alzette** (name) **Esch an der Alzette** (name:de) **Esch-sur-Alzette** (name:fr) **Esch-Uelzecht** (name:lb) **Ešas prie Alzeto** (name:lt) **Эш-сюр-Альзетт** (name:ru)
Type	boundary:administrative
Last Updated	2020-12-08T09:05:08+00:00
Admin Level	8
Search Rank	16
Address Rank	16 (city / town / village)
Importance	0.5126589314101977
Coverage	Polygon
Centre Point (lat,lon)	49.4959628,5.9850306
OSM	relation 407419
Place Id	258822107 (on this server)
Wikipedia Calculated	en:Esch-sur-Alzette
Computed Postcode	
Address Tags	
Extra Tags	**www.esch.lu** (contact:website) **town** (linked_place) **36218** (population) **2020-01-03** (population:date)

Figure 3 Open Street Map's relation ID

[15] https://www.openstreetmap.org/

3.2.2.6 *Retrieving polygons:*

On the Open Street map, we can use the polygon creation in order to retrieve polygons points by just adding the OSM relation Id. Once the Id is entered and the conversion is launched, the user can access the polygons in different formats: WKT, GeoJSon, poly and image. We are more interested in GeoJSOn which is the accepted format of Mapbox.

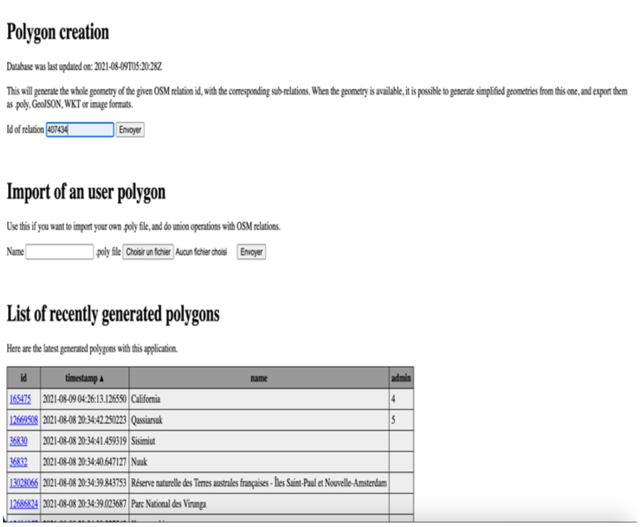


Figure 4 Retrieving polygons with OSM ID

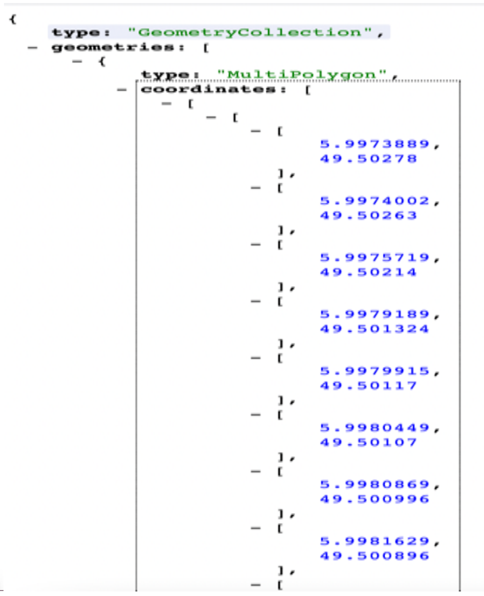


Figure 5 Generated polygons

3.2.2.7 *Replacing latitude and longitude with polygons:*

Once we have the polygons, I replaced the latitude and longitude of each commune with the polygons.

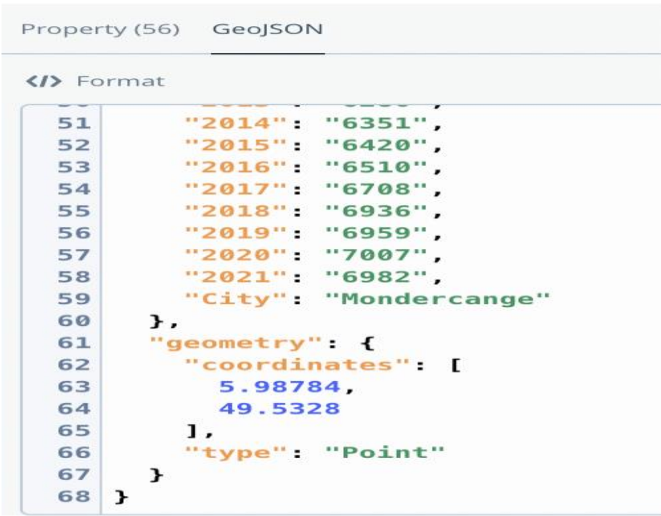


Figure 6 latitude and longitude to be replaced by polygons

3.2.2.8 *Tileset creation:*

As I have completed the creation of the dataset, the next step would be to create the tileset. After choosing the right dataset, the tileset is created with its vector layers and different fields.

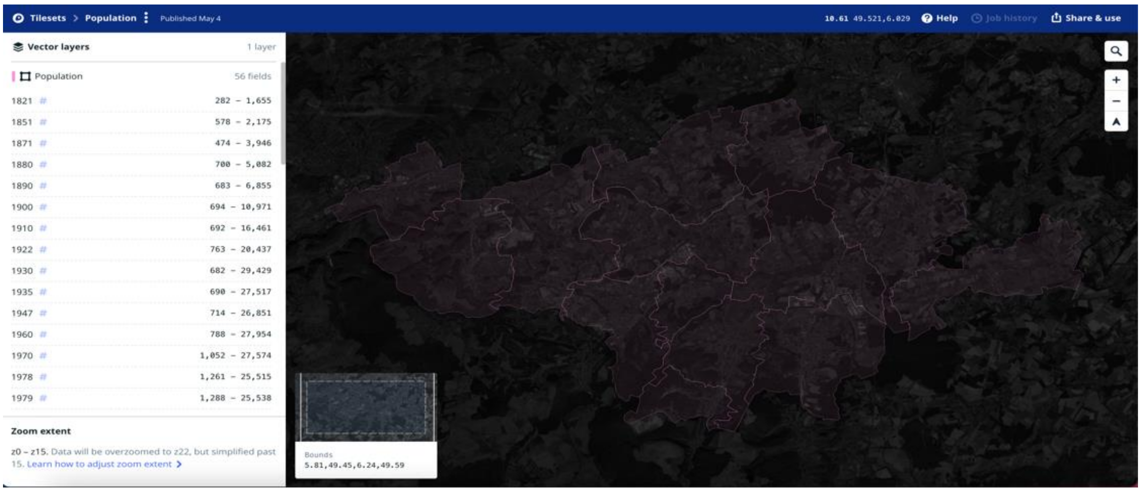


Figure 7 Vector layer of population

3.2.2.9 *Mapbox Unity SDK integration:*

For implementing the map into the unity scene, I used the Mapbox Unity SDK. The interface is appealing and there are lots of ready-to-use optionality which make it easy for basic Unity users to change map's configuration.

Then, I imported the map into the unity scene with the tileset ID provided by Mapbox. With some configurations like choosing the custom layer, adding features and using polygons as the modeling type of our visualization, a bar chart shape visualization showed up which represents each commune's administrative borders.

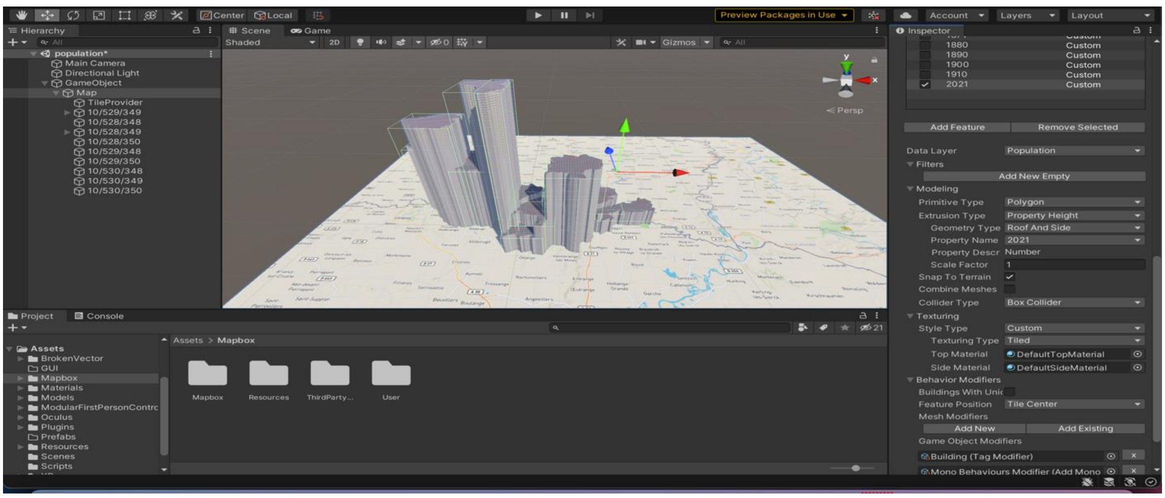


Figure 8 Data visualization in Unity

But unfortunately, the options were so limited and we couldn’t bring our custom preferences such as custom colors or name attribution for each commune in Mapbox Unity SDK. I’ll talk about this issue later in the encountered problems section.

3.2.2.10 Mapbox GL JS – alternative solution:

As we couldn’t customize the map like we wanted to do, with the advice of my supervisor I started to take a look at the Mapbox GL JS to see whether I’m comfortable using this javascript library which is designed for building web maps and web applications with Mapbox's modern mapping technology.

After working a few days with this library, I’ve felt that it was easier to use this library instead of Unity SDK where most of the options were limited or it demanded complicated and long codes to achieve little results.

Just after changing from Unity to Mapbox, the coding part went faster, and we achieved our first visualization with gradient colors according to each commune’s population from 1821 to 2021.

A simple menu is put in place in order to navigate through years and the visualization changes according to each year’s population.

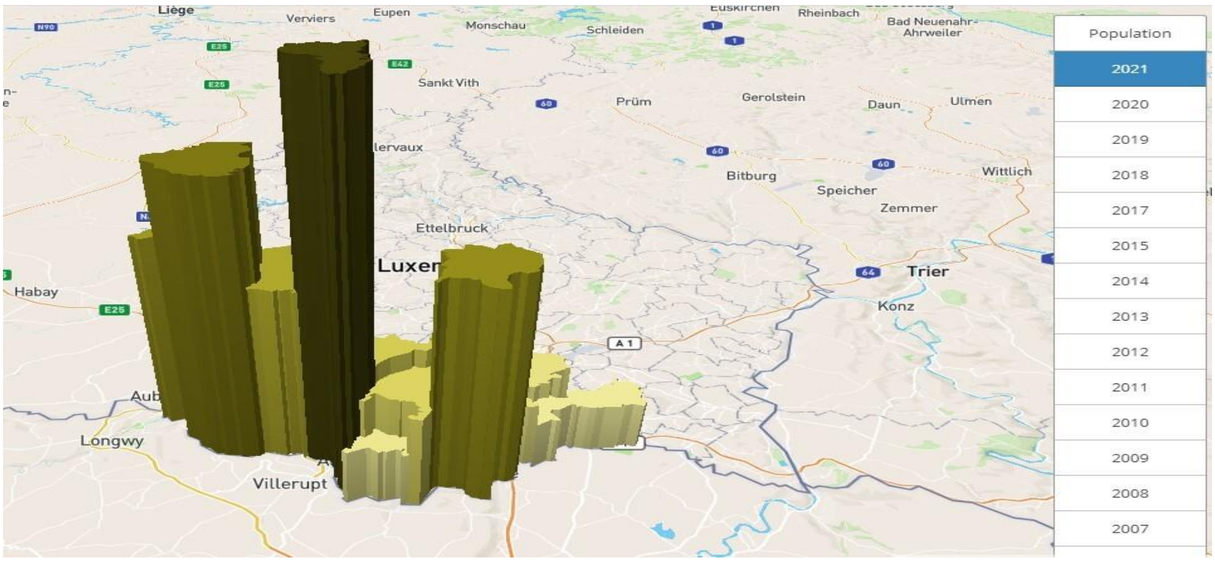


Figure 9 Bar chart shape visualization of Canton of Esch-sur-Alzette

3.2.3 Second use case of VR:

As we have already mentioned we had a collaboration with the Department of Engineering of the University of Luxembourg. They were in charge of the scanning the interior of Rumelange (Figure 2, Figure3 and Figure 4) mine with two different scanners: the first scan was done with a Faro scanner[16], and the second one was done with the GeoSLAM[17] scanner.

We received the first scans of the mine from the Engineering Department (Figure 5), and I started working on the point clouds in order to create our 3D model of the mine. The first scan has a good quality with around 180 million points.

However, they did another scan of the mine, and they merged the result of the two scans (GeoSLAM and Faro scanner) to provide a better result with more details.

3.2.3.1 Importing point clouds:

I used the Cloud Compare software for importing the point cloud file which was in “las” format. Compared to Meshlab which does not support las format import, I could import the point clouds with Cloud compare.

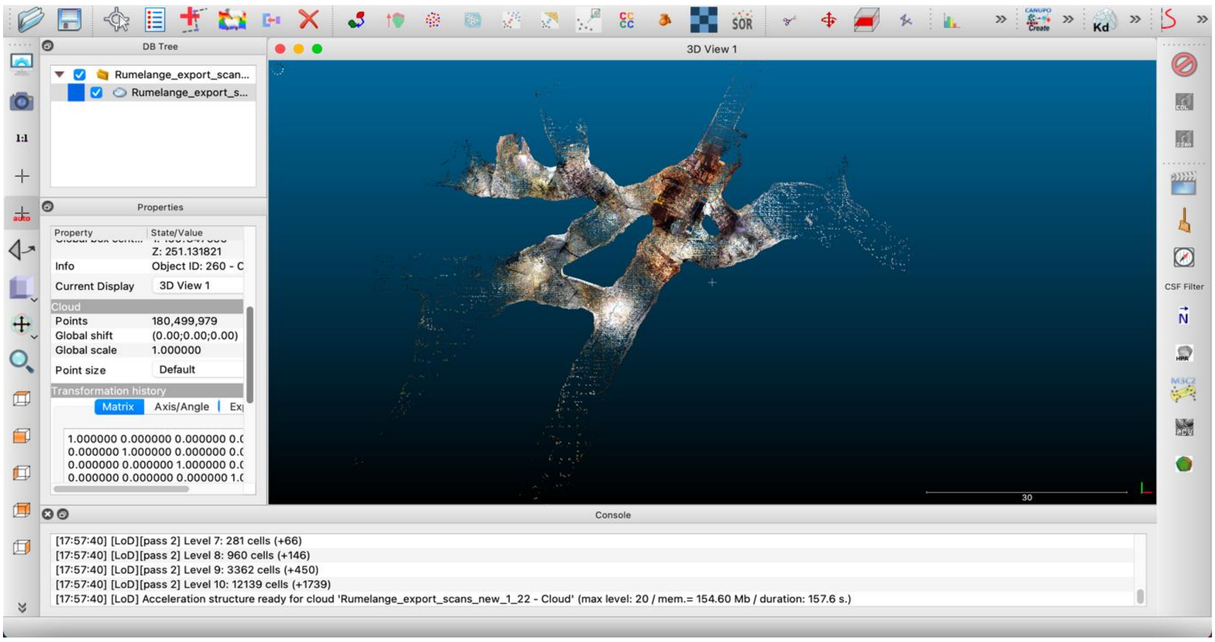


Figure 10 Point cloud before sampling

[16] https://www.faro.com/
[17] https://geoslam.com/

3.2.3.2 *Point cloud sampling:*

With a huge number of points in our point cloud, it is somehow impossible for almost all the modern desktop computers to convert point cloud to a mesh, to delete unwanted parts or to calculate the normals. This is the reason why I decided to reduce the number of points to 4 million in order to have a lighter point cloud.

For applying this reduction, I used the point cloud sampling function with a random method where we can choose a number of points.
Even though the final result is not comparable to the initial point cloud in terms of quality, it will let us explore and create a simple 3D model of inside of the the mine.

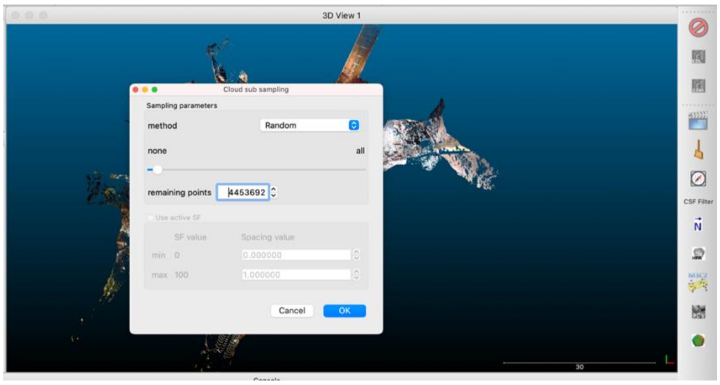


Figure 11 Point cloud sampling

As soon as the points were reduced to 4 million, I exported the result to a ply format in order to be able to import it in another software called Meshlab which has almost the same options as Cloud Compare but it's a little faster.

3.2.3.3 *Point cloud clean up:*

One of the first things that we might do before calculating the normal is to clean up the unwanted parts of our point clouds which are generated during the laser scan.
With the "select vertices" tool, I selected and deleted the noises.

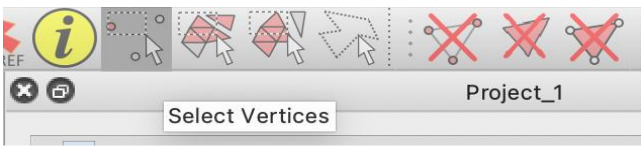


Figure 12 Selecting unwanted parts with vertices selection

3.2.3.4 *Computing normal for point sets:*

A normal is an object such as a line, ray, or vector that is perpendicular to a given object. In order to calculate the normal for our point cloud, I used the automatic normal calculation of Meshlab.

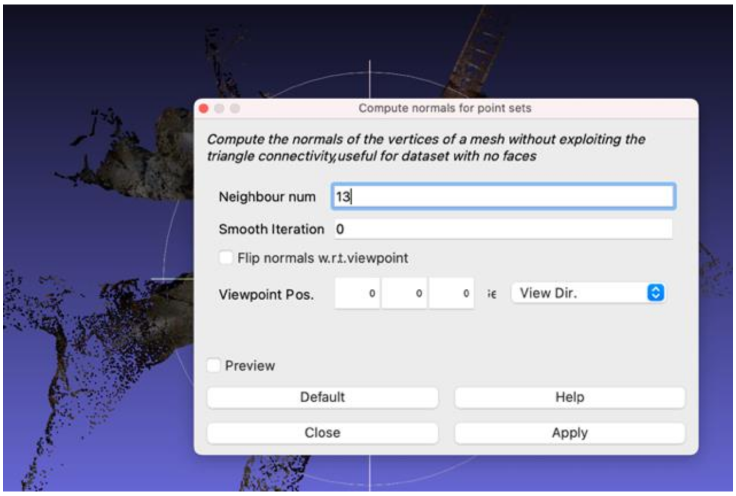


Figure 13 Normals computation

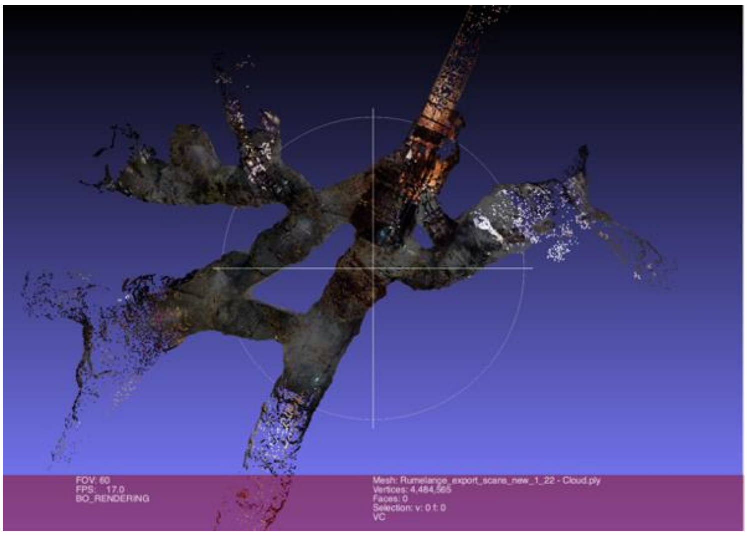


Figure 14 The result of Normals computation

3.2.3.5 *Converting point clouds to mesh:*

In order to convert point clouds to a mesh, I used the surface reconstruction algorithm which creates waterlight surfaces from oriented point sets. With the “screen poisson” surface reconstruction function we can achieve an automatic generated mesh which will be later used for our use case.

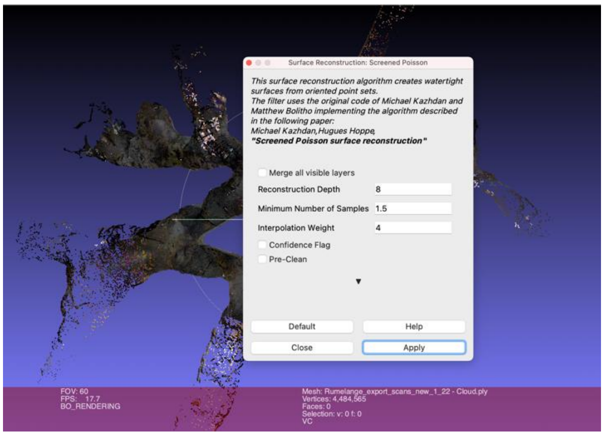


Figure 15 Poisson filter

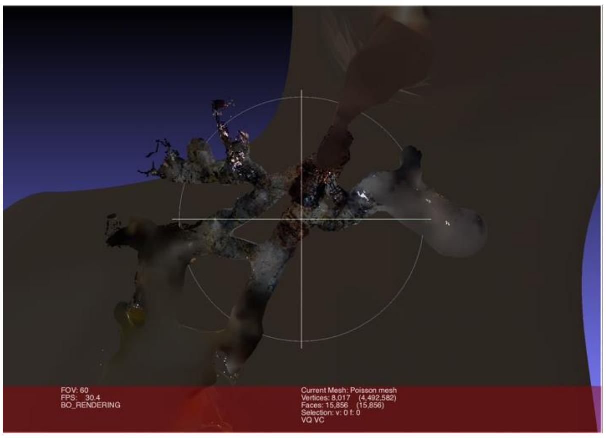


Figure 16 Generated mesh

3.2.3.6 Mesh cleaning up after using the Poisson filter:

After using the Poisson filter, some edges are created which don't belong to our mesh. In order to delete them, I used the select function which selects all the faces with edges longer than a threshold number and deletes them from the mesh.

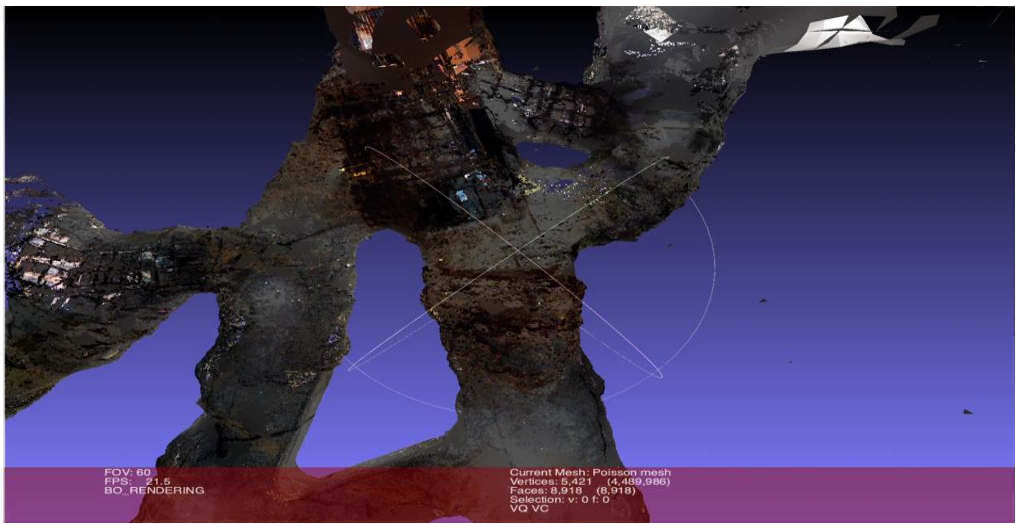


Figure 17 Final result

3.2.3.7 Mesh export:

Once the mesh is generated, I exported the result to an "obj" format mesh which can be later used in Blender for further modification.

3.2.3.8 Mesh conversion in Blender:

As we are using the WebXR for our VR experience, it is highly recommended to use the glTF format which is a format designed to let you move 3D files seamlessly between applications while retaining a consistent PBR workflow.[18]

3.2.3.9 VR environment development with Three.js

Three.js, alongside A-Frame, is one of the frameworks which are used for WebXR development. I used the Three.js framework in this project to create the VR environment.
A glTFLoader is used in order to load the 3D model in the HTML file.

The result was tested during the development on the computer's browser by using the VR Emulator add-on[19] which creates the VR environment, the VR Headset and the controllers and let us move around the VR scene.

3.2.3.10 Uploading the project on the server:

Once the project was almost ready to be tested on the VR headset, I asked my supervisor for a server and with the help of the IT administrator Mr. Beta, I received the credentials for uploading the project on the server.

For this purpose, I used the FileZilla[20] software to transfer the files into the server.
The final result is a character inside the mine but due to lack of time and other constraints, the development is not finished and the character can't walk through the mine but it can move his/her head to see around the mine.

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[18] https://sketchfab.com/features/gltf
[19] https://github.com/MozillaReality/WebXR-emulator-extension
[20] https://filezilla-project.org/

Figure 18 Inside of the Rumelange mine in VR environment

3.2.3.11 The VR headset:

In order to test our VR environment, we have used the Oculus Quest VR headset. Oculus Quest is a standalone device that can run games and software wirelessly and it has an android operating system which can install apps from its own Oculus app store.[21]

With the two frontal sensors which are integrated into the headset, the device supports position tracking which makes it a standalone device which doesn't need to be connected to anything and it can be worn directly and used in any environment.

With the Unity environment, we exported the Mapbox project in android apk format which can be installed on the headset and tested through the headset. Contrary to Unity, in Three.js we put our file into a server and the VR environment is web-based and it can be accessible via Oculus' browser or any other VR headset.

[21] https://www.oculus.com/quest/features/

3.3 Results:

I worked as a part of my master's degree studies, 5 months at the C2DH and I can frankly say that this experience was really fantastic. I got to know many kind people who warmly welcomed me. I had multiple discussions with my colleagues, and they did their best whenever it was possible to make me feel comfortable and they helped me resolve my technical issues.

Here I would like to mention the technical and social skills that I gained during this experience.

3.3.1 Improving programming skills:

As in our educational program we were not supposed to be a full stack developer, my programming skills were somehow at an intermediate level. During my internship I confronted many challenges in terms of programming and sometimes it took me multiple days to achieve the results I expected.

In order to overcome this weakness, I read some documentation and watched many tutorials. I also started using GitHub and Stack Overflow's forums for asking about my issues.

I was never discouraged when I had an issue and I think this perseverance helped me to be more confident in programming.

3.3.2 Learning new tools:

For implementing and developing the second use case, I was asked to work on point clouds. It was the first time I was working with such a file.

We already had some courses at University about Virtual universe development tools (Outils développement univers virtuels) and I was familiar with Cloud Compare and Meshlab but I never had the chance to work with point clouds or creating 3D models. In order to complete the tasks, I used most of the time the documentations as well as dedicated forums for 3D modeling.

Moreover, I found an interesting tool called Mapbox which provides a wide range of customizable map-based visualization. Even though I have never used it before, I think this internship helped me a lot to learn different aspects of Mapbox which can be later used in another project.

Therefore, this internship was a chance to work with Meshlab, Cloud Compare and Mapbox.

3.3.3 Participating in workshops and conferences:

As I have mentioned earlier, during my internship, I participated at a workshop on nodegoat which was held remotely. This workshop was very useful for me in terms of data modeling and visualization.

Moreover, I had received the free pass to participate in VivaTech which is an annual technology conference, dedicated to innovation and startups, held in Paris, France. I enjoyed listening to inspiring people of technology like Tim Cook of Apple and Mark Zuckerberg of Facebook.[22]

3.3.4 Submitting an abstract for the 8th annual conference of the association "Digital Humanities in German-speaking countries"[23]

With the advice of my supervisor, we decided to publish our study in an international conference which is organized by the University of Potsdam[24], and the University of Applied Sciences Potsdam in Postdam in Germany on March 2022.

We submitted our poster before 15th of July and we will wait for further reviews and a possible presentation of our work.

[22] https://vivatechnology.com/
[23] https://www.dhd2022.de/
[24] https://www.uni-potsdam.de/

4 Adding value of VR in data visualization in digital humanities:

The aim of this chapter is to present a literature study of virtual reality and the use of this technology in data visualization and especially in data visualization of the humanities.

4.1 Introduction:

We are living in an era where computers are becoming more complex and there are lots of data which need to be stored, normalized and visualized. Data visualization is a field of research and study which is now really important for decision making in many companies, organizations and governments.

As the data are multiplying and their amounts are gigantic it is easier to understand and extract information from data visualization. There are two common types of visualization: 2D and 3D.

The 2D visualization is the most common visualization which is used most of the times in a graph shape visualization. But in this type of visualization there is only one visible face of data and the relation between graphs is not shown. On the other hand, the 3D visualization can show other parts of data which are not visible in 2D.

However, using a normal screen for showing 3D visualization is not always satisfying because we won't have the necessary depth and the interactivity is not present.

Therefore, using a virtual reality environment may help to improve data visualization by merging characteristics of 2D and 3D visualization at the same time.

4.2 Purposes:

The first purpose of this work is to give an overview of what VR can propose in terms of data visualization by presenting related works. Moreover, we want to determine if virtual reality can offer an adding value for data visualization or not by presenting our prototypes that we have developed during this internship.

4.3 Potential questions:

- How does VR add value to historical visualization (Spatio-temporal data visualization)?
- Can VR overcome any of the limitations of 2D Data visualization?

4.4 Related works:

Previous research has explored the potential to enhance 2D data visualization through the use of 3D and Virtual Reality.

A research team of the Delft University of Technology shows the use of intuitive exploration tools for data visualization. The focus is put on the intuition and the interactivity of the exploration. The intuitive navigation and visualization tools can be a good approach for exploration of volumetric data.[25]

Different interactive tools are designed to explore differently throughout the dataset. Zooming can help to have a closer look at objects or regions of interest which helps us to select a particular part of objects or to focus on details.

Moreover, the use of probing tools such as line probing and point probing can helps us to read out medical CT scans.

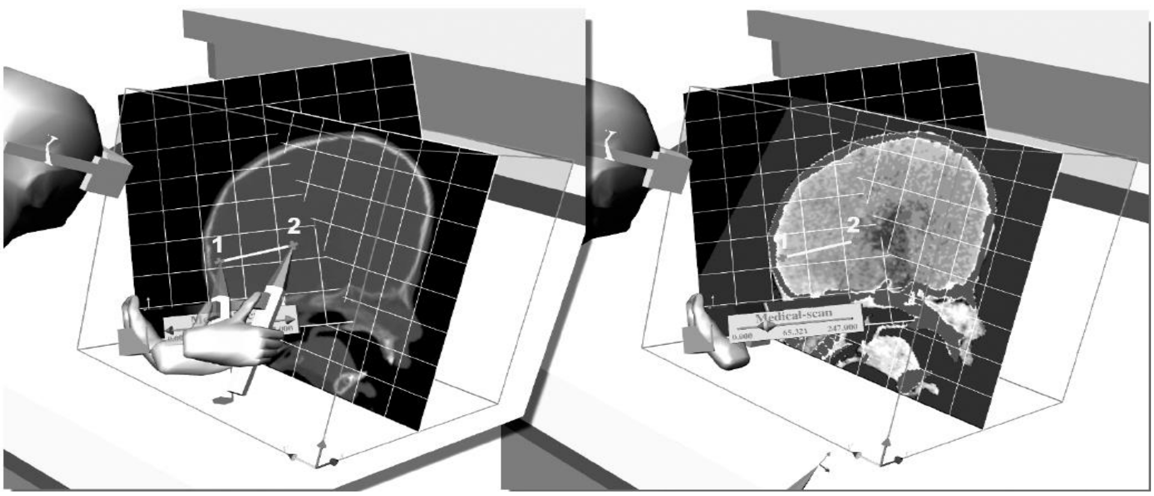

Figure 19 Line Probing: The user selects a line of interest to calibrate the gray-scale color mapper in a medical CT-scan

[25] Haan, Gerwin & Koutek, Michal & Post, Frits. (2002). Towards intuitive exploration tools for data visualization in VR. 105-112. 10.1145/585740.585758.

Regarding the time dependent data, there has been some researches in these fields at the University of Rostock in Germany where they used 3D information visualization and information hiding methods to represent the temporal dataset. [26]

As an illustration, they created a visualization of monthly health data by means of 3D icons like a pencil in order to represent cases of six diseases whereas the helix icons represent the cyclic aspect of selected disease.

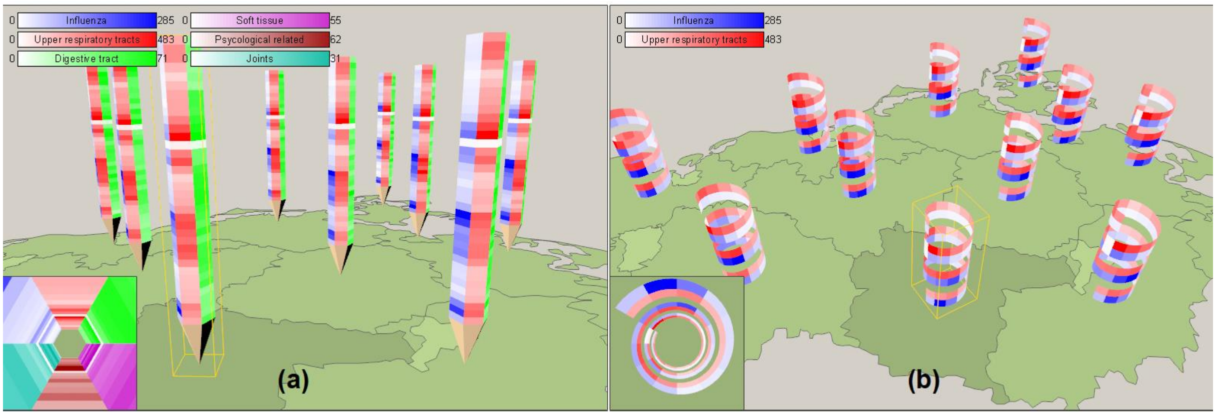

Figure 20 Visualizing monthly health data by means of 3D icons on a map: (a) Pencil icons representing cases of 6 diseases, some diseases show a certain pattern over time; (b) Helix icons clearly reveal the cyclic characteristic of 2 selected diseases. Additional "tunnel views" mitigate the problem of hidden information for a selected icon

As the article of Andrew Hanson of Indiana University Bloomington illustrates, time is an important attribute of data. The analysis of geo-spatial data can be sometimes complicated when the data involve a large number of individual time-varying data series that correspond to multiple variables.[27]

Therefore, a 3D visualization in form of space-time cube of the unemployment rate or number of the alcohol-related accidents in North Carolina is done in order to have a quick glance at data and to build a hypothesis around the subject (specially for analysts).

[26] Tominski, Christian & Schulze-Wollgast, P. & Schumann, H.. (2005). 3D information visualization for time dependent data on maps. 175- 181. 10.1109/IV.2005.3.
[27] Thakur, Sidharth & Hanson, Andrew. (2010). A 3D Visualization of Multiple Time Series on Maps. Proceedings of the International Conference on Information Visualisation. 10.1109/IV.2010.54.

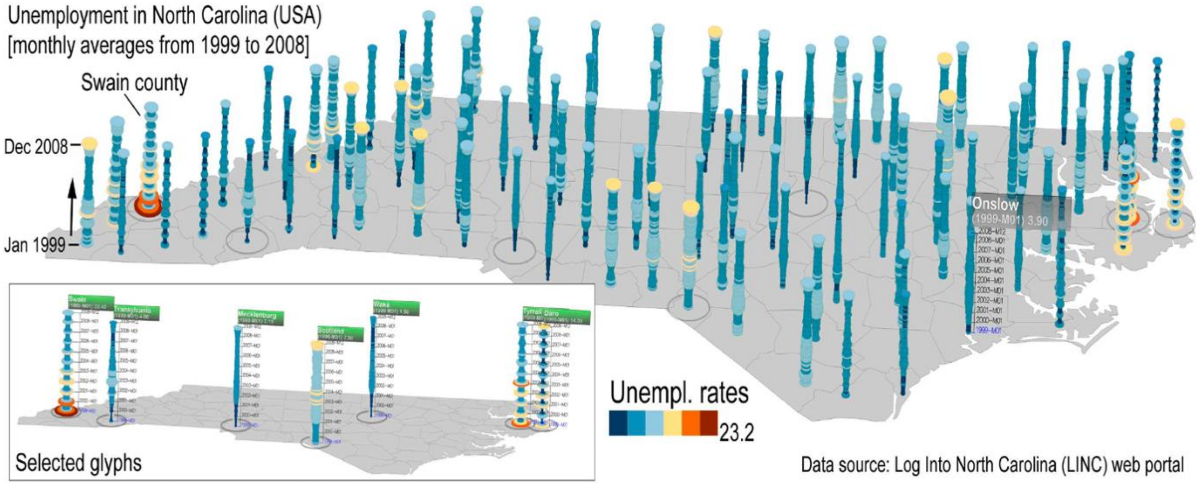

Figure 21 Unemployment rate in North Carolina, presented in 3D

Another use case of VR is designed by the California Institute of Technology in Pasadena and the University Federico II in Napoli where we have an immersive tool which turns astronomical data into a VR experience.[28]

They have created a Martian landscape in VR in order to train the planetary scientists or tele-robotic operators to walk around, to see the orientation of features and to calculate the relative distances between objects.

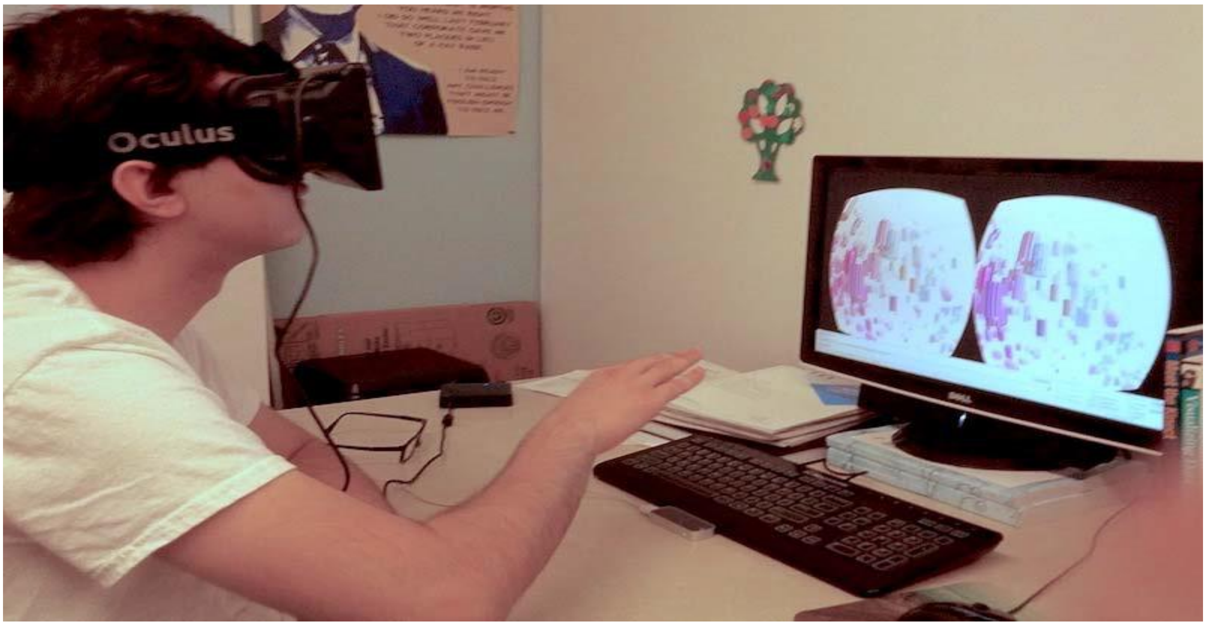

Figure 22 A student using the Oculus RiftTM VR goggles and navigating through the visualized data space using the hand motions and the Leap MotionTM sensor. The computer screen shows the stereoscopic image pair that is being displayed through the VR goggles

[28] C. Donalek *et al*., "Immersive and collaborative data visualization using virtual reality platforms," *2014 IEEE International Conference on Big Data (Big Data)*, 2014, pp. 609-614, doi: 10.1109/BigData.2014.7004282.

4.5 Strengths of VR:

4.5.1 Less effort:

As we have mentioned earlier the VR can give an interactive experience for users to use tools like brushing and linking techniques. VR can be used in visualization in the form of small multiples which are little charts with the same size in order to have an overview of data in one place. The small multiples compared to a normal desktop resolves the small screen problem because it doesn't need so much space.[29]

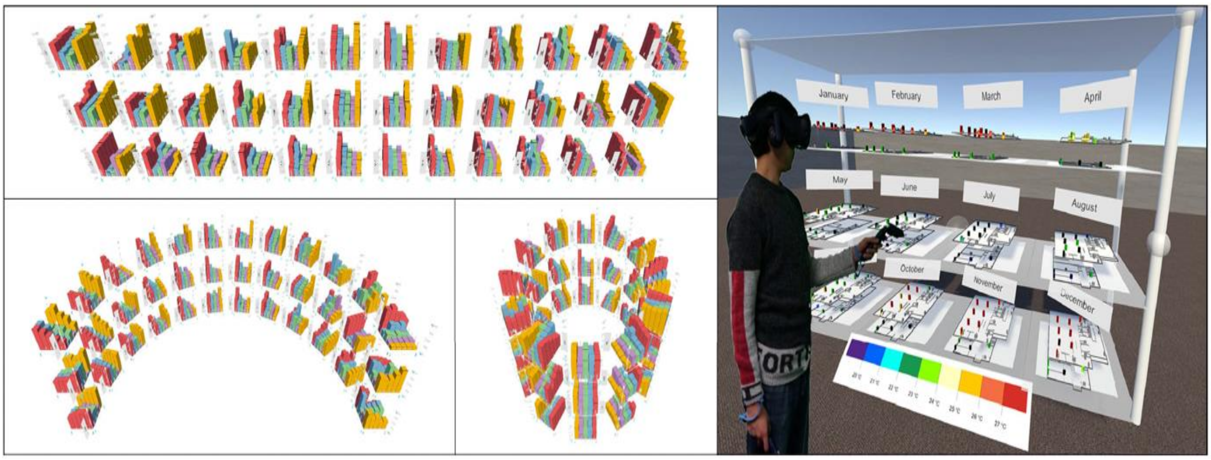

Figure 23 Left: different possibilities for layout curvature; right: small multiples presented in VR using a "shelves" metaphor.

The user tests have shown that most users prefer half circle layout because full circle layout is disorienting and the flat view is easy to use but it takes more space and users should walk to have an overview.

4.5.2 Data discovery:

2D visualization might not be suitable for displaying rich data at once. The absence of the third dimension and big screen might be the reason why 2D visualization is not suitable for rich data representation.

[29] Liu, Jiazhou & Prouzeau, Arnaud & Ens, Barrett & Dwyer, Tim. (2020). Design and Evaluation of Interactive Small Multiples Data Visualisation in Immersive Spaces. 588-597. 10.1109/VR46266.2020.1581122519414.

Depending on data type, some data are multi-dimensional and with 2D visualization the possibility to spread information in one place and one visualization is almost impossible unless using a line series 2D visualization.[30]

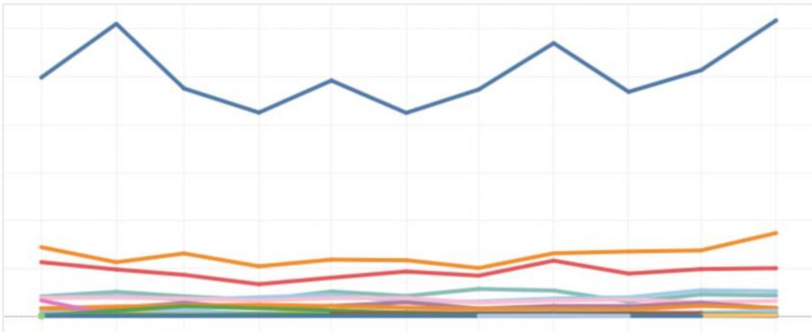

Figure 24 X-axis is time, Y-axis is sales volume and products are plotted by multiple line series

Virtual reality can give us the possibility to create multiple layers and options in order to select the type of data which is going to be analyzed. We can also display the data set in one place by just using VR.

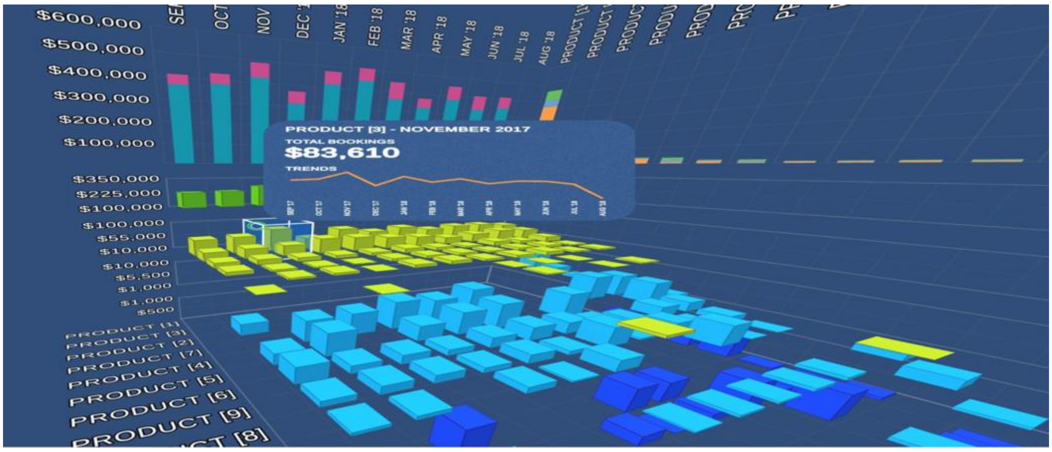

Figure 25 VR visualization of sales volume and products

4.6 Weaknesses:

4.6.1 Side Effects:

VR technology has its benefits, and it is used for many scientific purposes. Meanwhile, there are some side effects caused by VR headsets such as nausea, headache, dizziness and disorientation which we call motion-sickness.

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30 https://medium.com/telerik-ar-vr/

In this regard, researchers of Beijing Institute of Technology[31] and Beijing Film Academy[32] did a test on two groups of people in order to trace the visual fatigue caused by long-term immersion in the virtual environments and compare the differences between the virtual environments and the physical environments.[33]

One of the external factors is the light is totally avoided and the two tested groups were placed in closed environments where the only illuminations in the room were the lamps.

In this experiment 30 persons (male and female) participated and three persons left the experience because they were tired doing tedious tasks. Only 27 participants continued the tasks until the end. They were asked to perform these tasks during an 8-hour working day with, and without head mounted devices (HMD).

The result of subjective measures has shown that symptoms of eye strain, focus difficulty and nausea were not so much related to the environment but to working time. Some users had a headache during the experiments which might be due to long time wearing of HMD. The weight of HMD is not comparable to glasses which can be not so comfortable for users to wear it for a long period of time.

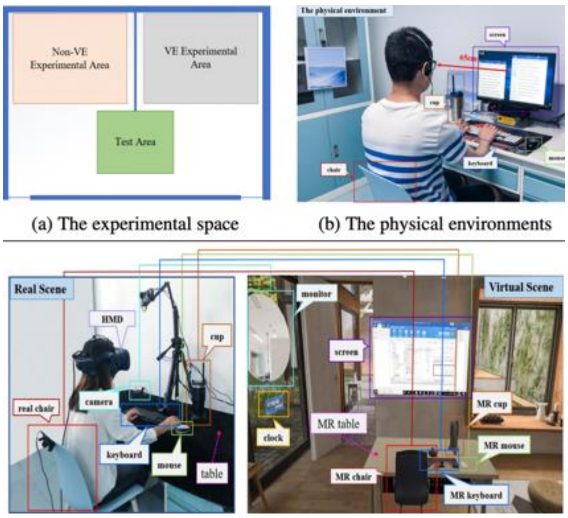

Figure 26 The experimental environments

[31] https://english.bit.edu.cn/
[32] https://eng.bfa.edu.cn/
[33] J. Guo et al., "Exploring the Differences of Visual Discomfort Caused by Long-term Immersion between Virtual Environments and Physical Environments," 2020 IEEE Conference on Virtual Reality and 3D User Interfaces (VR), 2020, pp. 443-452, doi: 10.1109/VR46266.2020.00065.

4.6.2 Perception: (3 graph-based data)

Another project in fields of data visualization in VR is done by Paul Sulyvan where he uses economic data of 40 years in a form of 3D graph-based visualization. In order to show the difference of perception of textual information in VR visualization and normal 2D line charts, he prepared a test on different users.[34]

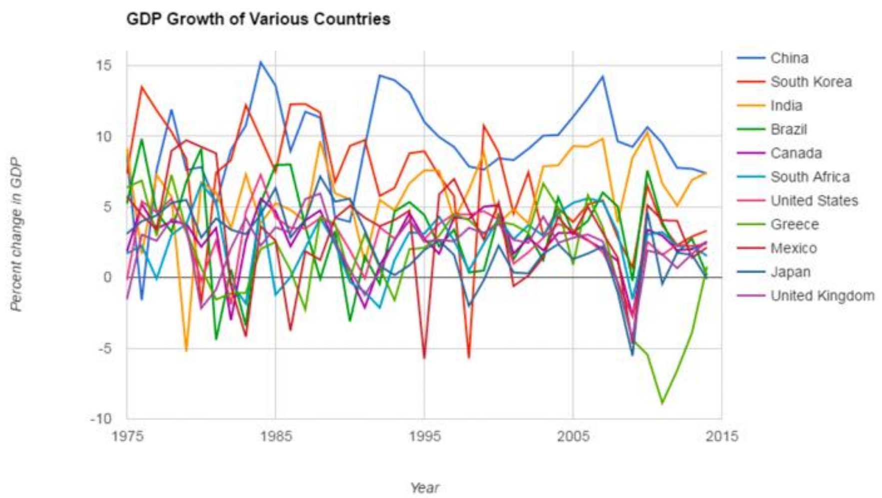

Figure 27 GDP growth of various countries

In this experience they asked multiple questions about countries in the world: e.g., GDP growth rate. Each user has his/her time to respond to the questions and the computer calculates the time of response and saves it automatically.

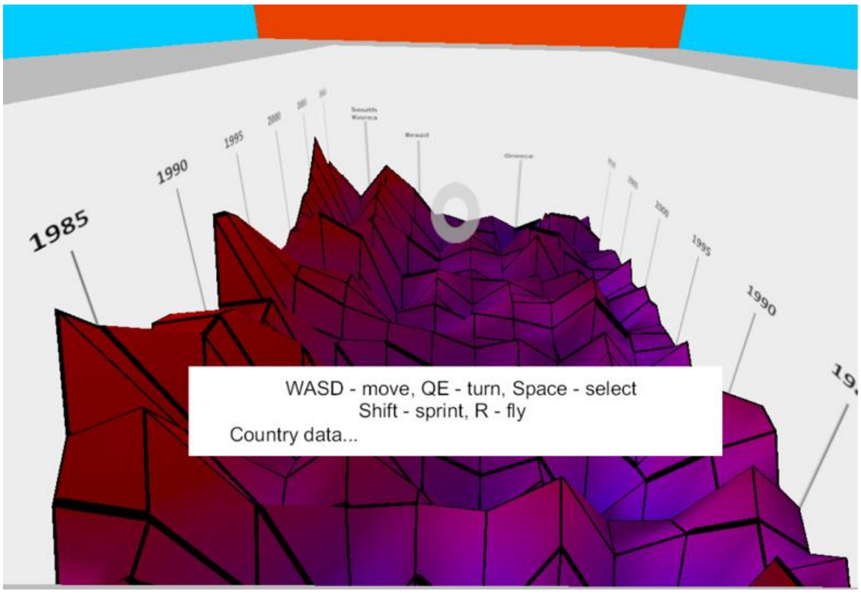

Figure 28 The VR environment

[34] Sullivan, Paul. (2016). Graph-Based Data Visualization in Virtual Reality: A Comparison of User Experiences.

The overall results were impressive. The graph group was far more accurate and faster whereas the VR group spent more time responding to the questions.

Moreover, the results were better when the user already had a gaming experience and they have been more successful than those who have never had a gaming experience.

Regarding the data visualization, in VR there are some inaccessible parts and some users had some difficulties to estimate the difference. For example, for best and worst countries in a field of interest it was hard to find out the lowest and the highest part and the cursor border is sometimes very difficult to distinguish.

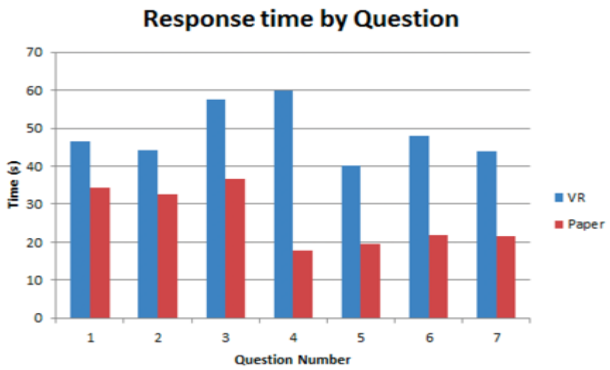

Figure 31 Response by time results

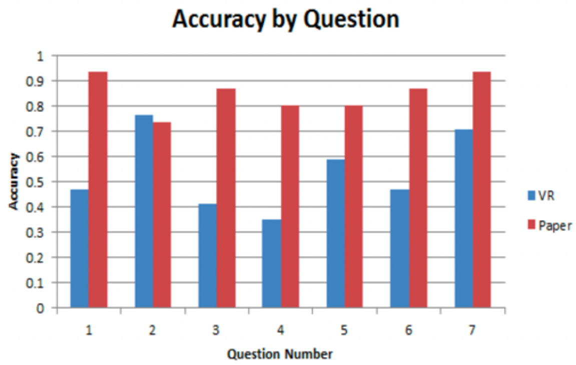

Figure 30 accuracy by question results

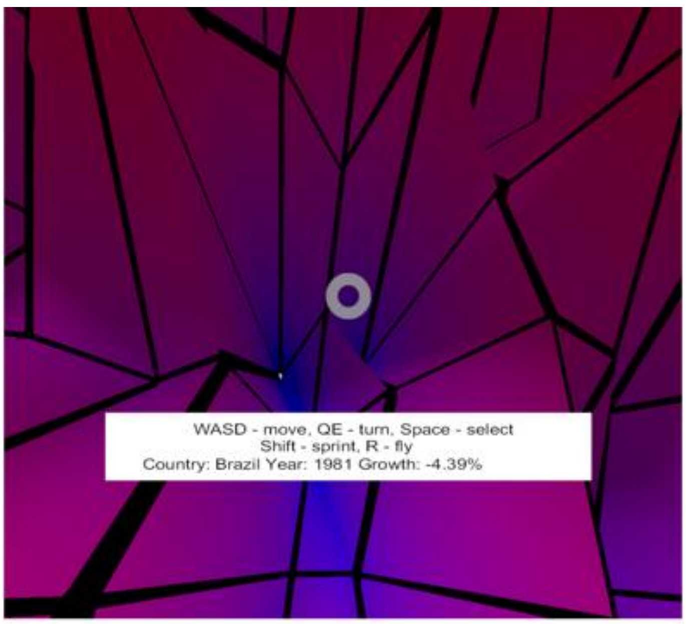

Figure 29 Cursor border

4.7 Discussion around our VR prototypes:

In this report we presented our project which was designed and developed during the 5 months of internship. It covers different historical data related to the history of Luxembourg and more specifically the history of the Belval region.

The main goal of this project is to demonstrate the pros and cons of using virtual reality and 3D contents in historical data visualization. In order to study this technology, we developed two use cases of virtual reality visualization, and we worked on the data visualization and perception of information.

The first case is a 3D representation of population per commune in Esch-Sur-Alzette Canton in Luxembourg. By using Mapbox tool, a map-based bar chart is put in place, and the bar charts take the form of each commune’s administrative border. At the end, the VR is put in place in order to have an immersive environment where the user is engaged with data.

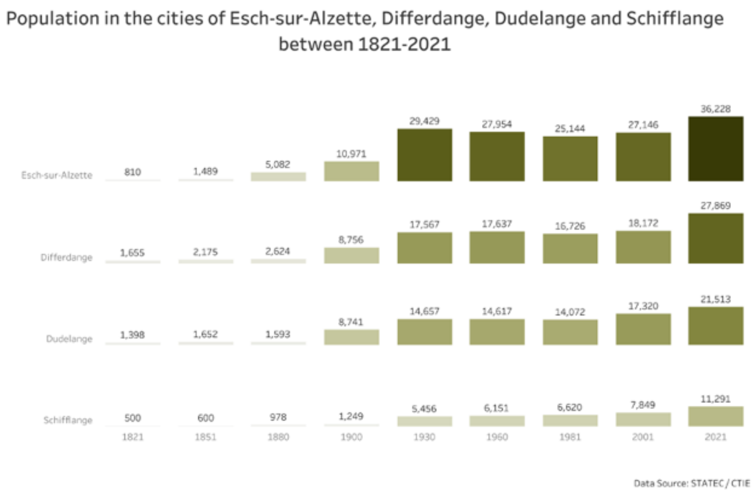

Figure 32 2D visualization of the population

Figure 33 3D visualization of the population

In the second case study, a virtual reality simulation of Rumelange mine in Luxembourg is designed where the user can see a typical place which is normally inaccessible for most of the people except miners and mining engineers. Secondly, it provides a tool to read dataset related to the mine. For example, a 2D visualization of the number of workers from 1881 to 1962 and the steel production (Figure 6) in tons from the same period is created which can be shown in the VR environment inside the mine.

Figure 34 VR environment of the mine

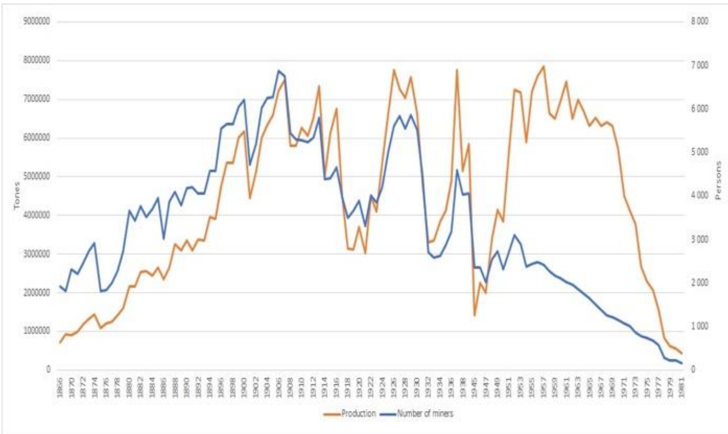

Figure 35

4.8 Thoughts:

After completing the two prototypes, it was time to question whether the use of VR was useful in our two use cases and if it facilitates the perception of information.

Regarding the first use case which is a VR map of south of Luxembourg we had the bar shapes representing each commune's population.

First of all, it seems that the bars' shape, their size and the gradient color can't really help the user to figure out the population difference between each commune. It is also difficult to see any differences in some periods of time when there was not so much difference in terms of population between cities of south of Luxembourg.

Therefore, the visualization can be misleading in some periods of time especially in the 19's and the first half of the 20's century.

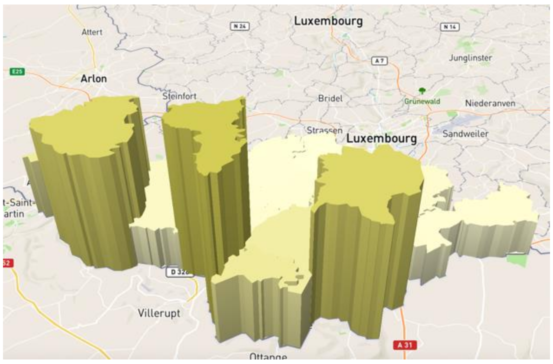

Figure 36 Population in 1900

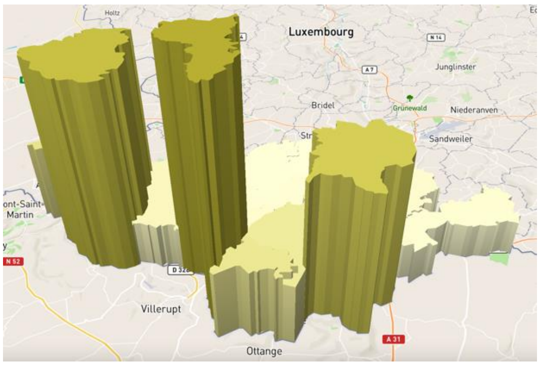

Figure 37 Population in 1910

As we see in figure 36 and 37, apart from three communes, the other parts of the Canton didn't have significant changes in our visualization. This can lead to misunderstandings of Luxembourgish history, and the user can think that there were no changes in population during 10 years in other parts of the Canton of Esch.

Secondly, the form of bar charts takes up so much space on the map, and it is impossible to see what is under these bar charts. For those who are not familiar with the region and its cities, it will be hard to understand the exact location of the cities, and the navigation will be complicated through the map. Therefore, the only visible cities are the bordering ones.

The second use case is the recreation of Rumelange mine in Luxembourg in VR which aims to embody the environment in a virtual way. A 2D visualization about the steel production and number of workers is planned to put in place inside the mine in order to increase public dissemination of a part of history which is normally not so common.

VR in the second case can help us to have a contextualized experience. With the help of mining sounds and wall handwritings of miners, certain kinds of feeling are transferred to the users.

This environment is a chance for those who are claustrophobic to enter a mine without having any issues. Even for those who are willing to enter to a mine, strict rules are put in place to avoid accidents.

In terms of visualization, the VR embodiment of the mine with the 2D visualization of statistical data is a good combination which can lead to an accurate and fast interpretation of information compared to the 3D bar chart visualization which demands more effort for the users.

4.9 Future work:

Our prototype was a good initial study on the adding value of data visualization using VR. Other forms of visualization such as AR or mixed reality can also be tested in order to demonstrate the effectiveness of each tool.

4.10 Improvements:

Some improvements can be developed in order to enhance the visualization for our two cases. Regarding the first use case which is the map of south of Luxembourg, the bar charts have the administrative borders shape which can be replaced by points of interest in order to reduce the density. Once each city has its own point of interest it will be possible for users to easily see a map without being interrupted by the full view visualization.

Another option is to implement an even-based approach where the user decides to see what he/she prefers. For this purpose, the user can choose further information by using the icons which are placed on the map for data representation. This method limits the amount of represented information, gives more space for data visualization and reduces the sense of being lost in the visualization.[35]

We can also put in place an animation which runs by a play button and gradually shows the population from 1821 to 2021.[36]

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[35] Tominski, Christian & Schulze-Wollgast, P. & Schumann, H.. (2005). 3D information visualization for time dependent data on maps. 175- 181. 10.1109/IV.2005.3.
[36] http://erikyan.com/police_interactions_resulting_in_death.html

Concerning the second use case of VR in our project we did a VR visit of Rumelange mine in Luxembourg. One of the most important improvements that can be done is to increase the quality of the 3D model. With the help of a high-end computer, we can create a 3D model which contains all the scanned points. The more our model is similar to the real experience, the more the experience will be closer to reality.

Another improvement is to integrate guided tours with voice over, oral-history recordings and putting mining and machine noises.

4.10.1 User test:

As we have already explained, due to lack of time, we couldn't perform a test to evaluate the user experience. User test avoids costly mistakes by receiving feedback about design, interface and usability. It can help to prevent visualization which draws the attention away. It can also help to find out the best visualization suitable for each set of information.

"The overall goal of usability testing is to identify and rectify usability deficiencies existing in computer-based and electronic equipment and their accompanying support materials prior to release."[37]

4.11 Suggestion for future works:

My first recommendation would be to choose the right development tool. Three.js and A-frame are the best choices for WebXR content. As we have worked with three.js, we have noticed that the documentation is quite good and lots of examples are given for inspiration. Moreover, the Three.js community is larger and more active than the Unity community which is mostly game development oriented and it doesn't normally touch visualization concerns. My personal opinion which is based on my experience during the internship is that the development with Three.js can go much faster but we can maybe use Unity for 3D modeling purposes and the Three.js for implementing the project.

[37] Lewis, James. (2006). Usability Testing. 10.1002/0470048204.ch49.

Regarding the data visualization with VR, it is recommended to study the data set before implementing a VR visualization because some types of information won't necessarily need the VR technology as other types of data are more appreciated and understood with the VR visualization.

As the VR technology is still not widely used in other fields except gaming, its potentials are not well known and not employed. There is the need to specify the adding value of VR technology and the value of VR can't be evaluated unless we do a prototype even if the visualization is not satisfying at the first sight.

Moreover, users need to be educated and trained for the oncoming interaction with this evolving technology. The visual literacy skill should be improved in order to have high performance while working with visualized objects.[38]

[38] Olshannikova, Ekaterina & Ometov, Aleksandr & Koucheryavy, Yevgeni & Olsson, Thomas. (2015). Visualizing Big Data with augmented and virtual reality: challenges and research agenda. Journal of Big Data. 2. 10.1186/s40537-015-0031-2.

5 Conclusion:

Virtual reality is a technology which is mostly used for gaming and entertainment purposes. However, with the decreasing prices of VR headsets, it is becoming more accessible and many scientists have already started developing scientific visualization.[39]

To conclude, I did 5 months of internship which was a part of my master's degree program at the C2DH in Luxembourg. During this internship, I have developed two prototypes for data visualization with virtual reality in the fields of digital history in order to evaluate the adding value of VR in data visualization for humanities.

I really appreciated my working experience in an international and multicultural environment in another European country and I learnt multiple aspects of the research work. During my internship I developed intrapersonal and technical skills, and I got to know for the first time how it looks like working for an institution which is working on digital humanities.

Moreover, I think that this internship helped me to evaluate my learnings during the Master's courses and to put them in practice. I found that I was lacking some skills which could have helped me to better perform my tasks. This experience helped me to concentrate myself on these skills and to extend my knowledge for future opportunities.

As I worked in a research infrastructure, the working environment gave me the desire to get involved in other similar projects for my professional life. The main things that I learnt after my internship at the C2DH are the importance of hard working, self-motivation and organization.

The prototyping and the evaluation of the results have helped me to answer the initial question which was "If VR can add complementary value in the visualization in the fields of digital humanities." We realized that it can be efficient for the embodiment of the physical environment and the engagement of the user with the dataset.
Finally, this internship has given me the motivation to pursue my professional career in the fields of digital humanities and especially in programming positions linked to data visualization.

[39] Steve Bryson,Virtual reality in scientific visualization,Computers & Graphics,Volume 17, Issue 6, 1993, Pages 679-685, ISSN 0097-8493

6 Appendices:

6.1 Figure 1

6.2 Figure 2


Entrée interdite aux
personnes non-autorisées
Site surveillé!

6.3 Figure 3

6.4 Figure 4

6.5 Figure 5


Scan_021
Cluster2
Scan_012
Scan_005
Scan_015
Scan_020
Scan_016
Scan_017
Scan_004
Scan_019
Scan_018
Scan_014
Scan_003
Scan_002
Scan_001

6.6 Figure 6

E. 302 Extraction de minerai de fer, ouvriers occupés et valeur de la production

Sources: Chambre de Commerce – Inspection du Travail et des Mines

Année	Production	Ouvriers occupés	Rendement annuel par ouvrier	Valeur de la production[1]
	t	Nombre moy.	t	Flux
1868	722 059	1 933	374	1 818 450
1869	924 382	1 824	507	3 048 730
1870	911 695	2 316	394	3 453 635
1871	990 499	2 203	450	3 373 237
1872	1 174 334	2 472	475	4 318 254
1873	1 331 743	2 732	487	4 820 977
1874	1 442 668	2 913	495	4 921 360
1875	1 090 845	1 810	603	3 794 484
1876	1 196 729	1 833	653	3 333 173
1877	1 262 825	2 009	629	3 766 747
1878	1 407 617	2 285	616	4 212 280
1879	1 613 392	2 732	591	4 439 019
1880	2 173 463	3 656	594	6 538 544
1881	2 161 881	3 433	630	...
1882	2 539 295	3 775	673	...
1883	2 551 090	3 510	727	...
1884	2 447 634	3 714	659	...
1885	2 648 449	3 945	671	...
1886	2 361 372	3 025	781	5 795 320
1887	2 649 710	3 868	685	6 675 005
1888	3 261 925	4 109	794	7 972 469
1889	3 102 753	3 798	817	7 686 813
1890	3 359 413	4 185	803	8 208 311
1891	3 102 478	4 203	738	7 550 478
1892	3 370 352	4 066	829	8 043 631
1893	3 351 938	4 054	827	7 797 848
1894	3 958 280	4 577	865	9 436 128
1895	3 913 076	4 587	853	9 590 443
1896	4 758 741	5 557	856	11 852 528
1897	5 349 009	5 662	945	13 980 550
1898	5 348 951	5 648	947	13 934 186
1899	6 014 394	6 043	995	16 237 500
1900	6 177 229	6 207	995	17 283 289
1901	4 455 179	4 714	945	11 770 046
1902	5 130 069	5 192	988	14 527 891
1903	6 010 012	6 023	998	15 278 923
1904	6 347 781	6 262	1 014	16 458 904
1905	6 595 860	6 278	1 051	16 514 630
1906	7 229 385	6 875	1 052	17 979 103
1907	7 492 870	6 762	1 108	21 997 404
1908	5 800 868	5 438	1 067	16 696 905
1909	5 793 875	5 302	1 093	15 850 966
1910	6 263 385	5 284	1 185	17 747 017
1911	6 059 797	5 250	1 154	18 647 326
1912	6 533 930	5 347	1 222	19 427 508
1913	7 333 372	5 807	1 263	21 965 818
1914	5 007 457	4 391	1 140	15 826 514
1915	6 139 434	4 408	1 393	19 485 064
1916	6 752 207	4 668	1 446	23 024 145
1917	4 501 950	3 970	1 134	17 833 214
1918	3 131 400	3 500	895	14 995 635
1919	3 112 472	3 660	850	25 366 646
1920	3 704 390	3 883	954	37 997 000
1921	3 031 626	3 304	918	26 461 773
1922	4 488 974	4 021	1 116	37 116 900
1923	4 097 549	3 852	1 064	39 308 000
1924	5 333 580	4 195	1 271	55 650 457
1925	6 673 192	5 027	1 327	79 189 989
1926	7 756 240	5 610	1 383	121 983 082
1927	7 266 249	5 850	1 242	134 090 223
1928	7 026 832	5 560	1 264	143 841 943
1929	7 571 206	5 858	1 292	162 161 842
1930	6 649 372	5 539	1 200	156 615 796
1931	4 764 926	4 435	1 074	109 926 843
1932	3 312 618	2 706	1 224	65 163 420
1933	3 362 417	2 587	1 300	61 639 559
1934	3 833 847	2 626	1 460	63 280 383
1935	4 133 808	2 867	1 442	71 193 000
1936	4 895 992	3 197	1 531	87 604 679
1937	7 766 254	4 593	1 691	150 693 328
1938	5 140 632	4 031	1 275	114 443 534
1939	5 852 538	4 053	1 444	146 313 450
1945	1 405 877	2 366	594	123 851 800
1946	2 246 908	2 367	949	222 292 855
1947	1 992 167	2 030	981	205 943 563
1948	3 399 274	2 537	1 340	335 841 320
1949	4 137 327	2 741	1 509	352 634 269
1950	3 845 096	2 318	1 659	321 767 098
1951	5 625 118	2 721	2 067	537 924 880
1952	7 244 865	3 111	2 329	633 270 332
1953	7 169 646	2 891	2 480	612 203 917
1954	5 887 068	2 388	2 465	482 445 223
1955	7 204 605	2 439	2 954	531 267 578
1956	7 593 926	2 487	3 053	557 470 108
1957	7 843 172	2 422	3 238	664 293 608
1958	6 637 998	2 284	2 906	586 634 391
1959	6 509 443	2 164	3 008	566 885 018
1960	6 977 304	2 101	3 321	569 556 685
1961	7 457 941	2 030	3 674	610 508 260
1962	6 507 176	1 963	3 315	...
1963	6 990 315	1 862	3 754	...
1964	6 679 677	1 762	3 791	...
1965	6 315 449	1 651	3 825	...
1966	6 527 614	1 504	4 340	...
1967	6 303 909	1 380	4 568	...
1968	6 398 458	1 260	5 078	...
1969	6 310 574	1 208	5 224	...
1970	5 722 459	1 151	4 972	...
1971	4 507 004	1 080	4 173	...
1972	4 116 181	1 007	4 088	...
1973	3 782 478	858	4 408	...
1974	2 686 464	788	3 409	...
1975	2 315 082	736	3 145	...
1976	2 078 655	680	3 057	...
1977	1 547 589	567	2 729	...
1978	834 905	282	2 961	...
1979	630 238	231	2 728	...
1980	560 165	226	2 479	...
1981	429 080	170	2 524	...
1982	–	–	–	–

[1] Les chiffres relatifs à la valeur de la production résultent de la vente du minerai de fer par les propriétaires privés à l'industrie sidérurgique. A partir de 1962, toutes les mines sont en possession de l'ARBED et de la MMRA qui utilisent le minerai pour leurs propres besoins; depuis lors il n'y a plus de données statistiques sur la valeur de la production.

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