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Creating Climate Awareness Through Data-Driven Graphic Design and Visualization

Dissertation in the context of the Master in Design and Multimedia, advised by Professor Evgheni Polisciuc and Professor Sérgio M. Rebelo and presented to the Department of Informatics Engineering of the Faculty of Sciences and Technology of the University of Coimbra.

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Abstract

Climate change is an urgent and complex problem that will require a global collaborative effort to solve. Nevertheless, not everyone still truly understands the gravity of the situation and even less understands its cause and consequences. Although some communication artefacts related to climate change are frequently noticeable in our everyday life, the typical ones are often too technical and visually oversaturated; consequently, they fail to effectively grab the attention of the viewer. There is, so, a need for mass communication artefacts that promote the creation of climate awareness. Information Design may have a key role in the design of these artefacts. Furthermore, we believe that Data Aesthetics may create a connection to the Arts that will provoke a more humane and emotional reaction to the data presented. We also believe that aesthetics interplayed with well-known strategies of communication design will create a stronger attachment of the general audience, who do not have the scientific background to fully understand climate change problems.

In this dissertation, we argue that a solution to inform (and consequently, fight) climate change can be an awareness campaign based on climate data used to create aesthetically appealing data artefacts. We start by developing a system which receives data from the causes or the consequences of climate change on a selected country and year and returns a data artefact. To do this we also had to previously do extensive data research and processing. Afterwards, we implemented this system into a web platform which allows its users to analyze and explore the data artefacts and the work in general. Finally, we explored the application of the data artefact and the web platform into an awareness campaign, specifically the creation of dissemination material and its insertion and physical and digital contexts.

Keywords

Climate change, Information design, Generative design, Dynamic visual identities, Information visualization

Resumo

As alterações climáticas são um problema urgente e complexo que irá exigir um esforço global de colaboração para a sua resolução. No entanto, nem todos compreendem verdadeiramente a gravidade da situação e ainda menos as suas causas e consequências. Embora alguns artefactos de comunicação relacionados com as alterações climáticas sejam frequentemente vistos no dia-a-dia, são frequentemente demasiado técnicos e visualmente saturados; consequentemente, não conseguem captar eficazmente a atenção do visualizador. Existe, portanto, uma necessidade de artefactos de comunicação em massa que promovam a criação de consciência climática. O Design da Informação pode ter um papel fundamental no design destes artefactos. Além disso, vamos concentrar-nos na Estética de Dados, na crença de que a ligação artística provoca uma reacção mais humana e emocional aos dados apresentados, criando uma ligação mais forte do que os dados sobre as alterações climáticas tipicamente criariam ao público em geral, que não tem a base científica necessária para os compreender plenamente.

Nesta dissertação, argumentamos que uma solução para informar (e consequentemente, combater) as alterações climáticas pode passar por uma campanha de consciencialização baseada em dados climáticos utilizados para criar artefactos de dados esteticamente apelativos. Começamos por desenvolver um sistema que recebe dados das causas ou das consequências das alterações climáticas de um certo país eano e devolve um artefacto de dados. Para o fazer, tivemos também de fazer previamente uma pesquisa e processamento extensivo dos dados. Posteriormente, implementámos este sistema numa plataforma *web* que permite aos seus utilizadores analisar e explorar os artefactos de dados e o trabalho em geral. Finalmente, explorámos a aplicação do artefacto de dados e da plataforma *web* numa campanha de consciencialização, especificamente focada na criação de material de disseminação e a sua inserção em contextos físicos e digitais.

Palavras-chave

Alterações climáticas, Design de informação, Design generativo, Identidades visuais dinâmicas, Visualização de informação

Em meados de Março de 2021, uma onda de incerteza caiu sobre mim, levando-me a questionar o meu percurso académico e de associativista. Numa breve chamada, o Cesário restaurou toda a confiança que eu tinha em mim mesmo, assegurando-me que tinha todas as capacidades para realizar com sucesso esta dissertação e simultaneamente alcançar os outro objetivos que tinha estabelecido comigo mesmo.

Um ano depois, em Março de 2022, a cerca de metade da realização desta dissertação, o Cesário faleceu num acidente, e tive que aceitar que ele nunca iria chegar a ver o fruto da motivação que me deu.

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And finally, I want to express my deepest gratitude for my family, my father Miguel, my mother Cecília and my sister Teresa for making me the person I am today — I can only hope I took full advantage of all the oportunities you gave me.

Acronyms

HCI: Human-Computer Interaction

IPCC: Intergovernmental Panel on Climate Change

GUI: Graphical User Interface

HTML: HyperText Markup Language

CSS: Cascading Style Sheets

CO2: Carbon Dioxide

VI: Visual Identity

DVI: Dynamic Visual Identity

NOAA: National Oceanic and Atmospheric Administration

API: Application Programming Interface

OWID: Our World In Data

WBOD: World Bank Open Data

CCKP: Climate Change Knowledge Portal

RLI: Red List Index

GDP: Gross Domestic Product

CSV: Comma Separated Values

JSON: JavaScript Object Notation

HTTP: Hypertext Transfer Protocol

URL: Uniform Resource Locator

MUPI: Mobilier Urbain Pour l'information

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1. Introduction

Graphic design, in its widest meaning, refers to the deliberate organising of text and/or images to transmit a certain message (Bailey, 2008). The phrase refers to both the method (a verb: to design) through which communication is created and the output of that process (a noun: a design). It is used to inform, market, or adorn, and it usually combines all of these tasks. The more the aesthetic and sensory flexibility involved or permitted, the closer graphic design veers toward art or poetics; the lesser, the closer to science or functionality (Bailey, 2008). A major design challenge that individuals face is how to make communication feasible that was previously difficult, unattainable, or unimaginable.

When there is an intervention into a current activity through the development of techniques, technologies, and processes that try to redesign interaction and so influence the possibilities for communication, this is referred to as communication design (Aakhus, 2007). The link between interaction and communication is a crucial challenge for design, just as it is for communication theory. Communication design emerged as a result of newly popularised media ideas connected with academics such as Marshall McLuhan and Quentin Fiore. In many ways, the word was more aspirational than factual, reflecting the optimism with which graphic-design approaches were being deployed on wider sizes. On the one hand, advertising became more systematic in its goal of projecting unified identities and ideas across nations using all available media; on the other hand, efforts to project institutional identities onto and into quasi-public spaces (for example, theme parks and events such as the Olympics or the World Fair) provided compelling examples of intuitive and accessible internationalism (Byfield, 2008).

Communication design can be an essential factor in the resolution of Wicked Problems. Wicked Problems are defined by a problem which defies any attempt to solve it, because it is a symptom or effect of various, contingent, and competing difficulties. Wicked problems, due to their complexity, necessitate the work of collaborative teams of people with a diverse variety of experiences across location and time. A method intended to handle a difficult problem often does not have a definite answer and can only produce incremental improvements to the situation. In this context, the design process's trans-disciplinary properties may and are employed to enable and facilitate a variety of disciplinary and professional specialists (including designers) to collaborate on the wicked problem with the appropriate audience (Marshall, 2008). Climate change matches with a lot of the criteria defined for a Wicked Problem, and as such, necessitates design solutions that aim to tackle it collaboratively as a society, such as, for example, the transmission of information.

In the modern world, information is more and more often gathered from data that is generated in high volumes every minute. The significance of design in establishing methods to enhance the autonomy of information systems while dealing with super-complex datasets is becoming increasingly important. The idea is to accommodate various styles and forms of information. Design's roles have been expanded beyond providing form to establishing meaning as a result of this process.

Because information is not composed of matter or energy, it cannot be designed directly. It must be converted into something apparent and real, as evidenced by terms like "information architecture," "information flow," and "information landscape" (Stephan, 2008). When applied to information, design functions as a catalyst for the creation of visual artefacts (mostly media-related items) that increase the likelihood of the receiver processing information in the desired and suitable manner (Stephan, 2008). Although information design often involves the visualization of data through visual or interactive means, classifying it as a subsection of graphic or communication design would be erroneous. Information design is a distinct subject that encompasses a multidisciplinary and intermedial range of activities that integrate scientific and design methodologies in novel ways. In the analysis and planning phases, for example, information designers will employ research methodologies derived from the social and applied sciences (specifically cognitive psychology, ergonomics, and environmental psychology), as well as practises such as scientific illustration, communication design, interface design, and graphic design (Diefenthaler, 2008). This subject of design, then, presents itself as a powerful tool to communicate messages that stem from a large quantity of data, clearly. With the spread of 'big data,' individuals are increasingly engaging in new social activities anchored in technology and data, which is referred to as data activism. Data activism strives to take advantage of the possibilities for civic engagement, advocacy, and campaigning that big data offers. It arises from existing activist subcultures such as the hacker and open-source movements, but overcomes their elitist nature to include regular people. It affects both persons and groups and functions at several geographical levels, ranging from local to international ('DATACTIVE', n.d.).

Information design can be particurlay difficult to practise without the use of the technology we have avaiable today. However, design in general is no longer a practice dependent on analogical and archaic tools. Since the invention of modern computers and displays, the tools used to create graphic designs have increased exponentially both in quantity and complexity. There is, therefore, an increasingly enormous potential in the use of computer and programming tools in the future of essentially every strand of design. In today's commercial scenarios, high-tech procedures and technologies are highly desired since they assist a product stand out in the eyes of consumers. High-tech items also represent some of the most exciting and radical design advances, shaping future vision and pushing the boundaries of traditional design expression. As a result, technological breakthroughs are frequently used as a jumping-off point for designers attempting to improve the quality of daily living today (Bibi, 2008).

The vision we hold in the developed project is that there is space for the discussion of computer-generated visuals as the future of design in the communication realm, mainly through the use of information design to transmit information, and further knowledge. The objective of this dissertation is to develop a solution representing this belief, through the creation of a climate awareness campaign that uses clearly defined and understandable data-driven visual elements to convey the message we want to transmit.

1.1 Motivation

Since the beginning of the 21st century there has been an exponential increase of the readiness that information is transmitted globally, largely thanks to the ubiquity of technology in our everyday lives. This readiness can easily be exploited for good causes, such as raising awareness for important issues that affect society globally.

Global warming and climate change have been noted as some of the most urgent problems on a global scale, raising a discussion about the future of our society as well as planet Earth and its ecosystems. Although this situation has been heavily disseminated in contemporary means of communication and in the social/political agendas of different institutions and governments around the world, the common citizen often can not clearly perceive how the problem is progressing and what actions can be done to decrease our environmental impact. In that sense, it is increasingly more important to develop means and tools that allow finding new ways of maximising the reach and impact of the communication of this situation and simultaneously inform and raise awareness about it.

There is a place for art-based projects in the climate change awareness/discussion paradigm. Cucuzzella *et al.*, in the paper *Eco-didacticism in art and architecture: Design as means for raising awareness* (2020) make a case for the exploration of the way "eco-messages" are delivered, between "eco-didacticism" and "eco-dialecticism". The first one stems from a message based on consensus and agreement, being considered a "one-sided conversation" and thus simply providing clear and easily readable information to the public. The second one is based on dissensus and thus is not limited to a one-sided conversation, requiring the participant to consider the ideas communicated through the work and make conceptual adjustments through iterations of reinterpretations. The dialectic eco-art piece, as an agent of change, not only actively communicates by asking the participant to construct an interpretation of what may be read, as in "political art," but also needs the spectator to offer a conceptual reaction via what they know and believe. There is, as such, an increased potential in the development of an "eco-dialect" artwork.

Our literature review revealed that climate change is often approached with scientific visualization, which requires specific knowledge to read and understand. However, there is a lack of work done to educate the general audience. We also concluded that data-driven designs are a powerful tool to transmit information and can be regarded as the future of communication design. The main motivation for this dissertation is, then, to create a data-based work that goes beyond simply informing the current state of climate change and its causes, favoring the delivery of the message even if it sacrifices some accuracy and precision of data representation. We aim to inform about effective solutions on a personal and global scale, while simultaneously developing a proof-of-concept for a data aesthetic artefact supported by data-driven visuals.

1.2 Scope

In the paper "*Interaction for crisis: a review of HCI and Design projects on climate change and how they engage with the general public*", Ferreira *et al.* (2021) provide an overview of Human-Computer Interaction (HCI) and Design solutions from the past decade (2010–2020) that tackle climate change communication, analysing some conceptual and practical choices, with the intent to understand how these fields are treating the topic, aligned with the latest recommendations regarding climate change communication, and discuss possible improvements and suggestions for future work.

A total of 74 projects were selected and analyzed based on the following criteria: (I) the research topic (climate change); (II) the target audience (a general public outside academia); (III) solutions that have an interaction component either through an artefact or in-person exchange. After the selection, the works were categorised based on the following factors: *Target audience*; *Context*; *Media used*; *Message scope*; *Framing*; *Presentation*; and *Presence of solutions*. To facilitate the analysis, we visualized the works and the research papers that share common topics with a *Sankey* diagram (Figure 1.2.1). We depicted each category of topics on a vertical axis and connected each topic with a curve, the width of which encodes the number of items that share these topics. The end of the process revealed many findings.

Analysing the topics found, it became clear that these followed trends based on social issues. The authors then claim that it's critical to stay on top of cultural, sociological, and technological advances since they all have an impact on the field's evolution. Designers tend to 'ride the current wave' rather than 'sit on the old', looking ahead to bring fresh ideas to the foreground. The solutions also focused on climate change as a global issue or on personal behaviour and local issues. Most of them present the facts and examples as the message itself and expect the user to show interest in the data and search for practical actions themselves while lacking suggestions for future action. Of the twenty-one projects that did present further steps, **seven had a neutral framing**, **nine a positive framing**, and **five a negative framing**. Of the fifty-three projects that did not, forty-three had a neutral framing. This finding suggests that the clear presentation of actionable steps goes hand-in-hand with framing the **interaction**.

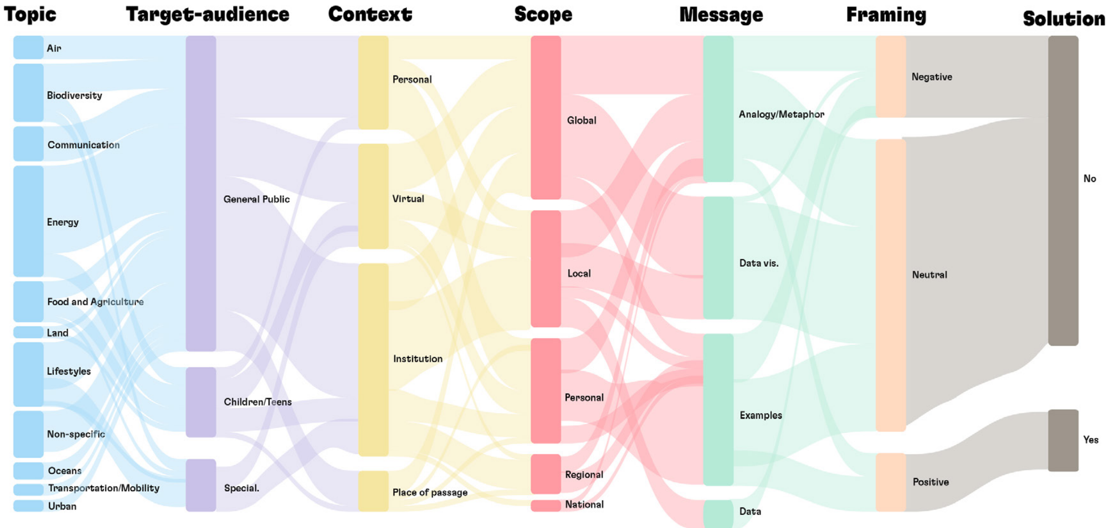


Figure 1.2.1

A sankey diagram categorizing the 74 projects collected by their attributtes.

These findings led the authors into proposing five design requirements for future applied research in HCI and Design on climate change that the solution developed attempted to follow closely:

1. Choose topics based on impact and audience; there is the opportunity for future research in these less developed themes precisely because they can be less obvious to most users and communities and have the potential for significant impact. These alternative paths of exploration can also align with the proposed "positive" framing of the message focused on the better user, community and social engagement.
2. Explore interactive engagement in daily routine places; considering only two media public installation projects in the place of passage context came up in the corpus, the authors see an opportunity for future research on climate change interactions to use public spaces like streets, public transportation, stations, shops, for example, where casual audiences are.
3. Help the users take action by proposing actionable steps; The great majority of projects analyzed explore ways of presenting the facts, a crucial step in climate change interaction, but leave it to the user to continue their journey if they are interested enough. With the multitude of information associated

with this complex issue, the authors see the need for a more detailed presentation of actionable steps.

4. Positively frame the message with a narrative adapted to the audience; The authors point to the Intergovernmental Panel on Climate Change's (IPCC) recommendations (Corner, Shaw, & Clarke, 2018) : a) focus on the real world, not abstract ideas, to frame the message in a relatable way; b) be compelling by using stories more than statistics or graphs; c) connect with what matters to your audience — consider values and political views; d) include solutions on your narrative so the audience feels empowered instead of overwhelmed (Chapman, Corner, Webster, & Markowitz, 2016).
5. Explore alternative and more inclusive perspectives; From the results attained, the authors see the opportunity for design research to explore these theoretical perspectives in applied projects. There is prolific debate around approaches focusing on system change, nature-culture, nature-based, more-than-human, decolonising design, futuring, sustainment, among others, but the needed step now is to apply these concepts to design practice (Liu, Bardzell, & Bardzell, 2019; Smith, Bardzell, & Bardzell, 2017) and engage the public with them.

In our dissertation, we considered these conclusions as a guiding framework for the development of the presented work. We chose topics that had an impact amongst the general audience, and presented them in a way that the audience would be able to construct a narrative that mattered. We also constructed the campaign so it would relate with its physical locations.

1.3 Goals and Implications

The primary goal of the dissertation is to develop a campaign to raise awareness about climate change. This objective was reached, essentially, through the means of information design. In particular, we used climate data to generate data-driven artefacts that aim to attract the attention of the viewer. Contrary to the traditional approaches where the information is delivered via scientific visualizations, we make the case for the use of data-driven generative design techniques for a data aesthetics alternative. We explored and exploited aesthetics as a more suitable channel for its purpose of speaking to the general audience and not only the scientific community.

As such, the solution had two main goals: (1) the development of an engine that uses climate data to generate a data artefact that is visually aesthetic, from a graphic and communication design standpoint; (II) the use of the created data artefacts to create an awareness campaign for climate change.

The secondary goals that result from the previous main goals are: (I) the insertion of the engine into a web platform in which the user can explore and interact with (for example, altering factors such as the location in space and time); (II) the application of the awareness campaign into dissemination materials, both physical and digital, so that the generated visuals can reach the final audience in an easier as well as more direct and natural form.

One of the most critical implications is the collection and treatment of data. Initially, we established two possible scenarios for the data used in this work: accurate climate data, that just by itself will necessitate treatment and interpretation in order to understand how it represents climate change; or data that by itself is already a representation of climate change. Research into both possibilities led us to create a mix of both scenarios, by choosing to analyze the **causes** and **consequences** of climate change, both **direct** and **indirect**. The indirect causes and consequences (*e.g.*, deforestation and poverty, respectively) are the most essential in the scope of the solution, as these represent what the general audience relate to the most, thus creating an emotional connection. The dataset was constructed so that the causes and consequences could be explored by year and country, which allowed the individual to both analyze the data locally and create a chronological narrative. All these factors are essential in making climate change data accessible to the general audience, as explained further in the Literature review section.

As previously stated, the solution aims to reach its final target audience in two ways: (I) through a web platform that allows direct interaction between the user and the data-driven visual, and a deeper exploration of the work; (II) through a campaign, with the objective of disseminating graphic material, both digitally and physically. The data aesthetics engine that was previously mentioned was developed using web technologies and as such was easily developed into a web platform with a graphical user interface (GUI). The platform uses web technologies (HTML, CSS and Javascript), specifically D3.js[1], and Regl.js[2]. In it we can view the generated data-driven artefact and interact with it manipulating its parameters, and analyzing the encoded data behind it. The campaign serves both as a way of disseminating climate change issues to the audience in a broader way, as well as generating interest in the platform so that the audience can reach it and consequently explore the work more deeply.

[1] **D3.js**
https://d3js.org

[2] **Regl.js**
http://regl.party

1.4 Document Overview

This document is structured in six chapters: (I) Introduction, (II) Work plan and Methodology, (III) The current climate change problem, (IV) Literature review, (V) Preliminary Work, (VI) Approach, (VII) Discussion & Future Work, and (VIII) Conclusion. In this first chapter (Introduction) we begin by contextualising the proposed dissertation by defining some of the essential aspects of design that the project relies on, explaining what motivated its development, in what scope it fits in, and finally, its goals and respective implications. The second chapter (Work Plan and Methodology) lays out the different tasks necessary for the conclusion of the project, including a brief description and timeframe of each one, while also presenting the design model that will guide the development. In the third chapter (The Current Climate Change Problem) we briefly address the main issue that the project focuses on, including its definitions, causes and consequences, as well as possible solutions. In the fourth chapter (Literature Review) we summarise the research that was done in this first phase of the dissertation, including the exploration of dynamic visual identities, information design (and, critically, approaching data aesthetics), and the use of these design approaches to climate and climate change data. This chapter also includes an exploration of related work that contributed to and influenced the development of our solution. The fifth chapter (Preliminary work) explains the brief work that was put into the pre-development of the project, mainly into researching datasets and technologies. The sixth chapter comprises the entirety of the development of the dissertation's solution, from its data work, the design conceptualization, the materialization of the data artefact and the development of the web platform and campaign that would comprise it. Finally, in the seventh chapter, we discuss and analyze critically the solution created, and, in the eighth chapter, we round up the dissertation by defining its conclusion.

2. Work plan and Methodology

This section presents the Work Plan that was defined for the development of the solution and the dissertation, and the methodology that was chosen to guide it.

2.1 Identification of tasks

A plan for the work's development was outlined, with different tasks in mind and different predicted/planned durations. This section covers a short description of each task and its implications, followed by Gantt chart with a prediction of the timeline (seen in Figure 2.1.1) and a Gantt chart that represents the real timeline (seen in Figure 2.1.2).

Writing the Dissertation
This task covers the process of writing and creating the document that resulted in the finished dissertation, including the pre-development work (such as the Literature Review and the work plan), and later the documentation documentation of the materialised solution's evolution. This task results in direct consequences of mainly the Research and Work development tasks.

Research
Researching and collecting information about a myriad of topics referring to different components of the project, from climate change information to the current state of data-driven design, resulting in the finished Literature review chapter of the dissertation.

Preliminary work
In this phase, we did some pre-development of the data, essentially by exploring the different ways we can approach the data and the technologies used.

Data work
Because climate and climate change data can be a matter of great complexity, there is a necessity for a specific span of time dedicated only to collecting datasets, studying them and defining the ways they can be aggregated and used in the information design context. This task also comprises the collection and processing of the datasets used to create the artefacts.

Conceptualization
In this task, the work was pre-developed from the design standpoint, including early drawings of visual elements and mockups that formed a draft of what would become the data artefact.

Work development
The development of the solution was divided into three different phases that cover its three essential foundations.

I. Data aesthetics engine development
This part covers the development of the engine that will process the climate data and transform it into visual elements. This comprises further adapting the data to be used by the artefact idealized, and developing a system which reads the data and processes it to render a data aesthetics artefact that matches the goals and criteria previously established.
II. Web platform development
This task comprises the development of the platform where it is possible to interact with the data artefacts and to better understand the work and the data behind their creation.
III. Campaign creation
In this part, we created the campaign behind the platform and the data artefact, which mainly consisted of the creation of dissemination material, both physical and digital.

Dissemination
This last task has the purpose of exposing and sharing the finished work with its intended audience. This includes deploying the web platform to a public domain and sharing it on social media, printing physical material, and creating a social media account. Additionally, due to the experimental nature of the solution, we also intend to publish an article in a conference, with potential targets being: SIGGRAPH Art Gallery, IEEEE VIS Art programa, and ACM Multimedia.

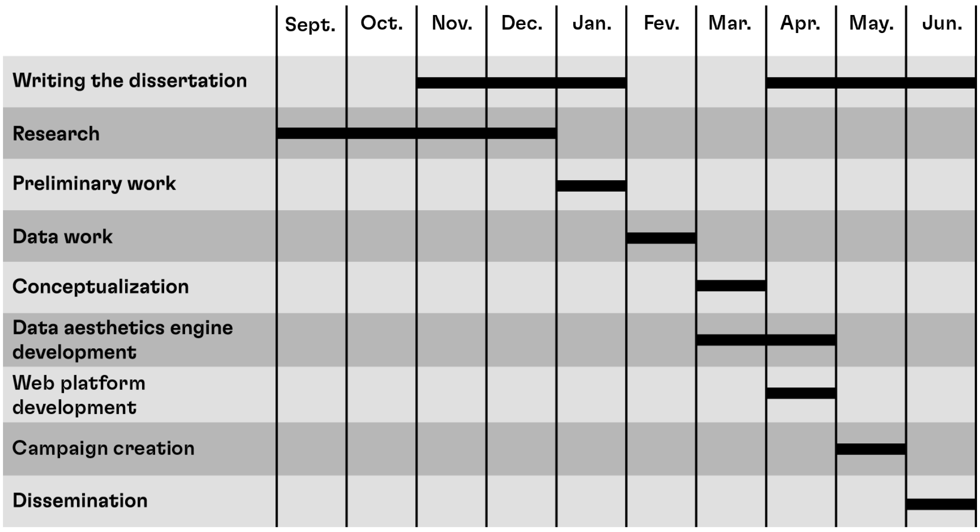


Figure 2.1.1

The different tasks and their predicted timeframes visualised in a Gantt chart.

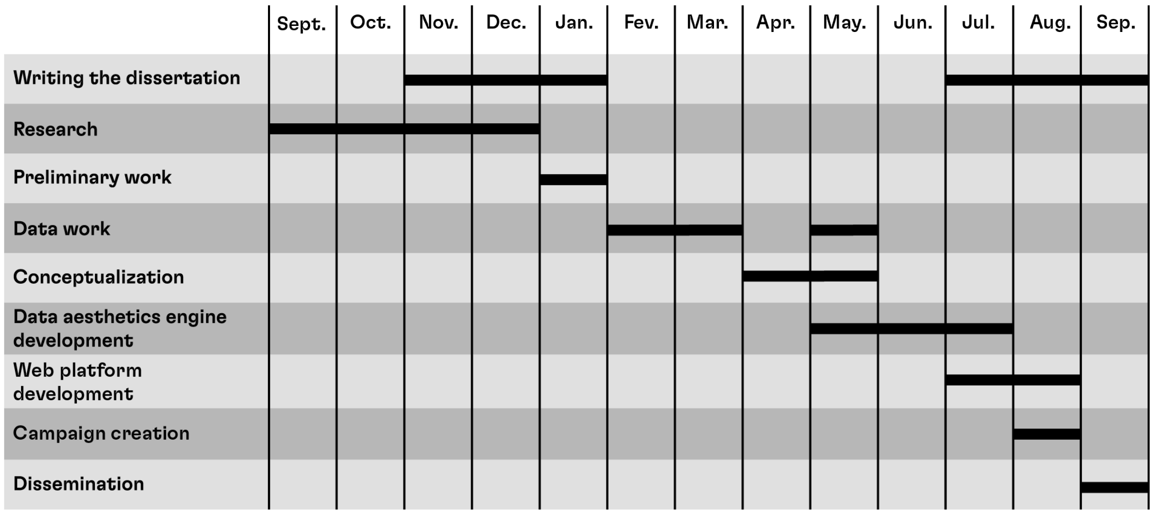


Figure 2.1.2

The different tasks and their real timeframes visualised in a Gantt chart.

2.2 Methodology

The development of the solution followed Nigel Cross' "*Four stage design process*" (Cross, 2021). This model, like most design research process models, aims to find a solution to a certain problem. The first phase is the "Exploration" of the problem and its context, with the objective of making it as clear as possible. After this phase, the process enters a loop between the "Generation" of a concept by the designer and the "Evaluation" of its proposal against the goals, constraints and criteria of the initial objective. When the designer decides the design proposal has reached its maximum potential he can terminate the loop and advance to the final phase, the "Communication" of the design.

This model, which visual explanation can be found in Figure 2.2.1, was chosen for its simplicity and effectiveness, as it is a simple descriptive process and it is based on the essential activities that the designer performs.

Applying the chosen model to our intended work plan, the Exploration phase covered the Research, Preliminary Work, Data Work and Conceptualization tasks. In the Generation and Evaluation loop comprised the Project Development tasks. In the context of this dissertation, the work was empirically evaluated based on our domain knowledge and experience. Finally, the Communication phase comprised of the Dissemination task.

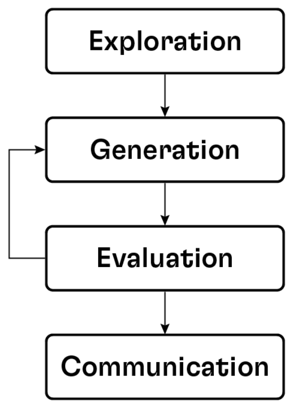


Figure 2.2.1

A diagram of Cross' design model.

3. The current climate change problem

Before the discussion for a design solution addressing climate change, there is a need to address climate change itself, including its definition, its causes and consequences, and what work can be done to solve it.

"Climate" is the usual weather conditions in a particular place or region (Merriam-Webster, *n.d.-a*). Climate change refers to a significant and long-lasting change in the Earth's climate and weather patterns (Merriam-Webster, *n.d.-b*).

The rapid climate change we are now experiencing is caused by humans' (excessive) use of oil, gas and coal for their homes, factories and transport. When these fossil fuels burn, they release greenhouse gases — mostly carbon dioxide (CO2). These gases trap the Sun's heat and cause the planet's temperature to rise (BBC News, 2021; Gómez, 2019). The world is now about 1.2° C warmer than it was in the 19th Century — and the amount of CO2 in the atmosphere has risen by 50% (Betts, 2021). Other main causes of climate change are found in deforestation, as living trees absorb and store carbon dioxide, and the increasingly intensive agriculture, which is responsible for the emission of greenhouse gases like methane and nitrous oxide (WWF New Zealand, n.d.).

This increase in the climate's average temperature, as seen happening in Figure 3.1, can bring disastrous consequences. Farmland will turn into desert, making some regions uninhabitable. In other regions, extreme rainfall will cause historical floodings (BBC News, 2021). The oceans are also under threat — The Great Barrier Reef, for example, has already lost half of its corals since 1995 due to the warmer seas driven by climate change (BBC News, 2020b). Wildfires are becoming more frequent. Wild animals will also find it harder to find the food and water they need to survive. Scientists believe at least 550 species could be lost this century if action is not taken (BBC News, 2020a).

In October 2018 the Intergovernmental Panel on Climate Change published the "Special Report on Global Warming of 1.5°C", which urged that the global average temperature increase be limited to a target of 1.5°C, as it is a possible target that would require severe emissions reductions and unprecedented changes in all aspects of society. The 1.5 °C target was established as when compared to a 2°C increase proved to cause a significantly less severe impact on the earth's ecosystem (IPCC, 2018).

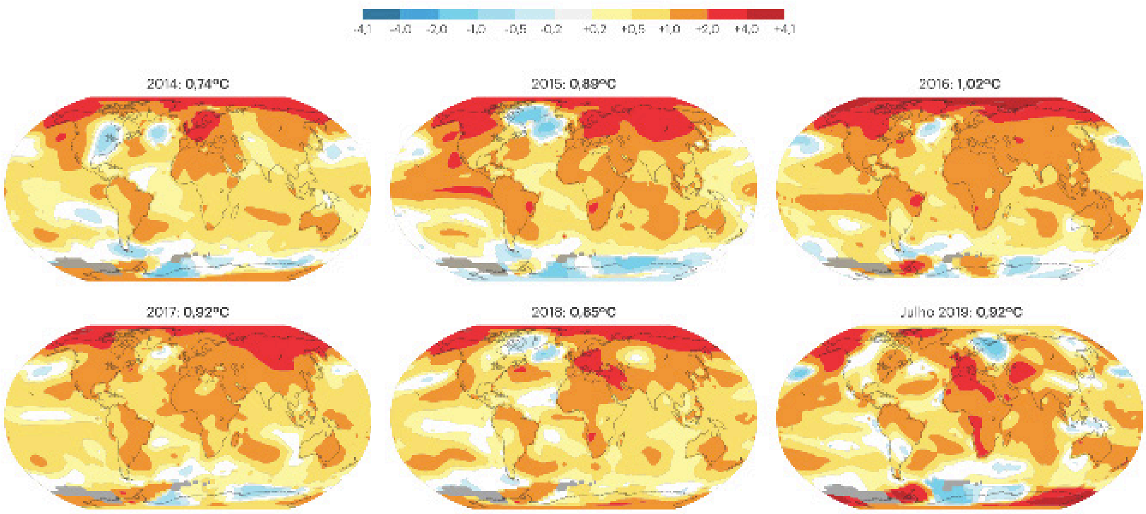


Figure 3.1

Average annual (2014-2019) temperature anomaly (when compared to the 1951-1980 period).

The fight against climate change will be collaborative between governments, businesses and individuals. On December 12 2015, 196 countries signed "*The Paris Agreement*", a legally binding international treaty on climate change. With the goal of limiting global warming to below 2° C, preferably to IPCC's goal of 1.5°C, countries aim to reach global peaking of greenhouse gas emissions as soon as possible to achieve a climate-neutral world by mid-century ('The Paris Agreement | UNFCCC', n.d.). The 2017 Carbon Majors Report indicates that 100 companies are responsible for 71% of the world's greenhouse gas emissions since 1988 (Griffin, 2017), which shows corporations have an increased resposibility in making an effort to mitigate their emissions. However, every single individual also has the civic duty to reduce their own carbon emisisons.

4. Literature review

In this section we address three critical topics necessary to understand the context of the literature that the proposed dissertation fits in: (I) the exploration of the meaning and models behind visual identities based on data artefacts; (II) the definitions of the different approaches to information design and its aspects, mainly exploring data aesthetics; (III) the application of the previous subsection to climate and climate change data in specific.

4.1 Dynamic data-driven visual artefacts and identities

As society inches closer to a hyper-technological paradigm, new forms of visual identity (VI) approach for communication design are necessary. Nowadays, the VI itself is not the only outcome that people expect, but its uniqueness, freshness, and effectiveness (Andrzejczak & Glinka, 2015). As such, an increasing number of designers are wagering on dynamic and flexible VI's, which are not particularly new. According to Kopp (2015), MTV's notoriety in the 1980s helped become visible to the broader public visual identities that revealed such characteristics as fluidity and impermanence in their traits and colours, as a critical part of its personality. Although we acknowledge the existence of earlier works of dynamic identities, there is a need for an innovative way of thinking and practising that reflects the evolution of the brand field. As in the words of Boylan and Cox, designers at the well-known brand design agency Wolff Olins (Bloomberg, 2008) — "the brand is no longer a single and neat tidy logo that you stick in the same place every time. Our thinking of brand has moved on. The brand is the platform, the brand is flexible, the brand is a place of exchange, and it is not fixed, so there is not one logo. There is a recognisable form and recognisable communication and behaviour, but it's not one type of constrained and fixed thing."

Martins *et. al*, in the article *Dynamic Visual Identities: from a survey of the state-of-the-art to a model of features and mechanisms* (2019), proposed a new model for analysing and defining dynamic visual identities based on the distinction between the variation mechanisms used to produce dynamism and the features obtained. The authors believe that the categorization should be based on how variation is visually done utilising the VI system's components. As a result, the suggested model takes three factors into account: Identity emphasis, variation mechanisms, and characteristics. The first factor considered is if the VI is focused on a graphic mark, that is, whether the entity is identified and recognized by a graphic mark only and not a bigger graphic system. The second factor considered is how VIs change graphically. It should be noted that a single VI can employ more than one variation mechanism, and that a single variation mechanism can be applied to different aspects of the VI system. Color variation, combination, content variation, positioning, repetition, rotation, scaling, and shape transformation are the eight variation methods. The final factor to evaluate is the collection of functionality available in dynamic visual identities (DVI). It should be noted that a single DVI might have several characteristics, which are: flexible, fluid, generated, informative, participatory, reactive, and unlimited.

From this definition, we aim to stand out, in particular, VI which focuses not only on the mark, and had fluid, generated and informative as their characteristics.

It only makes sense that modern DVI's are computer-aided and created through programming possibilities. The most commonly used tool is generative systems, derived from generative art, which is any artwork that results from a procedural process with some degree of autonomy that the artist creates. This process can be, for example, a set of natural language rules, a computer program, or a machine (Galanter, 2003). The use of generative principles in design opens many possibilities, as McCormack *et al.* (2004) affirm. The authors state that the electronic item is becoming increasingly common, with a substantial percentage of material being conveyed via dynamic displays ranging from the tiny screen of a mobile phone to big, animated billboards commonly found in public settings. Some of the medium's distinctive qualities may be exploited in electronic design for a plethora of displays. Electronic media, by definition, are fluid and malleable, with the ability to change structure and meaning in reaction to their surroundings, human engagement, incoming data, or other variables. Dynamic images, animation, textures, form, music, and typography are examples of generative processes that may be utilised to communicate (McCormack *et al.*, 2004). Guida (2014) complements by saying that the designer can use time as the fourth dimension, besides the three spatial dimensions, to modify the image in a programmed way. McCormack et al. (2004) summarise the key properties of generative systems as:

1. The ability to generate complexity, many orders of magnitude greater than their specification.
2. The complex and interconnected relationship between organism and environment.
3. The ability to self-maintain and self-repair.
4. The ability to generate novel structures, behaviours, outcomes or relationships.

The authors continue by claiming that designing with generative approaches entails creating and modifying rules or systems that interact to produce the final design. As a result, the designer does not directly influence the generated artefact, but rather the rules and procedures involved in its creation (McCormack *et al.*, 2004).

The amazing input-output data flow that a modern computer is capable of, coupled with its powerful processing capability, can be explored to create a one-of-a-kind design environment for creating new types of dynamically generated visuals. Programming code is a key aspect of harnessing a computer's processing power. Code is the means by which data is transmitted, translated, and transformed from a ("input") stream of information and output as a range of static and moving visual forms in the input/output digital world. Understanding and employing code as part of a larger approach to creative digital practice enables designers to tap into the computer's greater potential as a data-driven device. Data-driven design is the use of various sorts of data, such as numbers, text, or images, to develop novel types of output, *i.e.*, creative visual outputs for print and screen, using code (Richardson, 2016).

The foundation for the use of generativity in communication design is well established, and there are a lot of successful use cases. Our literature review reveals a strong focus on tooling. One of the noticeable examples is a group of toolboxes known as "Logo-Generators", which allow handling a limited number of mark modifications for use as an identification sign. Variations are controlled using a strong meta-design approach: the process design is preferred, giving control over the entire visual identity (Guida, 2014). Some examples of "Logo-Generators" are:

Casa da Música (Sagmeister, 2010)
It works on six versions of a basic sign, necessarily inspired by Rem Koolhaas's design of the building, shown from different perspectives, as demonstrated in Figure 4.1.1. A variety of music events for different kinds of audiences are hosted on Casa da Música, ranging from jazz to classical, to contemporary styles. Since the personality of the organisation is not static, neither can be its visual identity. The program provides an almost limitless number of options for both the audience and those who must handle the identity on a daily basis (Guida, 2014).

Figure 4.1.1

Different variations of the Casa da Música sign. Note that the colors are retrieved from the photograph, showing a connection in the visual identity language.

MIT Media Lab (Studio TheGreenEyl, 2011)
The 45,000 possible variations (10 of which can be seen in Figure 4.1.2) of the algorithmic Corporate Design of the MIT Media Lab represent what the Media Lab constitutes: creativity, diversity, and mutual inspiration. The design is based on three geometric figures rearranged and coloured for every application. Each figure symbolises the contribution of an individual toward the collaborative process.
The entire form stands for the result: a continuous redefinition of what media and technology could be today.

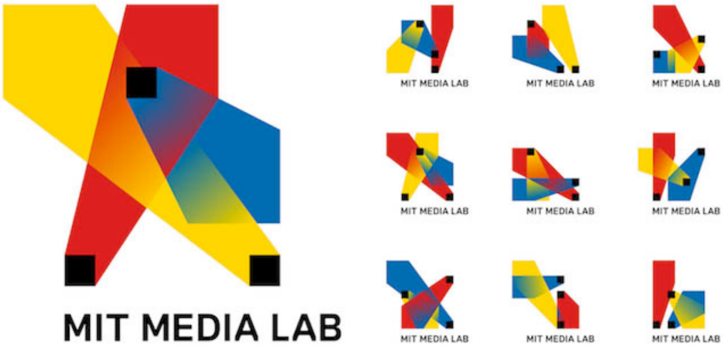


Figure 4.1.2

Logo variations for the MIT Media Lab.

Visit Nordkyn (Neue, 2009)
Nordkyn is the name of a peninsula in Finnmark, Norway's northernmost county. The people of Nordkyn are surrounded by nature and make their livelihoods from it. Based on a new brand strategy and live meteorological data, Neue developed a dynamic logo (demonstrated in Figure 4.1.3) that changes according to wind and temperature, in the same way, the area itself changes with the weather.

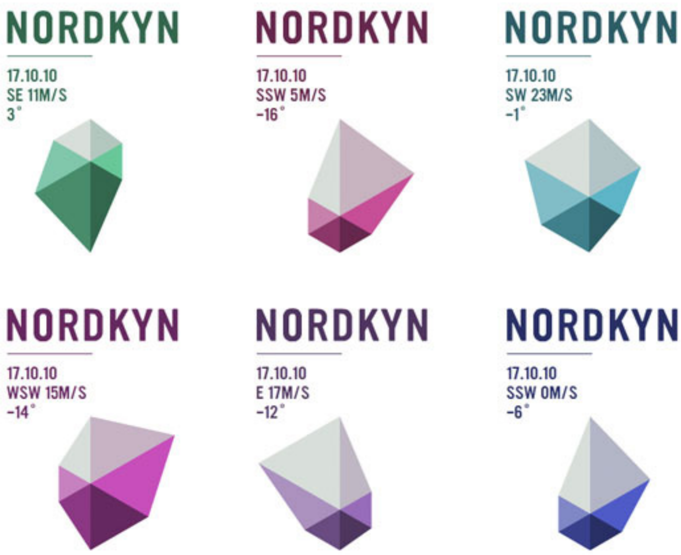


Figure 4.1.3

Logo variations for the Nordkyn place brand project, evidencing the use of data in its generation.

The last example, Visit Nordkyn, stands out from the previous as it uses actual input data to represent information instead of random generativity and abstract meaning.

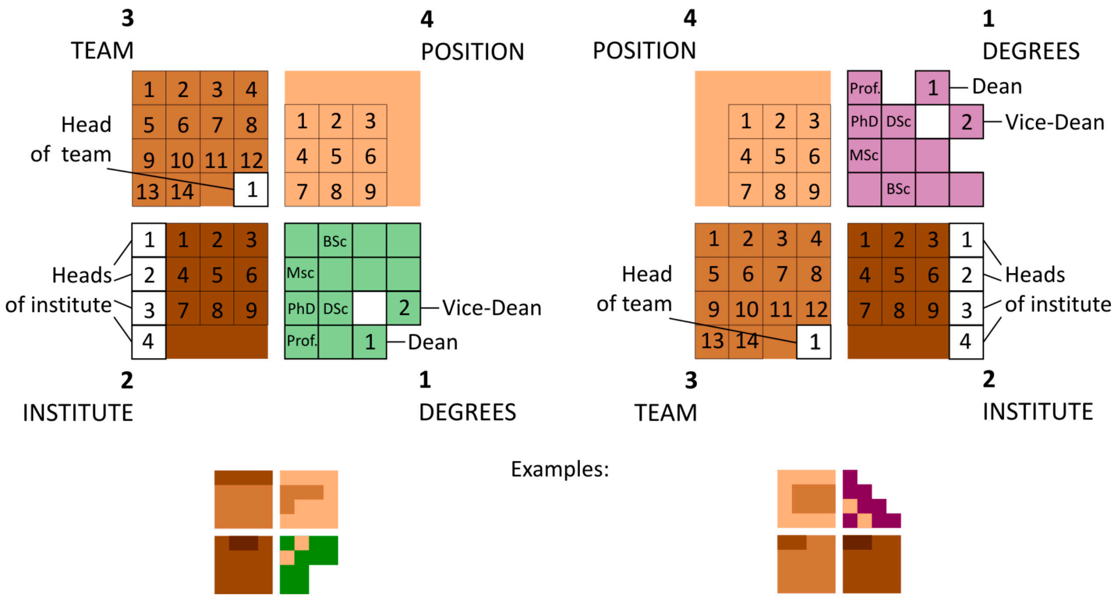
The operation of a generative system can be based not only on the established rules and restrictions but also on input data, thus becoming a form of information visualization (Klanten, 2010). Andrzejczak & Glinka (2015), in their essay "Generative Visual Identity System" elaborate on this concept, claiming that the logo is the most basic and sole created feature of identity in those systems, and the entire concept of generation revolves around it. Existing generative marks may be split into two categories: those that are generated randomly and those that are developed based on specific information or data, such as avatars. The complexity of implemented systems and even individual algorithms, on the other hand, might vary. The majority of them are dependent on the mark being generated at random. Those who start with data or information, on the other hand, are frequently confined to a small number of visualised characteristics (two or three), with no way of precisely understanding them from the generated mark.

The authors acknowledge that most dynamic identities recently made not only focus on the mark, but also lack data-based systems, visualised features, or the possibility of reading back information from the mark. With this in mind, the authors created a generative visual identity for research and education employees of the Lodz University of Technology. A visual representation (summarized in Figure 4.1.4) was created for each employee, using six categories of features that were able to form a coherent and complete data source to be visualised in the mark:

- sex;
- degrees (*MSc*, *PhD*, Prof., etc.);
- faculty and functions on it (dean, vice-dean);
- institute and functions at it (heads of institute);
- team and function on it (head of team);
- position at the university (assistant, adjunct, professor, etc.).

Figure 4.1.4

Graphic summarizing the construction of the mark by quarters: 1 – degrees and functions on faculty; 2 – institute and functions at it; 3 – team and function on it; 4 – position.



This system was able to generate 1.5 million permutations of the logo, and the authors concluded by claiming the constructed system's testing revealed the potential of information-rich generative logos, as well as the solution's strengths and drawbacks.

Users were able to read around 75% of the information presented despite the vast number of characteristics contained in the created sign, with a mean satisfaction level in the 72 percentile ("B" grade) (Andrzejczak & Glinka, 2015).

Although an information-rich and comprehensible visual mark was developed, the project still lacks in some aspects. The mark is not aesthetically pleasing, thus depreciating a fundamental aspect of graphic and communication design. Other data-driven elements of the graphic identity were also not developed, such as backgrounds or typography. Therefore, there is still space to develop an aesthetically pleasing dynamic visual identity based on data-driven artefacts.

4.2 Data visualization and Data aesthetics

In contrast to persuasive tactics more typically utilised in disciplines such as advertising, the term "information design" refers to communication design practises in which the primary goal is to inform, according to Meirelles (2013). Infographics are one of the many possible outputs of the wide discipline of information design. Other possible outcomes include the creation of systems, such as information systems, navigation systems, and statistical data visualizations. All examples have the goal of illuminating patterns and correlations that would not be known or as easily determined without the use of visual representations of information.

Historically, infographics and system design were static visual presentations. With technological advancements and accessibility, there is a growing practice in interactive and dynamic visual displays for information, which links with the ideas brought up in the previous subsection. According to "*Readings in Information Visualization: Using Vision to Think*" (Card, Mackinlay, & Shneiderman, 1999), data visualization and information visualization are terms commonly used in the scientific community to refer to "the use of computer-supported, interactive, visual representations of abstract data to amplify cognition."

One of the important aspects of the information visualization definition is cognition. In this context, cognition is the acquisition or use of knowledge, and external cognition is concerned with the interaction of cognitive representations and processes across the external/internal boundary to support thinking. Card (2008) claims that cognition is aided by visualization not because images are magically superior to other forms of thought and communication, but because it assists the user by making the world outside the mind a resource for thought in a specific way. He clarifies that Information visualization is for the mind what automobiles are for the feet. Visualization amplifies cognition by increasing the memory and processing resources available to the users; reducing the search for information; using visual representations to enhance the detection of patterns; enabling perceptual inference operations; using perceptual attention mechanisms for monitoring; and by encoding information in a manipulable medium (Card *et al.*, 1999). Meirelles (2013) defines the key principles in which information design aid cognition as the following:

- to record information;
- to convey meaning;
- to increase working memory;
- to facilitate search;
- to facilitate discovery;
- to support perceptual inference;
- to enhance detection and recognition;
- to provide models and theoretical worlds;
- to provide manipulation of data.

It is also important to note that one of the most essential components of visualisation is the interactivity, as it is what distinguishes it as a new medium, distinguishing it from generations of excellent work on scientific diagrams and data visualisations. Controlling the parameters in the visualisation reference model is what defines interactivity. This implies that there are several sorts of interaction, because the user may alter the parameters of data conversions, visual mappings, and view transformations (Card, 2008).

Designing visualisations is defined by different processes from different research and design communities. To define Visualisation Design for communicative visualisation, according to (Kosara, 2016), we must first define data presentation and communication in terms of what is wanted from the techniques. We utilise the same procedures in analysis because we know they usually always work, but presenting different facts with the same techniques will not help produce a lasting impact. Memorability and engagement are two characteristics that are particular to presenting approaches but are not useful (or even harmful) for analysis. The goal of a presentation is to get a message through and make it stick. To do this, there must be hooks on which your audience's memory may latch. People must find the viewpoints intriguing and engaging in order to pay attention to a presentation. This is vital not just in the news media, where a story must stand out among many distractions, but also while attempting to hold an audience's attention throughout a long presentation. Learnability is an important factor, especially for novel procedures.

Potential viewers will become dissatisfied and walk on if the way the visualisation works cannot be comprehended immediately.

This project is characterized as a Casual Visualisation project. Pousman *et. al* (2007) define Casual Visualization as "the use of computer mediated tools to depict personally meaningful information in visual ways that support everyday users in both everyday work and non-work situations". It is an umbrella phrase that reframes ambient, social, and artistic information visualization, as well as other edge cases as part of, but distinct from, more standard information visualization systems and methodologies. In *Casual Information Visualization: Depictions of Data in Everyday Life* the authors note four differences between traditional information visualization systems and casual information visualization.

- User Population: The user community has been expanded to encompass a diverse range of users, from specialists to novices. Users are neither expected to be analytic thinking specialists, nor are they required to be experts at interpreting visualizations.
- Usage Pattern: Usage extends beyond work to include other aspects of life. Systems are designed for either instant and repeated (weeks and months) use, or meditative use (a long moment at an art gallery).
- Data type: The data is often personal and relevant, rather than work-related. As a result, a user's connection with the data is frequently more strongly tied.
- Insight: The authors propose that the kinds of insight that casual information visualization may support are different from more traditional systems, and suggest that developers are interested in providing insight about data that is not analytical, but instead of a different sort.

Inside the Casual Visualization term, the solution can be considered specifically as an Artistic Information Visualization (Viégas & Wattenberg, 2007). Traditional information visualization systems keep a functionalist approach in that they are meant to be useful for a certain set of analytic activities. Data-driven artworks, on the other hand, may call into question some of our assumptions about visualization and computer-mediated knowledge, as well as our understanding of what comprises data and the infrastructure of computer systems. These systems deviate from being aesthetically beautiful or well-designed because they may arouse interest, puzzlement, or even annoyance. Of course, many of them are exquisite works of art. These systems, however, are artistic in their alignment and framing, not just elegant or beautiful (Pousman, Stasko, & Mateas, 2007).

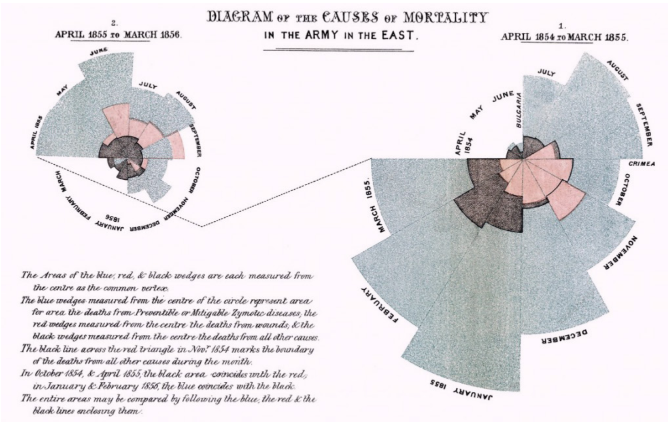


Figure 4.2.1

Causes of Mortality (1857), by Florence Nightingale, is one of the first instances of the use of information design as communication in the social-political context.

While the connection between art and design can be seen as getting lost, some practitioners believe focusing on the aesthetic of the information visualization itself can have a powerful impact on how strongly a message is communicated to the general audience. According to Murray (2014), work regarded to be on the "art" end of the spectrum, for example, may be purely aesthetic, with little to no functional purpose, and with little commercial or practical value (except, of course, as fine art, which can be argued is as practical a purpose as any). Work may be considered "design" if it has evident economic value, expresses a specific message, and has a defined goal. *Causes of Mortality* (1857), shown in Figure 4.2.1, can clearly be considered design in the way it expresses the clear message that most casualties in the war were actually caused by malnutrition, poor sanitation and lack of activity. However, "design" has aesthetic value and hence shares that aspect with "art." And "art," such as illustration, may be used in a "design" setting to transmit a message that is greater than the art itself. In his essay *Changing Minds to Changing the World: Mapping the Spectrum of Intent in Data Visualization and Data Arts*, Murray (2014) explores the intersection of interdisciplinary work by visualization experts, communication designers and artists, and he claims the most efficient approach to draw this distinction is to determine the creator's objective or intent. In the case of art, the goal may be to provoke a purely aesthetic or emotional response from the viewer/participant. The purpose of design is usually to transmit a certain message to the viewer/participant. So, regardless of medium or context, a picture created with the intention of communicating a certain message or meaning comes at the "design" end of the spectrum (this judgement is done regardless of whether or not the design is successful in meeting the aims of its creator). Art is defined as a picture with the purpose to evoke an emotional response, but without a specific message. However, to further muddy the waters, art often has a message. This might be reduced even further by saying that a work's position on the spectrum solely shows the specificity of its intended message: the more open it is, the more artistic; the more specific, the more design-oriented.

The author also uses several spectrums to categorise these types of projects, namely:

- Avenues of Practice (Data arts - Data visualization);
- Contexts (Gallery Primary, Online Secondary/Online-Only/ Print primary, Online Secondary);
- Media (Static - Interactive);
- Conceptual Structure (Exploratory - Explanatory);
- Goals (Inspire - Inform).

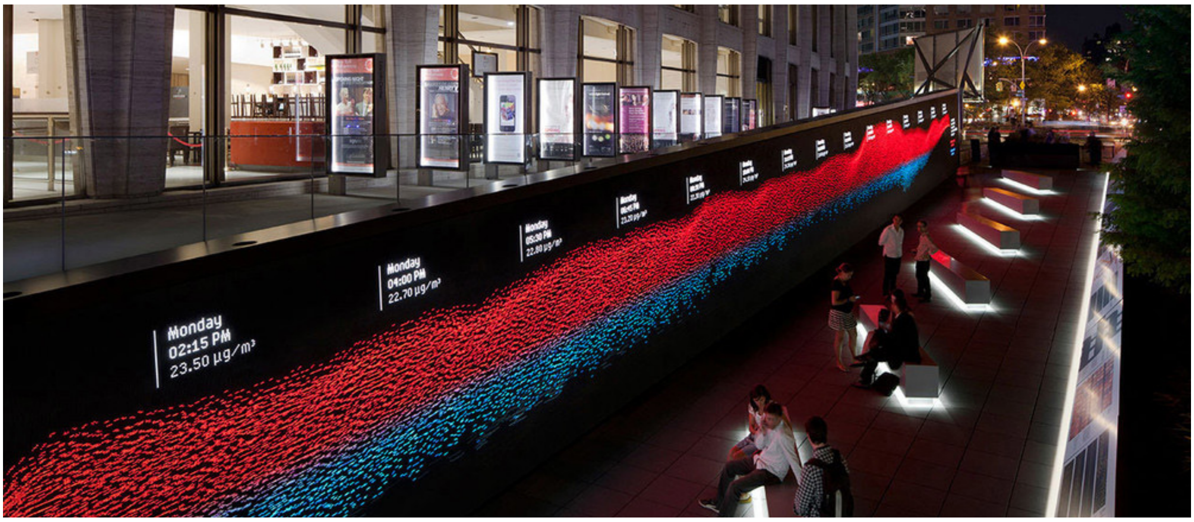


Figure 4.2.2

IBM's "THINK" exhibition (2011) by studio Mirada was a real-time data aesthetics visualization of New York City systems tracked and mapped on a 128-foot digital wall.

Lau & Vande Moere (2007) have a similar approach in proposing a model which shows that mapping technique (*Direct - Interpretive*) and data focus (*Intrinsic - Extrinsic*) are qualitatively associated, *i.e.*, the mapping technique typically determines the resultant data focus (and *vice versa*), as shown in Figure 4.2.3.

This approach means direct mapping-based visualization approaches frequently emphasise intrinsic patterns, whereas interpretative mapping emphasises extrinsic data meaning. A closer examination reveals that these two extremes are recognized as the domains of information visualization and visualization art, respectively, despite the fact that a large range of other visualization approaches lie between them. The authors propose that this subject be referred to as 'information aesthetics' (of which IBM's "THINK" exhibition, seen in Figure 4.2.2, is a great example), which comprises the subfields of social visualization, ambient visualization, and informative art. The proposed model, in particular, may be utilised by visualization designers from many domains to determine which technique is optimal for a certain visualization objective. For example, a visualization aimed at communicating the effects of global climate change (*i.e.*, extrinsic focus) may use highly interpretive mapping techniques with little regard for the effective representation of the complex data involved, demonstrating the power of visualization primarily for propaganda purposes.

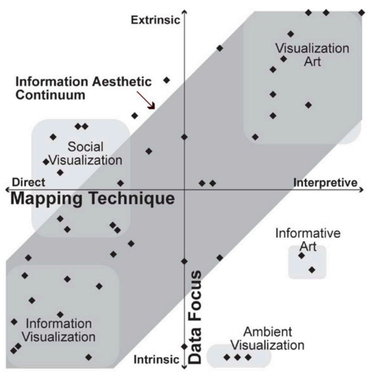


Figure 4.2.3

Categories within the Lau & Vande Moere model of information aesthetics. The X axis shows the mapping technique (*Direct-Interpretive*), while the Y axis shows the Data Focus (*Extrinsic-Intrinsic*).

4.3 Climate visualization and aesthetics

Climate and climate change visualization can appear as an unappealing subject, as most of the general audience will assume complex, scientific visualizations. This is because climate change is, in fact, of a particularly complex nature. Several interconnected fields of study are included in the research of causes, consequences, and ways of action. Atmospheric chemistry, oceanography, biology, palaeoclimatology, physics, biology, glaciology, natural and human geography, political science, economics, and sociology are all part of climate science. One of the most difficult issues is capturing the multiple nuanced links between these sectors in order to comprehend the repercussions of inactivity as well as the different action possibilities to reduce greenhouse gas emissions or adapt to a changing climate. Furthermore, climate change information needs big data sets and advanced modelling. The nature of climate change information is a particularly difficult challenge to explain to the public and decision-makers (Johansson, Neset, & Linnér, 2010). Because of that, when talking about climate to the general audience, a "cheap" solution is to drive the attention to significant impacts like climate disasters, such as droughts, floods, fires, and public health consequences such as disease and food security. Irving & Hamilton (2005) defend that while acknowledged, there is a lack of awareness about potential climatic impacts on biological diversity and ecosystem function. This reflects a broad underestimation by the media and the general public of the critical role that undisturbed natural systems play as the economic and ecological framework for human well-being. Scientists are challenged to translate the global implications of climate change on Earth's ecological systems into a more local, personal, and regional context in order to engage a broad public with various value systems. Their essay briefly discussed examples of ecological forecasting with downscaled climate models for two iconic conservation target species, the Jaguar (*Pantera onca*) and the Wolverine (*Gulo gulo*), in the belief that the repercussions of global climate change are transmitted at a personal level by displaying the impacts of climate change on the future distribution of plants, animals, and ecosystems that people are familiar with (for example, as seen in Figure 4.3.1), and may drive people to think creatively and actively about solutions.

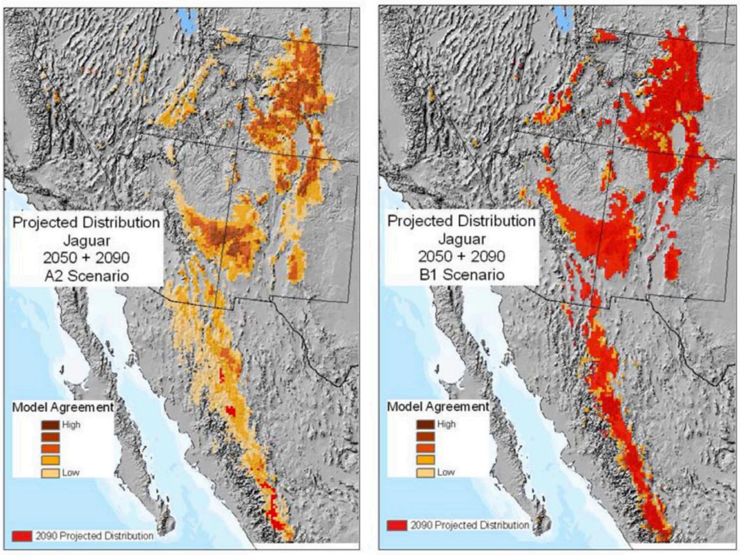


Figure 4.3.1

Projected distribution of Jaguar (*Pantera onca*) under the A2 (pessimistic) compared to the B1 (optimistic) emission scenario for 2050 (yellow) and 2090 (red). Figures represent preliminary results and are for demonstration purposes only.

This belief directly correlates with Johansson *et al.*'s (2010) belief that narratives frequently depict the complex interplay between humans and nature. Climate change narratives often have a chronological pattern (what has happened, what is happening and how will this develop in the future). In climate visualization, narratives frequently suggest the precise plot of a succession of images as well as the relationship between areas of content. Hawkin's series of stripes, seen in Figure 4.3.2, although being simply a succession of vertical stripes, has a clear chronological sense to it. It is also critical to connect the story to the possibilities provided, alternate futures, and how a future civilization will respond to climate change. Climate research and global discussions commonly deploy visions of alternate futures and future societies.

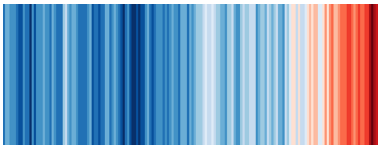


Figure 4.3.2

Ed Hawkin's (2018) "*Warming Stripes*", shifting from blue on the left to red on the right, representing warming global temperatures over time.

In the essay "*Cognitive and psychological science insights to improve climate change data visualization*" (2016), Harold *et al.* present ten evidence-informed guidelines to help climate scientists increase the accessibility of graphics to non-experts, around four main principles: direct visual attention, reduce complexity, support inference-making, and integrate text with graphics. These ten guidelines can be summarised as:

1. Present only the visual information that is required for the communication goal at hand;
2. Make critical visual features of the graphic perceptually salient so that they 'capture' the attention of the viewer;
3. Choose and design graphics informed by viewers' familiarity and knowledge of using graphics and their knowledge of the domain;
4. Only include information that is needed for the intended purpose of the graphic and breakdown the graphic into visual 'chunks';
5. Remove or reduce the need for spatial reasoning skills by showing inferences directly in the graphic;

6. Identify the essential relationships in the data that are to be communicated;
7. Cognitive principles should inform decisions to create animated graphics;
8. Match the visual representation of data to metaphors that aid conceptual thinking;
9. Keep the graphic and accompanying text close together;
10. Use text to help direct viewers' comprehension of the graphic;

Visualization as a tool has been established in climate and climate impact research, communicating results between climate scientists and conveying results beyond the scientific community. However, recent developments in interactive visualization using alternative visual metaphors are not widespread in the climate community. Thus, a significant task for future developments is further to bridge the gap between climate and visualization expertise, exploring the chances arising from sophisticated visualization approaches, and smoothly supporting and integrating the alternative visualization techniques into the users' ongoing research processes (Nocke *et al.*, 2008).

Corby makes a direct approach to climate aesthetics in the 2011 essay *Systemness: Towards a Data Aesthetics of Climate Change*, which he begins by exploring Felix Guattari's ideas concerning the role of the arts, science, and technology in environmental discourse, as well as Gregory Bateson's conceptualisation of mental ecologies, stating that both authors theorise about the importance of the mind in ecology and propose a role for the arts in drawing attention to the connections between mental states, behaviour, and natural ecology. According to Bateson, the arts enable a reconnection of human consciousness with the myriad couplings of interacting systems (of which art is itself a system); a cultural practice that recognizes the beauty of the modulating patterns of the ecological world is a prerequisite for a culture serious about its responsibilities to a healthy environment. Guattari argues for a science and technology detached from the capitalist aim, as well as an ethical aesthetic in which computational media serves as a hub for interdisciplinarity.

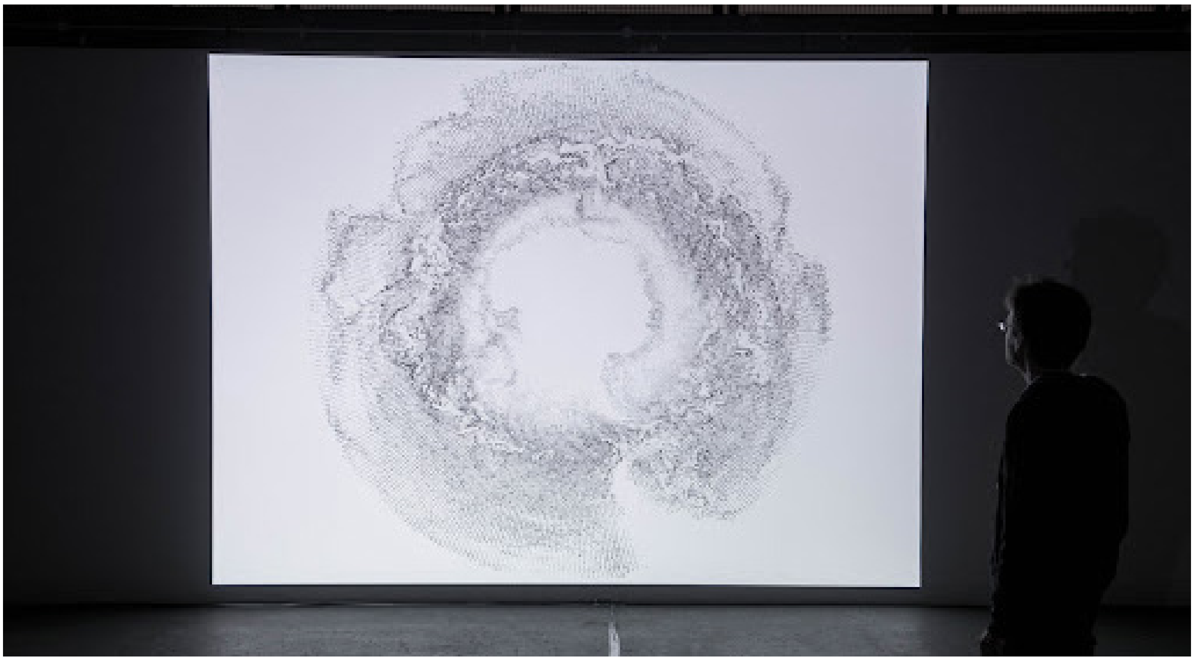
Before making a case for climate aesthetics in specific, he also cites an important Bateson statement, in which Bateson emphasises the role of aesthetics in the encoding of communications across nested systems. He does this in two ways: the aesthetic process serves as both a method for increasing awareness of ecological complexity and a monistic system of geobiotic encoded messages travelling amongst minds in the larger ecosystem. That is, Bateson regards art as more than just a semiotically enabling representational device of signs and metaphors, but as a mental system in its own right, mirroring and magnifying the larger informational ecologies of which it is a part (and to which it exchanges information 'news of difference'). Corby then discusses his project

"*The Southern Ocean Studies*", prefacing by briefly explaining his 2006 installation "*Cyclone.soc*", which reworked archival satellite data of storm fronts into animations with depth, complexity, and interaction. Live textual data streams from newsgroups and chat rooms arguing climate change was mapped to the isobars of these animated pressure fronts. When the audience entered the installation, they were able to follow these arguments and zoom in on particular talks using a mouse interface. The debates were conveyed as textual vortices of tension by the swirling storm fronts, creating the overall effect of a conversational churn and eddy of ideological argument and counter-argument. This work created a clear connection between technology and the environment to demonstrate how mediated public discourse may successfully focus knowledge toward environmental change concerns. This dynamic has gotten more prominent, as discussions over climate change data and modelling have become as visible as the ecological and societal challenges prompted by the phenomenon.

The project "*The Southern Ocean Studies*" (shown in Figure 4.3.3) expands on the concepts established in *Cyclone.soc*, but focuses on the phenomenon of climate models as vehicles for communicating environmental change and as emerging cultural phenomena in their own right. Working with British Antarctic Survey scientists Nathan Cunningham, an expert in circumpolar data, and Claire Tancell, an expert in the Southern Ocean's ecosystem, the authors gained access to a variety of models and data sources from which they derived the behavioural and ecological characteristics of a number of installation projects.

Figure 4.3.3

The data screen shown in the "*The Southern Ocean Studies*" exhibition.



Corby contends that attempts to create new subjectivities around climate change through art practice will need the audience to connect the social and emotional contours of their lives to the larger material realm of cause and effect, which links directly with Irving *et al.*'s (2005) claim. He also concludes by claiming that by illustrating the emotive, discursive, and poetic elements of climate data, this study makes the case for an ecotec aesthetic that bridges ontological barriers to identify a common cause between the arts and science in the development of sensory knowledge of environmental complexity. This study, however, is not science; it does not make an attempt to directly show whether or not climate change is occurring; the authors accept the scientific consensus that it is. Rather, it contributes to the epistemologies of media art practice by emphasising a subject beyond technological experimentation, and it produces a convergence-divergence model of collaboration between climate change art and science that respects differences in approach but ultimately shares a common goal.

4.4 Related Work

We present a selection of thirteen works that relate to the dissertation according to different factors: (I) climate data utilisation; (II) application of data aesthetics principles; (III) climate awareness in social contexts; (IV) application of data-driven design principles; (V) communication campaigns. There is, for each work, a brief description and the element that makes a connection with the intended work. We also conclude with a brief summary of the projects and their context in the proposed dissertation.

WALDEN: Multi-surface multi-touch simulation of climate change and species loss in Thoreau's Woods

WALDEN (Schneider, Tobiasz, Willis, & Shen, 2012) is a visual simulation application consisting of a large data wall with multiple displays that offer users the opportunity to interact with large visual datasets and observe complex visual simulations (as demonstrated in Figure 4.1.1). According to the authors, "The WALDEN simulation seeks to model changes in abundance of a select group of plants found in Concord, as a response to climate change and human intervention in the local ecosystem. The stochastic simulation uses empirical plant abundance and climate change data observed in Concord over the last 100 years, to make future projections on the floral populations in this area." The main takeaway from this project is how it allows users to interact with the data to see its effects on the future, based on predictive simulation.

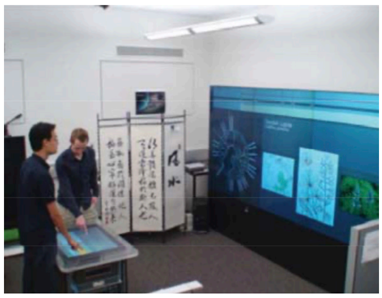


Figure 4.4.1
Users interacting with the "WALDEN" data wall.

ColorMoves: Real-Time Interactive Colormap Construction for Scientific Visualization

ColorMoves (Samsel, Klaassen, & Rogers, 2018) is an online tool offering artist-constructed colour scales and palettes in a real-time interactive interface (demonstrated in Figure 4.4.2), providing the scientific community with an easy-to-use method of exploring the impacts of changing colour encoding on their data. The objective was to put artistic principles and experience at the fingertips of scientists, thus furthering the connection between scientific visualization and data aesthetics to facilitate communication for the broader audience.

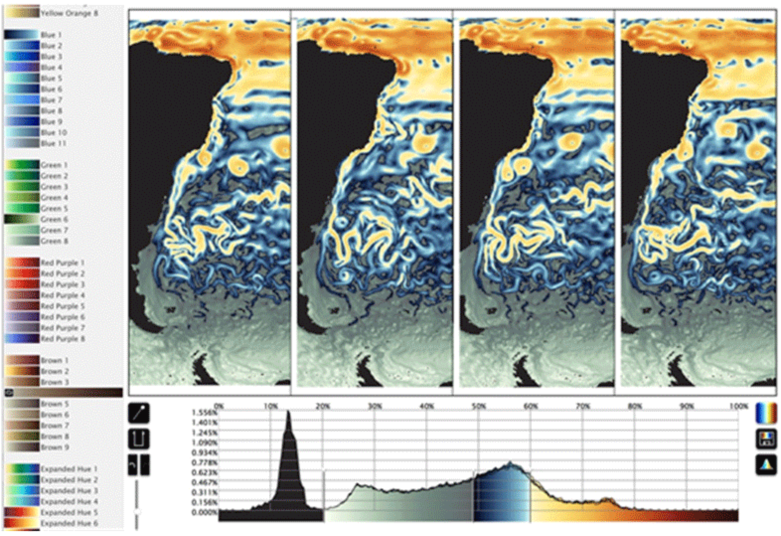


Figure 4.4.2

One of the "ColourMoves" color palletes being applied to four time steps of an MPAS–Ocean kinetic energy simulation.

The Prediction Machine

The Prediction Machine (Jacobs, Benford, Luger, & Howarth, 2016) is a data-driven artwork that engages the public with climate change issues through sensory, performative and physicalised representations of climate and weather data, designed to stimulate ongoing dialogues with the public. The artwork in the exhibition consists of two interactive machines (seen in Figure 4.3.3), the first one printing out predictions for our climate 30 years into the future, and the second one allowing visitors to input their promises and predictions for the future while also discovering more about the scientific processes that support how the predictions were made. The system, for each user's interaction, uses current weather data, location and age, to print out a prediction about a world with increased temperatures, based on an increase of 3.7 degrees to the current temperature, captured by a weather station set up in the locality of the exhibition.

Figure 4.4.3

The two interactive machines present in "The Prediction Machine" installation.

The Weather Followers

The Weather Followers (Colombini, 2017) is a project that, instead of relying on 'accurate' data, intangible algorithms and hidden lines of code-driven lifestyles, uses constantly evolving weather data recorded by four weather instruments to bring serendipity to the user's digital life. The project is essentially an installation comprising two elements: the four weather instruments, and the web app, both shown in Figure 4.4.4. Users are invited to connect to the weather machine through the web app and choose between one of the four weather instruments: Windy Encounters (when your digital social life follows the wind), Polluted Selfie (when your digital individual life follows the pollution), Drizzly Rhythms (when your digital audio life follows the rain) and finally Sun(e)rase (when your digital overwhelming life follows the sun). The project has value not as an accurate visualization of data and communicator of knowledge but from the way it connects to the user to transmit a message.

Figure 4.4.4

The four weather instruments (top) and the four corresponding components of the web app (bottom) of "The Weather Followers" project.

Globalance World

Globalance World (CLEVER°FRANKE, 2021) is an investment platform with the objective of engaging, inspiring and empowering investors to make sustainable investment decisions based on economic, societal and environmental data. Although this project stands out as it is a business platform with real clients and not a standalone artwork, many of the concepts explored in this essay were considered. A data-driven symbol — the "Pebble Shape" (Figure 4.4.6) — was developed as the main element of the platform's visual language. Inside the platform, the users can dive into many different data visualizations (an example can be seen in Figure 4.4.5) that value the aesthetic of the visual language as a whole.

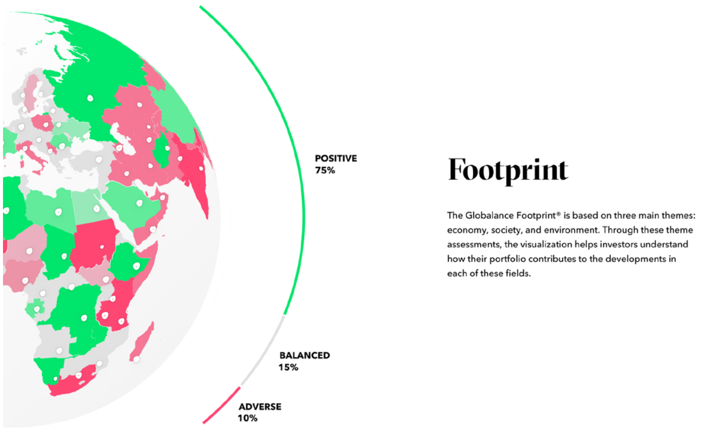


Figure 4.4.5

An example of one of the Globalance World's visualizations.

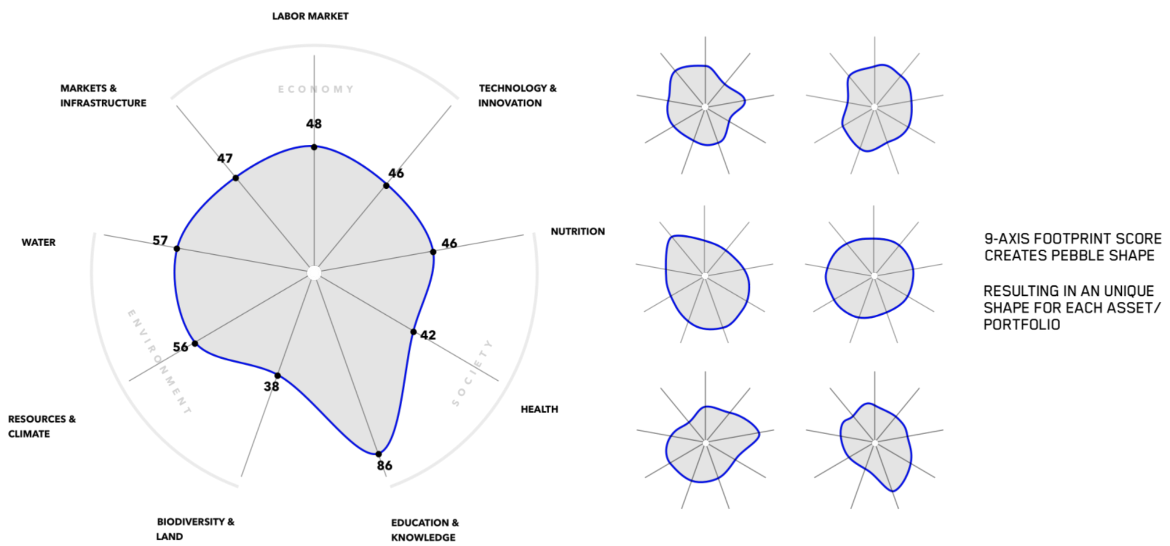


Figure 4.4.6

The design of the Globalance World's "Pebble Shape".

Cyclone.soc

Cyclone.soc (Corby & Baily, 2007) is an immersive interactive environment by Tom Corby and Gavin Baily, two London-based artists whose collaborative work focuses on climate change and uses public domain data, climate models, satellite imagery and the Internet. The artwork, seen in Figure 4.4.7, brings together two different datasets: a live internet stream of discussions from online forums; and meteorological data of cyclonic storm conditions from NASA. The project, according to the authors, "confronts the way that hate speech and 'alt facts' are penetrating public discourse through technological platforms, ultimately affecting our body politic, bodies and natural environments; a process described as the 'data abject'."

Figure 4.4.7

The “Cylone.soc” data wall, in which we can see live textual data streams from newsgroups and chat rooms arguing climate change that was mapped to the isobars of the storm fronts from archival satellite data.

The Southern Ocean Studies

The Southern Ocean Studies (Corby, Baily, & Mackenzie, 2009) is an installation (seen in Figure 4.4.8) produced with the British Antarctic Survey. It provided scientific advice and supplied data and climate models, thus cementing its place as an intersection of a scientific visualization and data aesthetics project. It explores, using a variety of data resources, models, physical theories, and sensing technologies, how these global infrastructures facilitate the opening up of hidden systems and processes in the larger material world.

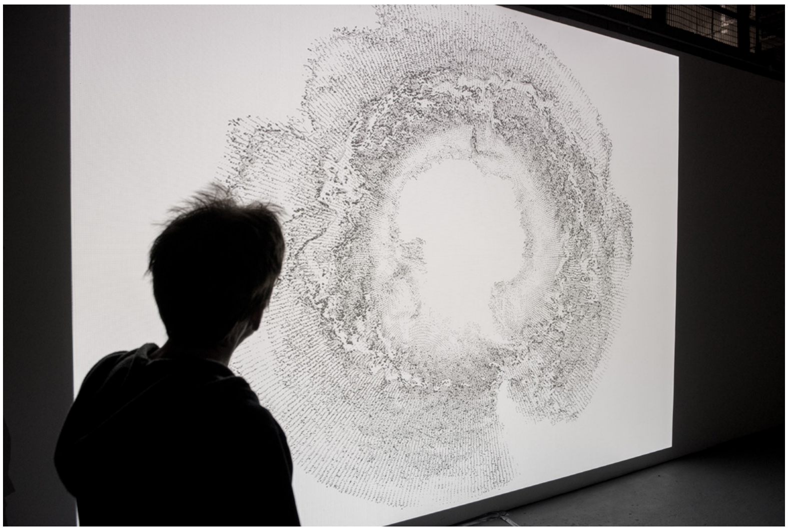


Figure 4.4.8

The generation of the ocean currents to which are mapped various other ecological data sets, shown on the “The Southern Ocean Studies” data wall.

The End of the Sun

The End of the Sun (Borsani, 2019) is an artwork consisting of a paradoxical installation: a timer that counts down the time remaining in the sun’s lifetime while simultaneously being powered by solar energy. This artwork, shown in Figure 4.4.9 uses a simple, scientific data point (14.4 billion years until the sun consumes all its fuel and starts cooling down) to transmit a powerful message that is easily understood by the general audience.

Figure 4.4.9

The entire “The End of the Sun” exhibition: a simple timer on the wall.

The Moldy Whopper

The Moldy Whopper (Ogilvy, 2020) is a marketing campaign developed for Burger King to promote that the food chain's "Whoppers" are now made with no artificial preservatives. In a way that breaks many advertising rules, the campaign shows what happens to a Whopper when left out for a month. The project is relevant as it uses an unusual and "uncomfortable" but consistent aesthetic to make a powerful statement. It is also a great example of the intended way of disseminating the project, as demonstrated in Figure 4.1.10.

Figure 4.4.10

A bus stop poster of "The Moldy Whopper" campaign, in which we can see a Whopper filled with mold and the legend "Day 32".

Dear (Climate) Privileged People

Dear (Climate) Privileged People (Niedzialek, Linh, & Campainha, 2021) is a university project developed as a part of the MA program at The Royal Danish Academy of Fine Arts, consisting of an awareness campaign and an open letter to the wealthiest 10% and the public, addressing the carbon inequality that requires immediate action. This project shares many similarities with the intended solution, as it uses data to create images that create a visual identity for the campaign and serve as a visualization to share the intended messages. It is particularly notable how the data-driven design is used for many of the identity's elements (see Figure 4.1.11) and not only the "mark" as previously discussed.

Figure 4.4.11

A poster wall of the "Dear (Climate) Privileged People" campaign, with variations of the same poster, evidencing the data-driven dynamic.

Climate Clock

Climate Clock (Usher, 2017) is a simple web platform (that can also be used in bigger mediums, as seen in Figure 4.4.12) that answers the following question: "Given the current trend of global CO_2 emissions and the level of human-induced warming, how long will it be until we emit enough to cause global temperatures to reach 1.5°C?". It calculates the answer using the best estimate of the remaining carbon budget from the IPCC Sixth Assessment Report, which for the 1.5°C temperature target corresponds to 500 billion tonnes from 2020 onwards. It also shows the "Global Warming Index", which represents the portion of observed temperature change that can be attributed to all human drivers of climate change, and the total accumulated CO_2 emissions from fossil fuel burning, cement manufacture, and land-use change since 1870, based on the most recent data from the Global Carbon Project. It is also possible to see different predictions based on possible scenarios of the data evolution.

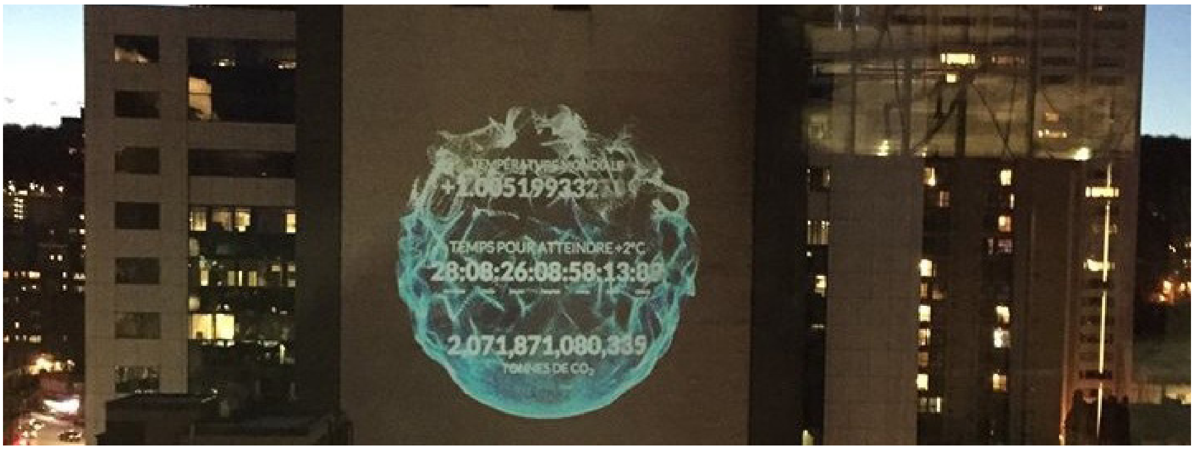


Figure 4.4.12

The "Climate Clock" platform being projected on a building, allowing us to see the three metrics being streamed.

Plastic Air

Plastic Air (Lupi, Cotton, & Cox, 2021) is a web-based, interactive experience that brings to life a sort of pollution that most people are unaware of: airborne microplastic deposition, which is the result of rising worldwide plastic manufacturing and consumption. The experience gives a lens through which to "see" and investigate the unseen plastic particles that are always present in the atmosphere around us, as well as to contemplate the influence they have on the environment and our health. The designers aimed for a highly engaging experience, a glimpse of which is shown in Figure 4.4.13, that would entice people to spend time with it and share it with their friends. The project, like most of Lupi's work, employs the ideas of "data humanism" — the use of data to unearth a relevant human aspect behind the numbers and statistics, in order to make the subject more accessible.

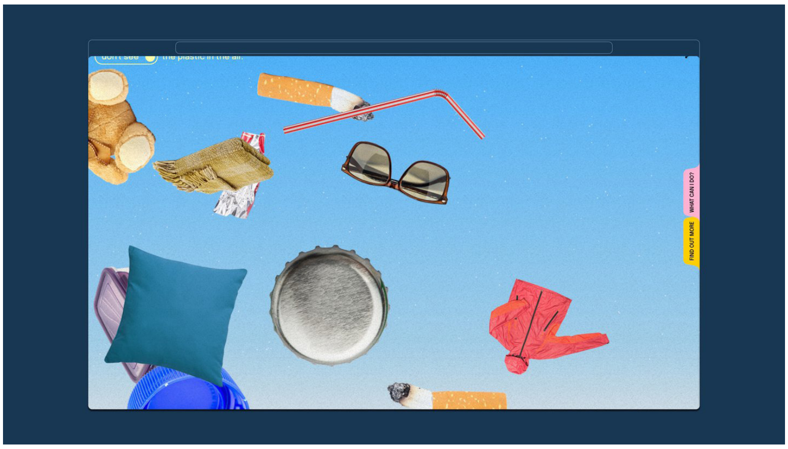


Figure 4.4.13

A screenshot of the “Plastic Air” web platform, with some materials floating around the screen that will soon turn into microplastics.

Summary

Although none of the works presented share every particular detail with the project of the dissemination, the sum of the parts makes for a definitive inspiration for it. Something every work has in common (except Ogilvy’s 2020 “The Moldy Whopper) is the intent to use data to transmit a message clearly that by itself would be difficult for the general audience, however, almost everyone does it in a singular way. “WALDEN” and “ColourMoves” still leverage some importance in the scientific process and visualization, but aim to be somewhat more understandable. “The Prediction Machine”, “The Weather Followers” and “The end of the sun” use very rudimentary data and, as such, don’t aim to be significantly understandable visualizations of it - however, they make the case for social experiments that make the participants question the subject. “Cyclone.soc”, “The Southern Ocean Studies” and “Plastic air” can be argued to be the opposite of the projects previously stated: they work with large quantities of complex climate data, to make artworks that are equally aesthetically pleasing as well as they inform the audience. “Globalance World”, although as an investment platform is far from the endgame that the proposed dissertation aims to be, and “Dear (Climate) Privileged People” are fine examples of the creation of dynamic visual identities in which their elements are as data transmitting as are functional elements of the identity. The Niedzialek et al. project also shares a common aspect with “Climate Clock” as both are climate awareness campaigns with the motivation of using data to transmit an urgent message to the general audience in a way everyone can understand. The stand-out, “The Moldy Whopper”, although not using data, is still a powerful inspiration to the solution for the way the campaign is handled and their particular way of disseminating the message.

5. Preliminary work

Before starting the actual development of the solution, we prefaced it with some preliminary studies which mainly focused on the collection and analysis of datasets that could be used as the source of data for the project, and the study of possible technologies and architectures for the implementation.

5.1 Data sources study

As previously stated in this dissertation, at this point of the development we figured the data utilised in this research might fall into two categories: accurate, direct climate data that will require treatment and analysis to understand how it depicts climate change, or data that is already a representation of climate change. We collected and analyzed possible examples of both categories, defining advantages and disadvantages.

Global Climate Change Data[3]
This dataset focuses mainly on global land and ocean temperatures, packaged in a way that allows for slicing into interesting subsets (for example by country). The data has already been cleaned and processed, making for a very light collection. The source is Berkeley Earth, an independent U.S. non-profit organisation focused on environmental data science, which supplies comprehensive open-source world air pollution data and highly user-accessible global temperature data that is timely, impartial, and verified.

Although this dataset is advantageous in the sense of its data been directly about climate change, and thus not requiring interpretation, its disadvantage is having been created in 2015 and not being updated since then. This makes its utilisation somewhat irrelevant as climate change is mainly noticeable by comparing a large time span, and one of the solution's main objective is for the viewers to be able to construct a narrative from it.

Global Climate Station Summaries[4]
This map service from the National Oceanic and Atmospheric Administration (NOAA) provides hourly worldwide climate station summaries. Global Hourly Summaries are basic indicators of observational normals that comprise climate data summaries and frequency distributions. The summaries are derived from the hourly global surface dataset. This dataset, which is about 350 gigabytes in size, is made up of 40 distinct types of weather observations from 20,000 stations throughout the world.

[3]**Global Climate Change Data**

https://data.world/data-society/global-climate-change-data

[4]**Global Climate Station Summaries**

https://catalog.data.gov/dataset/global-climate-station-summaries

This dataset has essentially the opposite advantages and disadvantages of the previous one. Rather than its data representing climate change, it simply represents the current climate, and will require interpretation and analysis.

Global Historical Climatology Network - Daily[5]
The Global Historical Climate Network was created to satisfy the demands of climate research and monitoring projects that require data at a sub-monthly temporal resolution. It comprises daily land surface observations from across the world (e.g., assessments of the frequency of heavy rainfall, heat wave duration, etc.). Observations from the World Meteorological Organisation, Cooperative, and CoCoRaHS networks are included in the dataset. If a station is monitored, the information contains maximum and lowest temperatures, total precipitation, snowfall, and snow depth on the ground. This dataset, like the preceding one, cannot be utilised to quantify all elements of climate variability and change without additional processing. Furthermore, the stations providing daily observations were not managed to fulfil the needed requirements for climate monitoring in general. Rather, the stations were set up to address the needs of agriculture, hydrology, weather forecasting, aviation, and other industries.

[5]**Global Historical Climatology Network - Daily**

https://www.ncei.noaa.gov/metadata/geoportal/rest/metadata/item/gov.noaa.ncdc:C00861/html

Summary
The main takeaway we can take is that climate change datasets should be, by nature (as the data is already analyzed and processed), much lighter and easier to handle than climate datasets. For example, we can compare the “Global Climate Change Data” dataset which is about 150 megabytes in size, with the “Global Climate Station Summaries” which is about 350 gigabytes. However, the fact that the data is already analyzed and processed, and in addition with the lightness that comes with it, can also possibly be disadvantageous.
There is much less data to work with, both in quality and quantity, which can make the project poorer in terms of the information transmitted. Working with heavier datasets will require a lot more data research, but can reflect positively in the solution’s quality.
Figure 5.2.1 shows a summary of the data that comprises the datasets listed.

Table 5.2.1

Table comparing the datasets listed by a few of their attributes.

	Land Temperature	Ocean Temperature	Humidity	Precipitation	Wind	...
Global Climate Change Data	x	x				
Global Climate Station Summaries	x	x	x	x		
Global Historical Climatology Network - Daily	x	x	x	x	x	x

5.2 Technologies study

It was previously mentioned that the project will use mainly web technologies. We utilized this preliminary stage of development to research technologies that can create a functional synergy between the data aesthetics engine and the web platform, essentially creating a singular working application. Some investigation was conducted into finding a possible framework for the operation of this application, with the possibilities of having a client-side interactive input-output platform, a server-side engine that is capable of collecting data from the client-side platform and from external Application Programming Interfaces (API), and store it in a database, and the publication of outputs to external platforms such as social media. Fig. 5.2.1 exhibits a conceptual outline of this application.

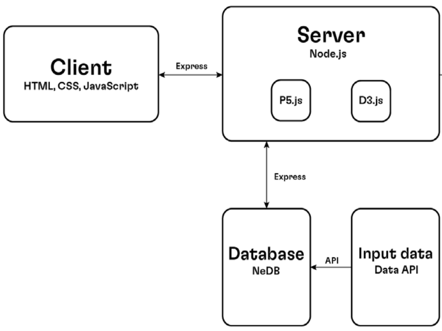


Figure 5.2.1

A diagram of the intended outline of the project's system.

Node.js[6] would be the main stage of the application, as an asynchronous event-driven JavaScript runtime environment, working as the bridge between all platforms used. The client-side platform would run on the Node.js server, allowing us to create an accessible website along with the Express[7] web application framework. Inside the Node.js engine, there would be implementations of the D3.js and P5.js[8] that would work collaboratively to produce the data-driven visuals that could either be used internally by the developers, or as output to the client platform or to the external platforms. D3.js is a JavaScript library for manipulating documents based on data, and P5.js is a JavaScript library for creative coding. The data used by the solution, either coming from the external datasets or from input data from the client platform, would be stored in a database powered by NeDB[9], which is a lightweight embedded document DBMS written in JavaScript. It should be noted that the data stored in the NeDB database would only be the data temporarily necessary for generating the visuals at hand, as it was not made for storing large amounts of data. Finally, the Node.js server would also allow the application to use the APIs. The APIs could function as inputs, for example, allowing us to receive the climate datasets from external sources, or as outputs, to publish the generated visuals to social media.

[6] **Node.js**
https://nodejs.dev/

[7] **Express**
https://expressjs.com

[8] **P5.js**
https://p5js.org

[9] **NeDB**
https://dbdb.io/db/nedb

6. Approach

In this section, we describe and analyze all the work put into this dissertation's intended solution. We start with two critical subsections: the first one (6.1) details the work put into the data aspect of the solution, from its collection to the analysis and processing; while the second (6.2) describes how the data was developed into a data artefact that fulfils the goals we set earlier as a work of data-driven design. The following subsection (6.3) comprises the development of the web platform, the central stage of the work where the data artefact can be viewed and interacted with. The last subsection (6.4) describes how the solution was disseminated, including its visual characteristics and how we proceeded with the divulgation.

6.1 Data

The first step of the process was to continue the research into climate data that we started as Preliminary Work (see section 5.1), where we mainly researched climate and climate change datasets. The first step of the process was to delve into some research about what actually is climate and climate change data. It was previously stated that the data utilised could fall into two categories: (I) accurate, direct climate data that will require treatment and analysis to understand how it depicts climate change or (II) data that already represents climate change. The first impression of this research phase was that the first option would eventually prove ineffective. We found climate change to be mainly brought to light to a human understanding not in actual climate data, such as temperature, humidity, and others, but in the information that is more easily translated into our everyday life. This belief might sound familiar, as in section 4.3, it was indicated that it was a challenge to translate the massive and complex climate change data into something that the general public could comprehend and that it was primarily possible by creating chronological narratives that displayed the impacts of climate change at personal levels. Similar reasons were behind the gradual decrease of the use of the term “global warming” to use “climate change” instead — not only is “global warming” just one part of climate change, but this could also lead to confusion and doubts when the planet was still reaching colder temperatures, resulting in people not relating to the “warming” part (Enten, 2014).

As such, the objective at this stage was to understand what data could be understood by everyone regardless of scientific knowledge and effectively explain what is happening around climate change. At this point, we decided that the best way to achieve this was to delve into the **causes** and **consequences** of climate change. However, the problem persisted, as the direct causes and consequences of climate change, like the greenhouse effect and the global surface temperature anomaly, were also challenging to understand and irrelevant to our intended audience. The key was to inquire about the indirect causes of climate change, such as what causes the greenhouse effect and the impacts of the global surface temperature anomaly, and how they relate to our lives in the short and long term.

As previously mentioned, the data would also be organised by country and year to construct a chronological narrative of climate change at a personal level. So, we outlined seven both direct and indirect causes and consequences of climate change, prioritising the indirect ones, and ended up selecting the data detailed in the following sections.

Causes

Carbon Dioxide

As previously stated, the main driver of climate change is the greenhouse effect. The primary greenhouse gas emitted by human activity is carbon dioxide (CO_2) (US EPA, 2015). As part of the Earth's carbon cycle, carbon dioxide is naturally present in the atmosphere (the natural circulation of carbon among the atmosphere, oceans, soil, plants, and animals). Human activities affect the carbon cycle by releasing more CO_2 into the atmosphere and modifying natural sinks' ability to take and store CO_2 from the atmosphere, such as forests and soils. CO_2 emissions can then, for the sake of the solution, be classified as the leading direct cause of climate change.

Fossil fuels

The decay of buried carbon-based creatures that died millions of years ago produces fossil fuels (ClientEarth Communications, 2022). They produce carbon-rich deposits, which are mined and burnt to generate energy. They are non-renewable and supply around 80% of the world's energy. They also create plastic, steel, and various other items. When fossil fuels are used, they emit significant volumes of carbon dioxide. According to the IPCC, emissions from fossil fuels are the primary driver of global warming. As such, the consumption of fossil fuels can be classified as the leading indirect cause of climate change.

Fertilizers

Nitrogen is one of the essential elements for plant growth (Manthiram, 2021). Plants, however, cannot absorb nitrogen from the air like they can absorb carbon dioxide or oxygen. In the early 1900s, scientists developed a method for mass-producing ammonia, a nitrogen-containing chemical that plants can take in from the soil. Ammonia is now the world's second-most-produced chemical, widely employed as a very effective fertilizer. However, ammonia production accounts for between 1% and 2% of global CO_2 emissions. Fertilizers emit greenhouse gases after being applied to fields by farmers. Crops only absorb around half of the nitrogen provided by fertilizers. Much of the fertilizer sprayed flows off into streams or is broken down by soil bacteria, releasing the potent greenhouse gas nitrous oxide into the sky. Although nitrous oxide contributes just a minor portion of global greenhouse gas emissions, it heats the globe 300 times more than carbon dioxide.

Deforestation
Forests store a significant quantity of carbon (Dean, 2019). When forests are cut or burned, stored carbon, primarily CO_2, is released into the atmosphere. While forests are major carbon sinks, absorbing carbon dioxide from the atmosphere, the carbon stored in these sinks is part of an active, relatively fast carbon cycle. When living organisms expire and degrade, the carbon they once held is released into the atmosphere. The loss of carbon sinks due to deforestation has contributed to an increased amount of carbon dioxide in the atmosphere - more than it can be absorbed by existing carbon sinks such as forests.

Meat industry and consumption
As they digest grasses and plants, cows and other ruminant animals (such as goats and sheep) release methane, a potent greenhouse gas (Waite, Searchinger, Ranganathan, & Zionts, 2022). This process is known as "enteric fermentation," and it is the cause of cow belches. Manure emits methane as well. Nitrous oxide, another potent greenhouse gas, is also released by ruminant waste on pastures and chemical fertilizers used on crops grown for bovine feed. Indirectly, but no less crucially, expanding beef production necessitates increased land use, which leads to deforestation.

Renewable sources of energy
In any debate about climate change, renewable energy is frequently at the top of the list of improvements that the globe can make to mitigate the worst consequences of increasing temperatures (Nunez, 2019). This is because renewable energy sources like solar and wind do not create carbon dioxide or other greenhouse gases contributing to global warming. It is the underutilization of renewable sources, thus, that is categorized as a cause of climate change.

Overpopulation

In the solution's scope, the Population (or overpopulation in this case) can be used not only as a cause of climate change but also as a measurement of the country's dimension. Climate change is inextricably related to population expansion (Population Connection, n.d.). Every new person increases carbon emissions and the number of climate change victims. Slowing population increase can dramatically cut future greenhouse gas emissions, according to research assessing the implications of alternative population predictions on future economic development and energy usage. Using different population forecasts in climate models reveals that higher population increase leads to higher emissions.

Consequences

Surface temperature anomaly

Surface temperature and precipitation anomalies are the primary repercussions of climate change, with other effects being considered indirect. Land surface temperature refers to how hot the "surface" of the Earth feels to the touch at a particular region (National Centers for Environmental Information, n.d.). Temperature anomalies are more important in climate change research than absolute temperature. A temperature anomaly is a deviation from the average or baseline temperature. Averaging 30 or more years of temperature data is commonly used to get the baseline temperature. A positive anomaly implies that the observed temperature was higher than the baseline, whereas a negative anomaly indicates that the measured temperature was lower.

Precipitation anomaly

Climate change has the potential to alter the intensity and frequency of precipitation (US EPA, 2016). Warmer oceans cause more water to evaporate into the atmosphere. More moisture-laden air can create more intense precipitation, such as heavier rain and snow storms, as it flows over land or converges into a storm system. Heavy precipitation does not necessarily indicate that the overall amount of precipitation at a site has risen; it just indicates that precipitation is happening in more intense bursts. Variations in precipitation intensity, when paired with changes in the time between precipitation episodes, can contribute to changes in overall precipitation totals.

Decrease of agricultural land

Soil moisture has declined notably in the Mediterranean area and increased in portions of northern Europe since the 1950s (European Environment Agency, 2019). An analysis predicts similar repercussions in the following decades as average temperatures continue to climb and rainfall patterns shift, with potentially catastrophic consequences for food production. With population growth predicted, global food production must expand rather than decline, which is heavily dependent on preserving good soil and sustainably managing agricultural regions. Research on impacts and susceptibility also emphasises additional effects of climate change on soil, such as erosion, which may be increased by severe weather events such as heavy rain, drought, heat waves, and storms.

Biodiversity loss

Humans are intricately linked to many species that are threatened by rising temperatures, whether they pollinate crops, filter rivers and streams, or feed us (Jones, 2022). If the Earth heats by 1.5°C, up to 14 per cent of all plants and animals on land would face a severe danger of extinction. Some plants and animals, particularly those living in arctic regions, would most likely encounter temperatures beyond their historical experience in the coming decades. Even 1.2°C of warming — barely over present levels — puts many ecosystems in danger from heat waves, drought, and other climatic extremes.

Air pollution

While not a consequence of climate change, air quality is inextricably tied to the Earth's climate and ecosystems globally, as burning fossil fuels is one of the leading causes of air pollution and contributes to greenhouse gas emissions (WHO, n.d.). Particulate matter, carbon monoxide, ozone, nitrogen dioxide, and sulfur dioxide are pollutants of significant public health concern. Air pollution reduction policies, therefore, provide a win-win strategy for both climate and health, lessening the burden of sickness caused by air pollution while also helping the near and long-term mitigation of climate change.

Poverty

The global impact of the repercussions of climate change is unequal (McCarthy, 2020). Above all, they endanger the world's most vulnerable populations. People living in poverty suffer the most from climate change. Because climate change impacts everything from where people may live to their access to health care, millions may fall further into poverty as environmental conditions deteriorate. Climate change exacerbates disparities inside a country, and stratifies international relations to a greater extent since some countries are more vulnerable to it than others. Furthermore, developing countries have fewer resources to address the issue.

Economic crisis

Climate change can cause significant economic loss and raises long-term dangers (International Monetary Fund, n.d.). It is a global externality — emissions from one nation affect all countries by increasing the stock of heat-raising gases in the Earth's atmosphere, which causes warming. Climate change is expected to have a considerable economic impact on many countries, with many low-income countries particularly vulnerable. Climate damage and stranded assets, such as coal deposits that become uneconomic with carbon pricing, pose hazards to nonfinancial business sectors, and the disruption may impact company balance sheet quality. Just as Population, the economy can not only be a measure of the consequences of climate change but also of the country's dimension.

The resulting final set of data will then be divided into two, each part comprising seven attributes. Of these seven, two are directly related to climate change, and one is also a measure of the country's dimension, but all are causes or consequences of climate change and are interconnected. This resulted in an approach that does not disregard scientific data — instead, it complements it with data that touches each of us personally, allowing the resulting data to be eye-catching, raise awareness, and educate the general audience, which aligns with the knowledge we gained from our Literature Review.

Having researched and worked out which data to be explored, we advanced to the technical stage of this phase: collecting the data and processing it for visualization. The criteria for selecting the datasets at this phase was that they had to comprise almost all countries and about the last thirty years. Our first and foremost point of the search was the Our World in Data (OWID) website, which aggregates hundreds of datasets not only of climate change data but of "the world's biggest problems". However, other websites, such as The World Bank Open Data (WBOD) and Climate Change Knowledge Portal (CCKP), were considered.

The following sections detail the process of collecting each individual dataset.

Causes

Carbon Dioxide[10]

The best way to measure the carbon dioxide contributing to the greenhouse effect is to measure its emissions. Although many different approaches and breakdowns of this data were found, for the sake of simplicity, the dataset chosen was the most straightforward one: Annual production-based emissions of carbon dioxide (CO_2), measured in tonnes and based on territorial emissions. This dataset, found on OWID and published by the Global Carbon Project, has a time span of 1750-2020.

[10] **Annual CO_2 Emissions**
https://ourworldindata.org/grapher/annual-co2-emissions-per-country

Fossil Fuels[11]

There are three fossil fuels: oil, coal and gas, and their consumption (to produce energy) emit CO_2 into the atmosphere. So, the best way to measure its impact is to measure the cumulative (oil, coal and gas) consumption (in tonnes) to produce energy. A Fossil Fuels Consumption dataset was found on OWID, published by BP Statistical Review of World Energy and has a time span of 1965-2021.

[11] **Fossil Fuels consumption**
https://ourworldindata.org/grapher/fossil-fuel-primary-energy

Fertilizers[12]

As mentioned previously, both the production and consumption of fertilizers emit greenhouse gases. However, most of the data available pertained to the consumption of fertilizers — regardless, there cannot be consumption without production, so both served as a measure of the impact. This conclusion led to choosing the data as total fertilizer consumption, as the sum of synthetic inputs of nitrogen, potassium and phosphorous, plus organic nitrogen inputs. The dataset, which was also measured in tonnes and was found on OWID, has a timespan of 1961-2019 and was published by the United States Department for Agriculture.

[12] **Fertilizer consumption**
https://ourworldindata.org/grapher/fertilizer-consumption-usda

Deforestation[13]

Although the best option for this particular data would be to measure changes in forest area, either by hectares or percentage, none of the datasets containing this data met the criteria established. We found the dataset which best represented the data was forest area as % of land area per country, which allowed us to view the differences in value effectively. The dataset was found in WBOD and published by the Food and Agriculture Organization and has a timespan of 1990-2020.

[13] **Forest area**
https://ourworldindata.org/grapher/forest-area-km

Meat industry and consumption[14]

It was previously described the multiple factors around the meat industry that contributed to the emission of green-

[14] **Meat production**
https://ourworldindata.org/grapher/meat-production-tonnes

house gases, from the animals themselves to the manure and land use. However, the general audience does not relate directly to the meat industry itself — making consumption the best measure, as it is done daily in almost every household. The dataset chosen, found in OWID, measures meat consumption in tonnes from the sum of cattle, poultry, sheep/mutton, goat, pigmeat and wild game. It was published by the Food and Agriculture Organization of the United Nations and has a time span of 1961-2018.

Renewable sources of energy[15]

This attribute was particular as using renewable energy sources is a positive factor in the fight against climate change, so it was essential to view its negative space — the lack of renewable energy sources as a cause of climate change. Multiple datasets were found regarding renewable energy production, consumption, and others. However, the chosen one presented the percentage of primary energy that came from renewable sources (hydropower, solar, wind, geothermal, bioenergy, wave, and tidal). This allowed for easier reading: the fewer the percentage, the worse for the environment. The dataset was found on OWID, published by BP Statistical Review of World Energy and had a timespan of 1965-2021.

[15]**Share of primary energy from renewable sources**

https://ourworldindata.org/grapher/renewable-share-energy

Overpopulation[16]

As mentioned, the objective was to use the measure of the Population not only for the sake of climate change but also to get a sense of each country's dimension. This factor invalidated some datasets, like the population growth rate, that, although beneficial to get a sense of the rising population, failed to meet the aforementioned objective. This meant the most straightforward dataset, which also allowed us to measure the country's size, was Population by country. The dataset found on OWID was based on data retrieved from three key sources: HYDE, Gapminder and the United Nations Population Division. It has a timespan of 10,000 BCE - 2021.

[16]**Population**

https://ourworldindata.org/grapher/population

Consequences

Surface temperature anomaly[17]

In this case, there are not many ways to explore this data, just as there were not many different datasets found. The dataset chosen examined surface temperature anomaly in degrees celsius relative to the 1951-1980 global average temperature. It was found on OWID and published by the Climatic Research Unit (University of East Anglia) in con-

[17]**Surface Temperature Anomaly**

https://ourworldindata.org/grapher/hadcrut-surface-temperature-anomaly junction with the Hadley Centre (UK Met Office). It has a timespan of 1850-2017.

Precipitation anomaly[18]

Researching precipitation data proved difficult as almost every dataset found had only the long-term average precipitation per year calculated in 2017. The only website found that had accurate estimations of precipitation in mm per year was the CCKP. Still, even then, there was no dataset aggregated globally by country — only individual country datasets. This meant that the data would have to be aggregated in the later data processing. In the end, the dataset measured precipitation by country in mm per year and had a timespan of 1901-2021.

[18]**Precipitation**
https://climateknowledgeportal.worldbank.org/download-data

Decrease in agricultural land[19]

This attribute followed the same process and line of thought as the Deforestation attribute, so the dataset chosen is agricultural land as percentage of land area (of the country), allowing us to view the differences in value effectively. The dataset was found in WBOD and published by Food and Agriculture Organization and has a timespan of 1961-2018.

[19]**Agricultural land**
https://data.worldbank.org/indicator/AG.LND.AGRI.ZS

Biodiversity loss[20]

This attribute was probably the most difficult one to obtain a dataset of, as although there are multiple ways of approaching the measure of this data, there was not a straightforward dataset that represented it globally at a country level and in the desired timespan. Most of the datasets found that effectively did were of a specific set of species like Endemic birds or Fish species. We found the dataset which met the criteria and was the easiest to read pertained to the Red List Index. The Red List Index (RLI) defines the conservation status of significant species groups and measures trends in the proportion of species expected to remain extant in the near future without additional conservation action. An RLI value of 1.0 equates to all species being categorised as 'Least Concern'; hence, none are expected to go extinct soon. A value of 0 indicates that all species have gone extinct. The dataset was found in OWID, published by BirdLife International and IUCN and has a timespan of 1993-2022.

[20]**Red List Index**
https://ourworldindata.org/grapher/red-list-index

Air pollution[21]

Air pollution is also tricky to attain data on as it can be measured in many ways, most of which are not easily understandable. The emission of air pollutants, such as ammonia, and sulphur dioxide, is not as easily translatable as the emission of CO2. The unit measurement of exposure

[21]**Deaths by Air Pollution**
https://ourworldindata.org/grapher/air-pollution-deaths-country

to air pollution with fine particulate matter, μg, is not a unit that most people are familiarised with. We found the most accessible data to read that still gave a sense of the impact of air pollution and met the criteria was Deaths from air pollution. The dataset which sums the attributed deaths to indoor and outdoor pollution was found on OWID, published by the Institute for Health Metrics and Evaluation, Global Burden of Disease and has a timespan of 1990-2019.

Poverty[22]

Since there are multiple definitions of poverty and even more ways of measuring it, multiple datasets were found that represented this data. We selected the number of people living in extreme poverty (defined as people living below the International Poverty Line of 1.90 international-$ per day). We also considered the percentage of the population living in extreme poverty. However, we presumed that the number of people has more impact on an individual than the share (as opposed to other attributes such as forest area and agricultural land, where the percentage impacts more on a personal level and contributes more to the narrative than a hectare). The dataset was found on OWID, published by World Bank PovcalNet, and has a timespan of 1981-2017.

[22]**Number of people living in extreme poverty**

https://ourworldindata.org/grapher/above-or-below-extreme-poverty-line-world-bank

Economy[23]

Following the same line of reasoning as the overpopulation attribute, a dataset was needed that not only allowed to measure economic growth but also to get a sense of the country's dimension. We figure the GDP (Gross Domestic Product) was the safest measure because, as a broad measure of overall domestic production, it functions as a comprehensive scorecard of a given country's economic health. The dataset found measured the national GDP adjusted for inflation and for differences in the cost of living between countries in a timespan of 1952-2019. It was found on OWID and published by Feenstra, R. C., Inklaar, R. and Timmer, M.P. (2015).

[23]**National GDP**

https://ourworldindata.org/grapher/national-gdp

Data processing

After the selection and collection process, we ended up with fourteen high-quality datasets from credible sources, with a large span of both countries and years, in Comma Separeted Values (CSV) files. The next step would be to process this data and compile it into a singular dataset.

For the data analysis and manipulation stage, we used Pandas, a data tool built on top of the Python programming language. The primary function of the initial code is straightforward, as its purpose was merely to merge all datasets based on Country and Year. It can roughly be understood through this excerpt:

```
csv_list = []
csv_merged = pd.merge(csv_list[0],csv_list[1],on=["Entity","Year"])
for i in range(2, len(csv_list)):
  csv_merged=pd.merge(csv_merged,csv_list[i],on=["Entity","Year"])
```

Figure 6.1.1

Excerpt of the code that merges the datasets.

Most of the other lines of code pertained to rearranging some of the datasets, as they needed to be all of similar layout and columns to be merged. However, since almost all came from the same source (OWID), few did not already have the same layout, which meant minimal additional effort was required. Few other lines were required for data cleaning.

The result was two similar datasets, one for the causes and the other for consequences. Since it was merged based on the Years and Countries that every dataset had in common, it ended with the following items:

- Years: 1993 - 2017 (Total of 24 Years).
- Countries: Algeria, Australia, Austria, Azerbaijan, Bangladesh, Belarus, Belgium, Brazil, Bulgaria, Canada, Chile, China, Colombia, Croatia, Denmark, Ecuador, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, India, Indonesia, Ireland, Israel, Italy, Japan, Kazakhstan, Latvia, Lithuania, Luxembourg, Malaysia, Mexico, Morocco, Netherlands, Norway, Pakistan, Peru, Philippines, Poland, Portugal, Romania, Slovenia, South Africa, Spain, Sri Lanka, Sweden, Switzerland, Thailand, Trinidad and Tobago, Turkey, Turkmenistan, Ukraine, United Kingdom, United States, Uzbekistan and Vietnam (Total of 59 countries).

Although the time span proved to be somewhat disappointing as it is outdated by five years and started 29 years ago, it still met the criteria and is large enough to be able to construct the narrative we expected. We were also satisfied with the pool of countries as we were able to represent every country (except Antarctica) and very different sizes, cultures, and levels of industrial advancement.

In Table 6.1.1, we can observe an excerpt of the resulting datasets, including the attributes and example of values.

Country	Year	CO2 emissions	Fertilizer consumption	Forest area	Fossil Fuels consumption	Meat production	Population	Renewables %
Algeria	1993	76737628	142089	0.7	314.575	436014	25758872	0.12
Algeria	1994	78806834	106172	0.7	311.229	453646	26400468	0.26
Algeria	1995	79883305	112284	0.69	319.639	469412	27028330	0.17
...	...	...	...	...	...	...	...	...
Vietnam	2015	193003686	3418372	46.35	659.056	4709383	92677082	19.31
Vietnam	2016	192765567	3325890	46.37	697.203	4938792	93640435	24.18
Vietnam	2017	195249310	3361794	46.49	698.723	5072358	94600643	20.44

Country	Year	Agricultural land	Deaths by Air Pollution	Surface temp. anomaly	GDP	Precipitation	Red List Index	Inhabitants in Poverty
Algeria	1993	16.32	14899	0.5	198018334720	59.76	0.91	1646007
Algeria	1994	16.64	15168	0.48	199213318144	79.72	0.91	1762662
Algeria	1995	16.65	15368	0.65	208607150080	76.38	0.91	1618399
...	...	...	...	...	...	...	...	...
Vietnam	2015	39.18	73330	1.26	511142723584	1834.01	0.74	2011835
Vietnam	2016	39.26	72409	0.22	518788218880	1864.5	0.73	1690023
Vietnam	2017	39.25	71712	0.18	558548910080	1967.96	0.73	1698982

Table 6.1.1

Excerpts of the Causes dataset and the Consequences dataset.

With the structured data at hand, we proceeded to the next development phases. Further data transformations will be described in the following sections, as it is tightly related to the comprehension of the development of the resultant visualization technique.

6.2 Data artefact

The first step in designing the visualisation was to assess the knowledge we gained from the Literature review and use its conclusions to establish some objectives. The objectives we established for the visualisation were for it to:

- Use data that had meaning to the general audience (accomplished in the previous stage);
- Be readable, *i.e.*, the viewer can retrieve and understand information from it;
- Have value as a form of data art and aesthetics;
- Be eye-catching and inspiring for the viewer to want to explore more;
- Have value from a graphic design perspective;
- Be capable of being used and explored in an awareness campaign and, consequently, a visual identity.

The Globe

Having these goals in mind, we sought out ideas and inspiration that would eventually lead to a visualisation design of our own. Being a climate-focused work, we started by taking inspiration from the visuals of Planet Earth as a globe, as seen in Figure 6.2.1.

Planet Earth's area can be divided into many continents, countries, cities, climates, seas, oceans, rivers, etc. Each of these "divisions" represents an area on the globe and, consequently, information. So, we started exploring ways to replicate this line of thought as a visualisation tool, starting by exploring other graphic design artefacts that replicated a globe, which can be seen in Figure 6.2.2.

Figure 6.2.1

Photograph of the Planet Earth from which we took initial inspiration.

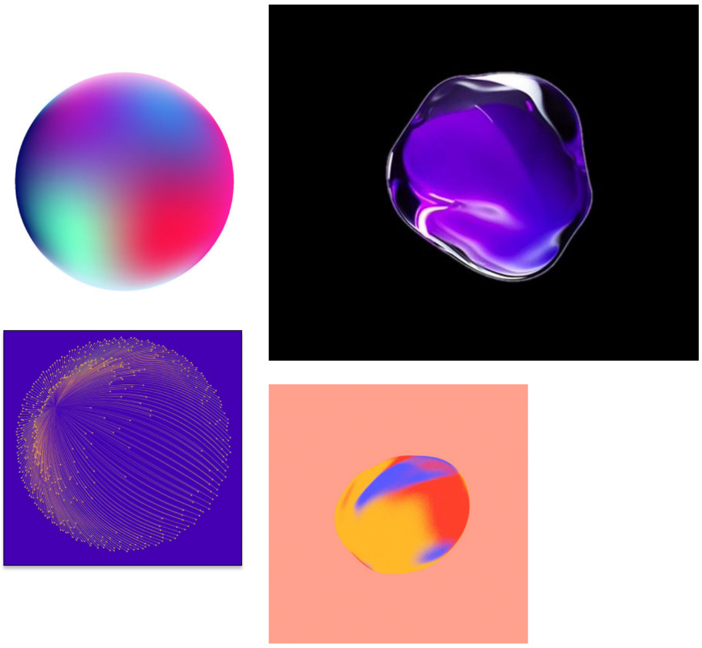


Figure 6.2.2

A set of visual artefacts gathered that replicated a globe that we used to retrieve inspiration from.

The idea of a globe-based visualisation artefact started taking form. We figured the globe could transmit the information through divisions in its area as the visual mark, with each area of different size and colour (and, optionally, relief) as its visual channels.

The Voronoi

The next step of the process was researching visualisation techniques that had a similar process of dividing an area into different sections, thus representing information. We quickly turned our attention to Treemap diagrams. A treemap is a visual method for displaying hierarchical data that uses nested rectangles to represent the branches of a tree diagram. Each rectangle has an area proportional to the amount of data it represents (Shneiderman & Wattenberg, 2001).

Even though treemaps' focus is on hierarchical data, the critical aspect we retrieved from it was the use of rectangles with an area proportional to the data. Although it would not use the visualisation to its full potential, a treemap can still transmit data without the hierarchical component. So we figured this could be a good starting point.

From treemaps, we advanced to Voronoi treemaps (Balzer & Deussen, 2005). Instead of being created from a tiling algorithm designed to give each rectangle an aspect ratio of one and create a sense of order in the display of the input data, a Voronoi algorithm is used. Voronoi treemaps visualise hierarchical data by recursively partitioning convex polygons using weighted centroidal Voronoi diagrams. The polygon areas are proportional to the relative weights of their corresponding nodes (Nocaj & Brandes, 2012).

To define a Voronoi Diagram, suppose there are n points scattered on a plane. The Voronoi diagram of those points subdivides the plane into exactly n cells enclosing the portion of the plane closest to each point. This produces a tessellation that completely covers the plane. As an illustration, in Figure 6.2.3, 100 random points are plotted and their corresponding Voronoi diagram. Every point is enclosed in a cell whose boundaries are exactly equidistant between two or more points. In other words, all of the area enclosed in the cell is closer to the cell's point than to any other point.

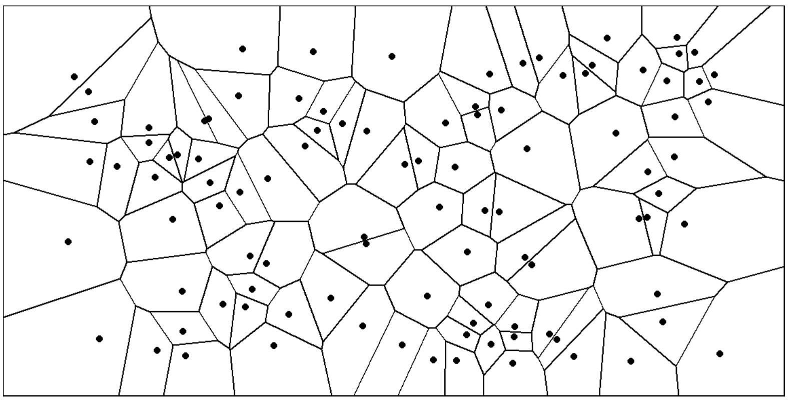


Figure 6.2.3

An example of a randomly generated Voronoi diagram, including the cells' centroids.

A fascinating aspect of the Voronoi algorithm is that its pattern is prevalent in nature, as seen in Figure 6.2.4. We found this very exciting as it further cemented the visualisation connection to the planet and climate.

Figure 6.2.4

Examples of the Voronoi algorithm being applied in nature.

The final step of the sequence, circling back into our initial concept of a globe, led us to Spherical Voronoi Diagrams. These diagrams are precisely what they sound like: Voronoi diagrams mapped onto the surface of a globe, as exemplified in Figure 6.2.5.

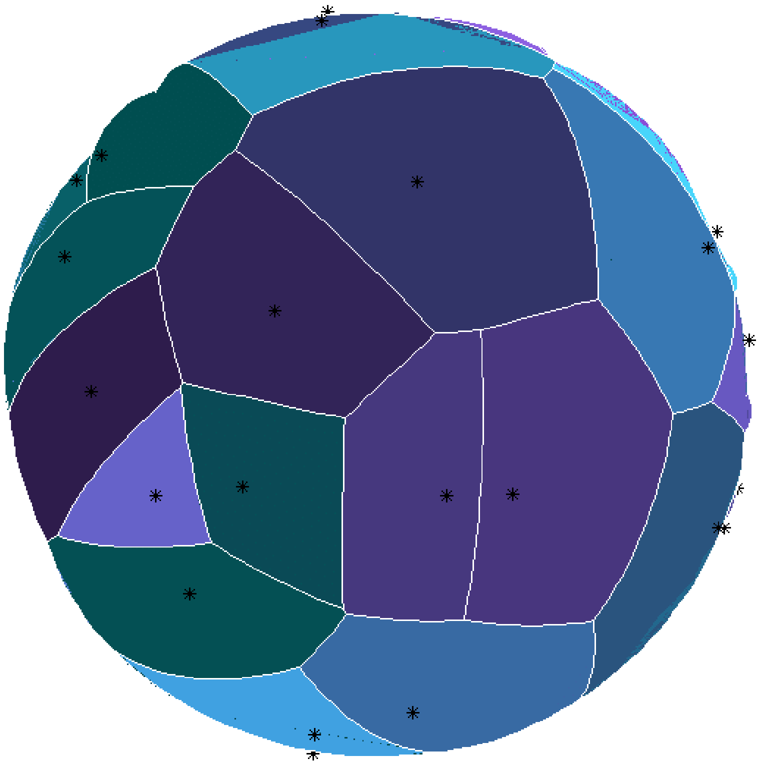


Figure 6.2.5

An example of a Voronoi Spherical Diagram.

This visualisation technique ended up being almost exactly what we were searching for — it only lacked by simply mapping the surface of the sphere and not having relief, which, although not an essential visual channel, could contribute to a more visually appealing, exciting, and ultimately, memorable result. However, we did not give up on that idea and figured it would be an additional exploration once we implemented it.

Initial sketches

To better understand what we were looking for, some sketches were drawn on paper, which can be seen in Figure 6.2.6.

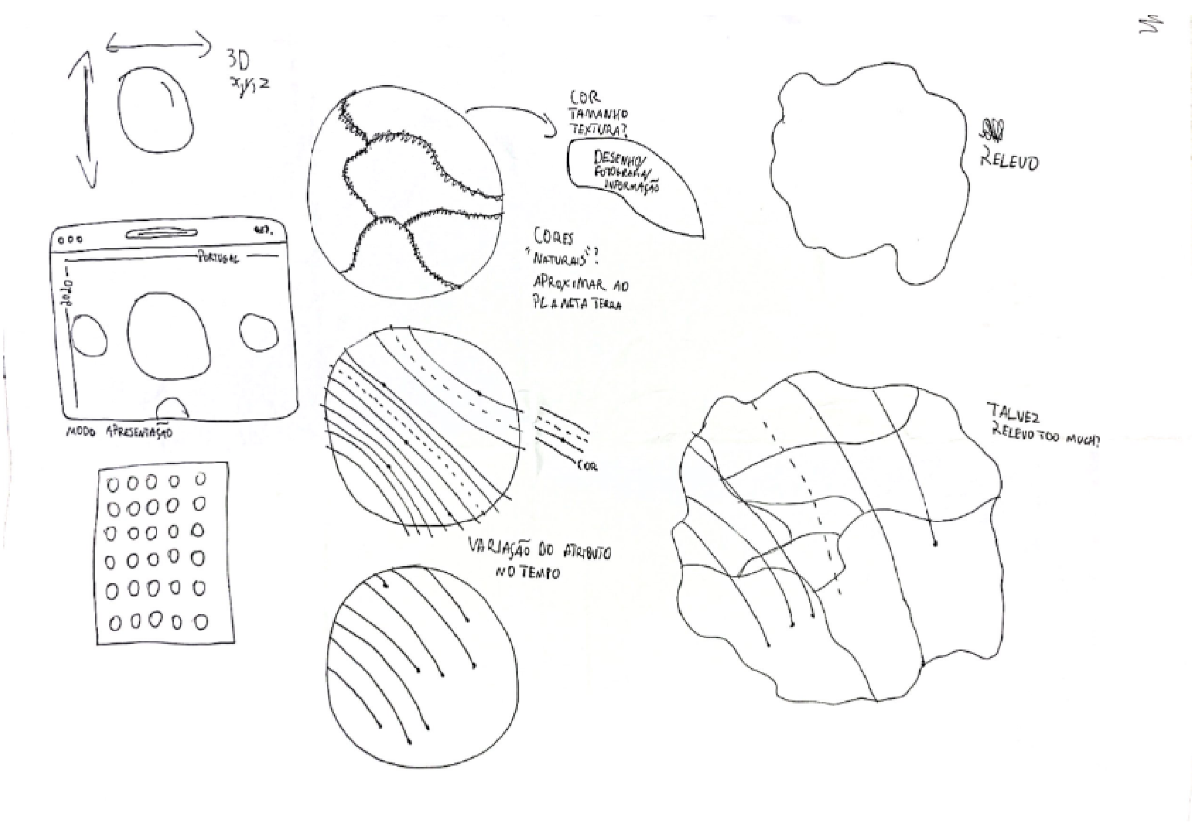


Figure 6.2.6

Several small sketches of ideas of the data artefact envisioned, and possible applications.

Figure 6.2.7 represents our best idea of what we wanted the outcome to resemble.

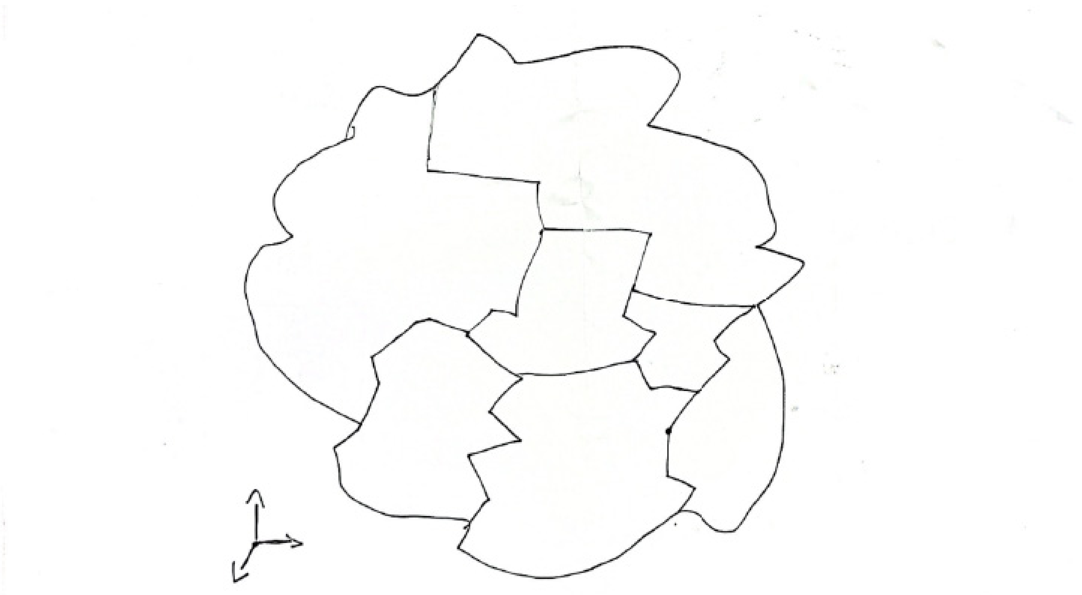


Figure 6.2.7

The final sketch that best represents the intended result.

This visualisation would translate into the scope of our work by generating two artefacts for each combination of Country & Year: one for the causes dataset and the other for the consequences dataset. This meant generating a total of 2832 different artefacts, which was an exciting thought on the development's pathway. Nonetheless, some questions were raised at this point.

If a Voronoi diagram represents weighted data, how could we visualise a dataset with multiple attributes, each with different scales and units of measure?

For each pair of country & year, we calculate the weight of the attributes relative to each other (the process of which is described later in this chapter). This would mean that the readability of the actual value of the data would be lost — but we took this as an acceptable loss as it allowed us to generate a single, aesthetic data artefact, which would always be a difficult challenge if the actual values were to be readable.

Furthermore, even if it lost readability, the aesthetic component would always draw the user to want to explore more and delve into the data themselves, as described in the Literature Review section. However, this also meant that the interface implemented for the visualisation would have to consider this lack of readability of the artefact, having ways of reading and analysing the data. Further depth into these topics is described later in the dissertation (see Section 6.3).

The engine

At this point, we describe one of the most crucial aspects of the work: the data engine that receives the processed data and returns our final artefact. The engine implemented receives data that was previously processed and adapted to a Voronoi algorithm. The resulting artefact also went through a visual refinement process.

We started by searching implementations of Voronoi treemaps and spherical Voronoi diagrams. "*d3-voronoi-treemap*" was our first find, a D3.js module which produces Voronoi Treemaps. Figure 6.2.8 shows an example of an artefact generated using this module.

Figure 6.2.8

An example of a dynamically generated hexagonal voronoi treemap using the D3.js Voronoi Treemap Module.

Although this module proved helpful in a later phase, we continued our search as it only produced 2D maps. "*d3-geo-voronoi*" is a very similar plugin capable of producing spherical Voronoi diagrams, which was what we were looking for. However, we found it was not exactly what we expected, as it offered little visual manipulation and focused on actual spherical data.

We found a very compelling implementation of "Delaunay + Voronoi on a sphere"[24] on the "*Red Blob Games*" website by Amit Patel, which met much of our needs and expectations. This method renders 3D graphics of an artefact similar to a "Voronoi Planet" (see Figure 6.2.9). It is a much more visually appealing rendition of the spherical Voronoi diagram, as it not only renders a 3D relief, its WebGL-based implementation allows it for the manipulation typical in computer graphics.

This method begins by calculating the Delaunay triangulation of the set of points, which is equivalent to the nerve of the cells of the Voronoi diagram, *i.e.*, that triangulation of the convex

[24] **Delaunay + Voronoi on a sphere**

https://www.redblobgames.com/x/1842-delaunay-voronoi-sphere/

hull of the points in the diagram in which every circumcircle of a triangle is an empty circle. It then uses that triangulation to generate the Voronoi regions, formed by connecting all the triangle circumcenters for the triangles touching one of the input points. Finally, it renders the Voronoi regions in a computer graphics approach by using regl.js, which is a functional abstraction for WebGL. As such, we decided to base our implementation on this method.

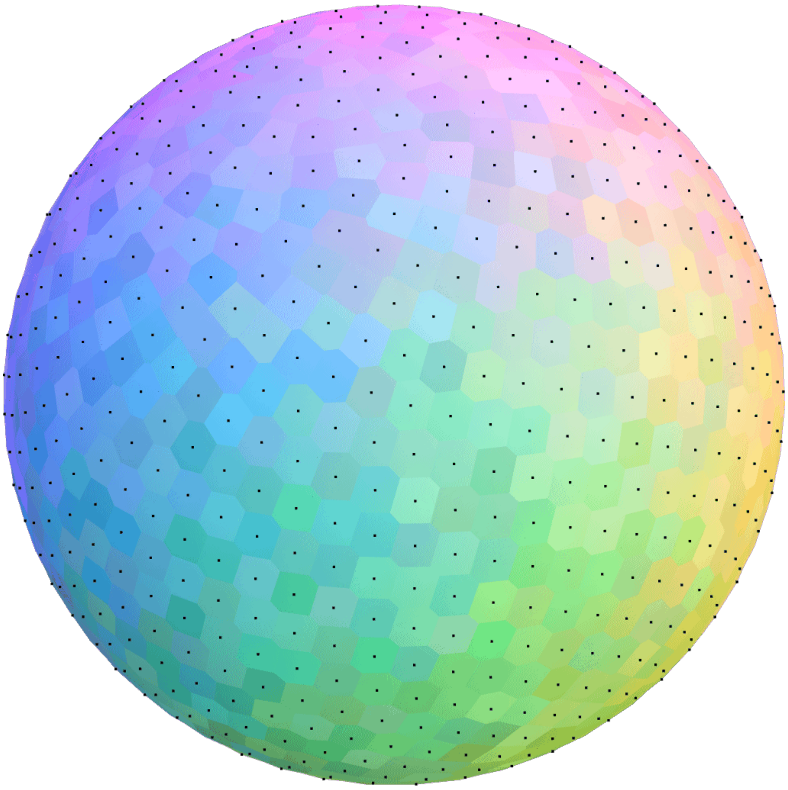


Figure 6.2.9

An example of the Voronoi Planet Code, using an algorithm to generate the centroids.

The implementation

We began implementing an engine that took our data and turned it into our desired version of the spherical Voronoi diagram, using our iteration of the Voronoi Planet. Since it involved some exploration and trial and error, at this point, we also implemented a live web development server to test the code in real-time. As our data was still needing further processing to be used in this context, we used a placeholder JavaScript Object Notation (JSON) file with data from "The Global Economy by GDP"[2] retrieved from a code repository made available on Bl.ocks website by the user LEBEAU Franck.

The engine begins by using D3.js to read a JSON file which returns a weighted hierarchy. Because the original Voronoi Planet code randomly drew the points used to calculate the Delaunay triangulation from an algorithm, the next step would be to get a set of points that would result in a division of areas representing the data. We accomplished this by first drawing a 2D Voronoi treemap

[25] **The Global Economy by GDP dataset**

https://bl.ocks.org/Kcnarf/fa95aa7b076f537c00aed614c29bb568 from the hierarchy obtained using the D3.js Voronoi Treemap module. Next, we used the D3.js Polygon module to get the centroids of each cell in cartesian coordinates, and using the D3.js Geo module projection's capabilities, we converted the cartesian coordinates into latitude and longitude coordinates. With this set of points, we could calculate a 3D Delaunay triangulation using the Delaunator.js library, similarly to the Voronoi Planet code (as shown in Figure 6.2.10). This, in turn, allows us to generate the Voronoi geometry using Patel's code, rendering it to an HTML canvas using regl.js.

To summarise, this is the outline of the final algorithm that would render our intended artefact:

1. Read the data using D3.js, returning a weighted hierarchy;
2. Draw a 2D Voronoi treemap using the D3.js Voronoi treemap module;
3. Get the centroids of each cell from the Voronoi treemap using the D3.js Polygon module;
4. Use the Equirectangular projection from the D3.js Geo module to convert the cartesian coordinates of each centroid into latitude and longitude coordinates;
5. Generate a 3D Delaunay triangulation from the spherical coordinates with the Delaunator javascript library;
6. Generate a Voronoi geometry from the Delaunay triangulation;
7. Render the Voronoi geometry using regl.js.

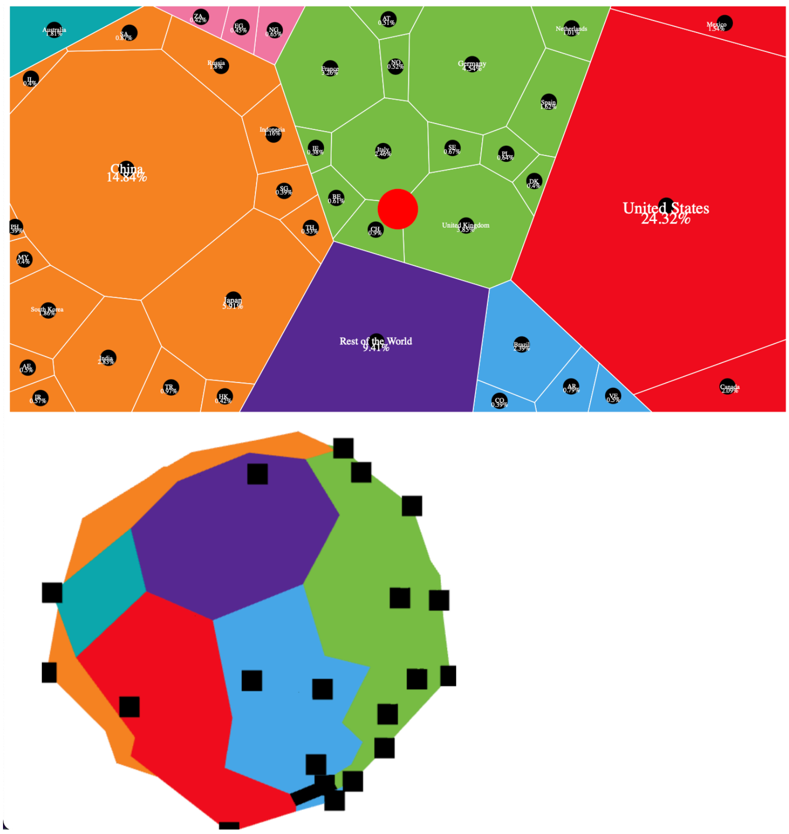


Figure 6.2.10

First experiment of the engine developed, with the 2D Voronoi Treemap (top) and its generated Voronoi Planet (bottom).

Figure 6.2.10 shows the first experiment of the data engine developed, using a placeholder dataset. We can see the 2D voronoi diagram generated (image on the top) and the resulting Voronoi Planet (image on the bottom).

This is the final system used to generate each artefact corresponding to a specific country and year, either causes or consequences data. Since the Voronoi algorithm allows for finding different spatial arrangements of the same data, a different artefact is generated each time the engine is used for a specific dataset. With enough cells, there is a possibility that every artefact generated is unique.

Data transformation

As it was described previously, we implemented an artefact using a Voronoi engine, usually used to visualise hierarchical, weighted data. This requirement meant additional efforts in processing our dataset to be usable in the developed system. Since the datasets are a compilation of multiple datasets with multiple variables across different scales and measurements, adapting all these attributes into a single hierarchical, weighted data proved challenging. Nonetheless, the result was worth its effort, as it allowed us to view very different data in a single artefact, as aforementioned.

To accomplish this, we took a step back into our Python data processing script with the goal of further processing our data so that the script returned two individual datasets in JSON format for each country and year — one for causes and another for consequences, with its attributes weighted relative to each other. In the end, the script would return files that could be read through the engine.

This is the process that the data needed to go through to return a weighted hierarchy:

1. Normalise every column (except percentage values) to a scale of 0 to 100 by the Min/Max normalisation method;
2. For each column, get the sum of all its values;
3. Sum all the sums of each column;
4. Find the relative weight of each column by dividing its sum by the sum of all sums.

This process results in hierarchical, weighted data by finding the relative weights of all the attributes, compared to each other, per the objective established. Since, as also previously stated, the actual readability of the data would be lost in the artefact, the original value of each attribute was also saved onto the dataset.

Parametrisation

Having developed the visualisation system and further processed our data to be able to be used by it, we advanced onto the visual development of the artefact, intending to make it as aesthetic as possible without losing the idea and readability of the initial concept.

We loaded our data into the development server used, which at this point simply rendered a 2D Voronoi treemap of the data and the resulting Voronoi Planet artefact (as shown in Figure 6.2.11).

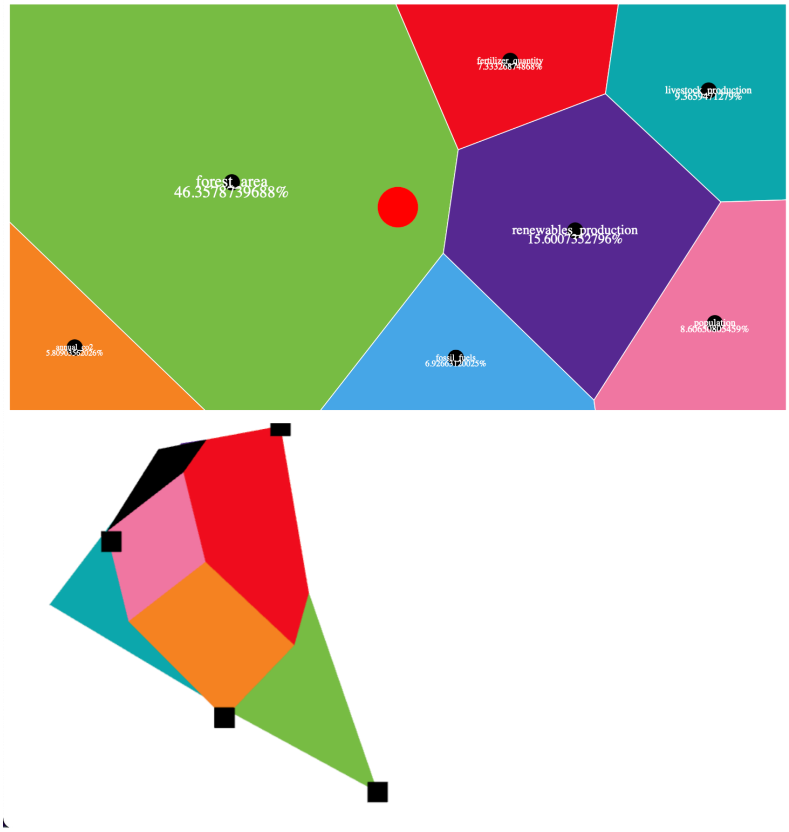


Figure 6.2.11

First attempt at using our own dataset to generate the artefact.

The first thing we noticed was that with just seven cells (one for each attribute of our datasets), much of the “roundness” of the sphere was lost and was instead very “spiky” looking. The cells had turned into pyramids because of how the 3D Voronoi geometry was generated. The reason this had not happened before was that the placeholder dataset we were using had about 40 cells, so even though it still had a noticeable “relief” texture in comparison to the original Voronoi planet (which was our goal regardless), it was still very “globe-looking”. Our method of bypassing this obstacle was very straightforward: Instead of having just one cell for each attribute, we took advantage of the hierarchical data aspect and divided each cell into multiple, smaller cells. For example, if the “CO2 Emissions” cell had a 30% weight on the diagram, we would divide it into multiple, smaller "children" cells that would eventually add up to a 30% weight. We did this by once again (and for the last time) returning to our Python script and for each cell, creating multiple children and dividing their weight by the total number of children.

Figure 6.2.12 shows the result when dividing each cell into ten children:

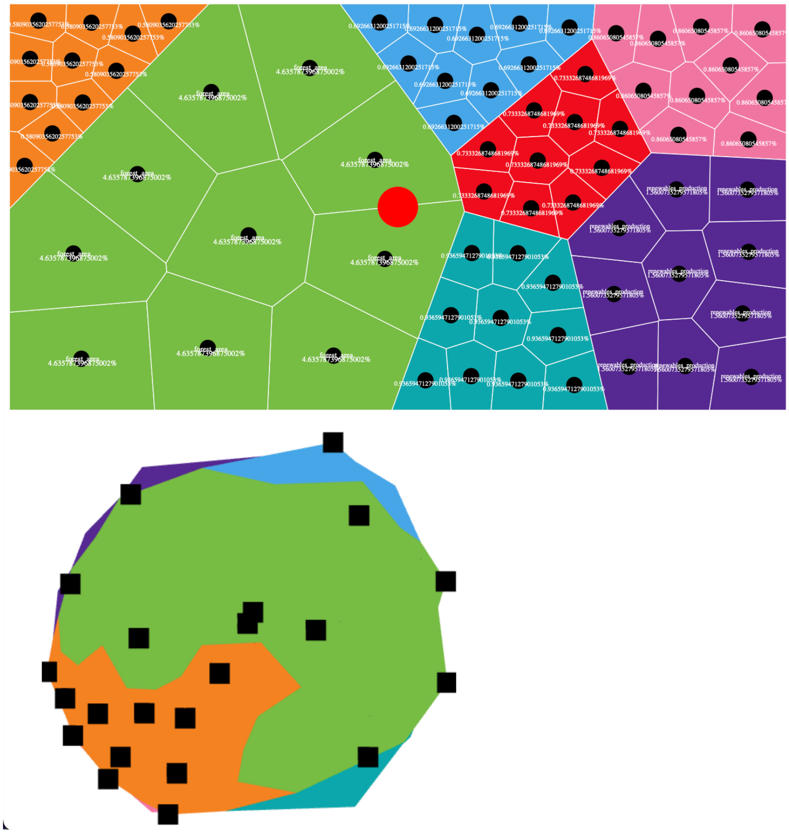


Figure 6.2.12

Second attempt at generating the artefact using our own dataset, after diving each cell into ten children.

Light model and shaders

At this stage, we were satisfied with the shape of the sphere, so we advanced onto the shader. The Voronoi Planet code uses regl.js, a functional abstraction for WebGL. WebGL is a web API used to create 3D graphics in a web browser. Since, when using these technologies, shaders are responsible for the shape, material, colour of the material, lights, shadows, reflections, refractions, and textures of the rendered model, further developing the shader was our natural next step. Figure 6.2.13 shows the artefact's appearance as we started the shading process.

Figure 6.2.13

The artefact's appearance without the original 2D Voronoi Treemap and the cells centroids.

The original Voronoi Planet shader was rudimentary and only implemented plain colour. We further advanced it by implementing lightning, in particular an adapted model of Phong shading technique (Bishop & Weimer, 1986). The first step was to adjust the visualisation engine to calculate the normals, which is the technical term used to describe the orientation of a surface of a geometric object at a point on that surface. Without them, we cannot compute the brightness of the objects rendered. Technically, the normal to a surface at point P can be seen as the vector perpendicular to a plane tangent to the surface at P. Normals play an essential role in shading, where they are used to compute the brightness of objects. After they are calculated, the normals are passed onto the regl.js renderer. This addition to the code allowed us to implement lights, from which we began with just a directional light and an ambient light. Figure 6.2.14 shows the result.

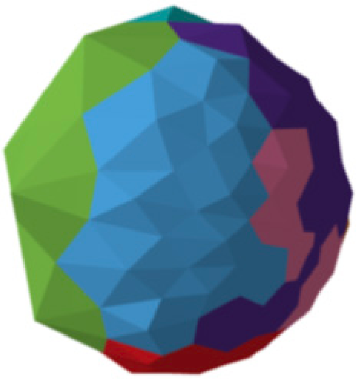


Figure 6.2.14

The artefact's appearance after implementing a directional light and an ambient light.

With this change, the sphere gained more personality and uniqueness from the original Voronoi Planet. The next step was implementing light reflection to give it a "shiny" look. Technically, we adapted the implementation of the specular component of the Phong shading model (Bishop & Weimer, 1986). Figure 6.2.15 shows the result.

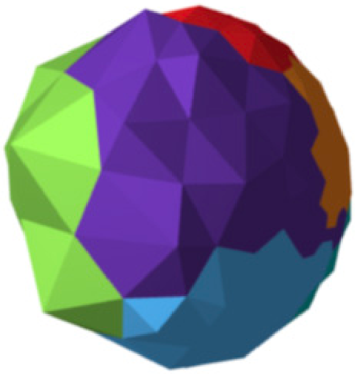


Figure 6.2.15

The artefact's appearance after implementing light reflection.

The reflection accentuated even more the 3D relief, which elevated the artefact increasingly. To conclude the lightning development, we added another directional light and adjusted some of the parameters, resulting in the artefact in Figure 6.2.16.

Figure 6.2.16

The artefact after adjusting the lightning for the last time.

As a final step, we modified our model in order to give the vertices a rounded-off look instead of the sharp edge. Instead of using normals in our lighting algorithm, we use interpolated vectors, which are the mean vectors in the peaks and the normal vectors in the valleys. Figure 6.2.17 shows the result.

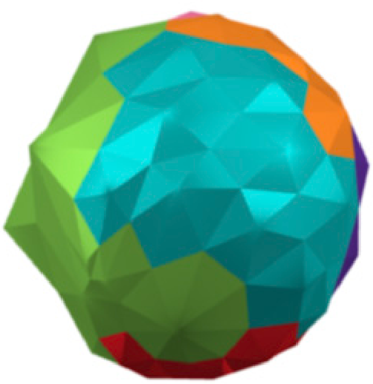


Figure 6.2.17

The artefact after rounding the vertice of the centroids.

We were very satisfied with this iteration and advanced to what would be the final step in manipulating the shader and in the design of our artefact: the colors. Up until now, we have been using an arbitrary set of colours. It was time to select two color palettes, one for the causes visualisation and another for the consequences visualisation, with one color for each attribute. The goal was simple: Choose a color for each attribute that represented it well without compromising the aesthetic value of the palette. These were the colors chosen for each attribute:

Causes

- CO2 Emissions: Dark blue (#1B1F3B);
- Fertilizer consumption: Brown (#865B3B);
- Forest area: Green (#0F7806);
- Fossil fuels consumption: Grey (#464646);
- Meat production: Light Red (#C20A41);
- Population: Light Blue (#246BD4);
- Renewables %: Yellow (#E2CF21).

Consequences

- Agricultural land: Dark brown (#713D0D);
- Surface °C temperature anomaly:
    If negative: Ice blue (#2298CB);
    If positive: Red (#B21313).
- GDP: Light Green (#49A133);
- Air Pollution: Dark Grey (#303030);
- Precipitation: Blue (#202C9C);
- Red List Index: Orange (#EC7F1A);
- Poverty: Beige (#DCB186).

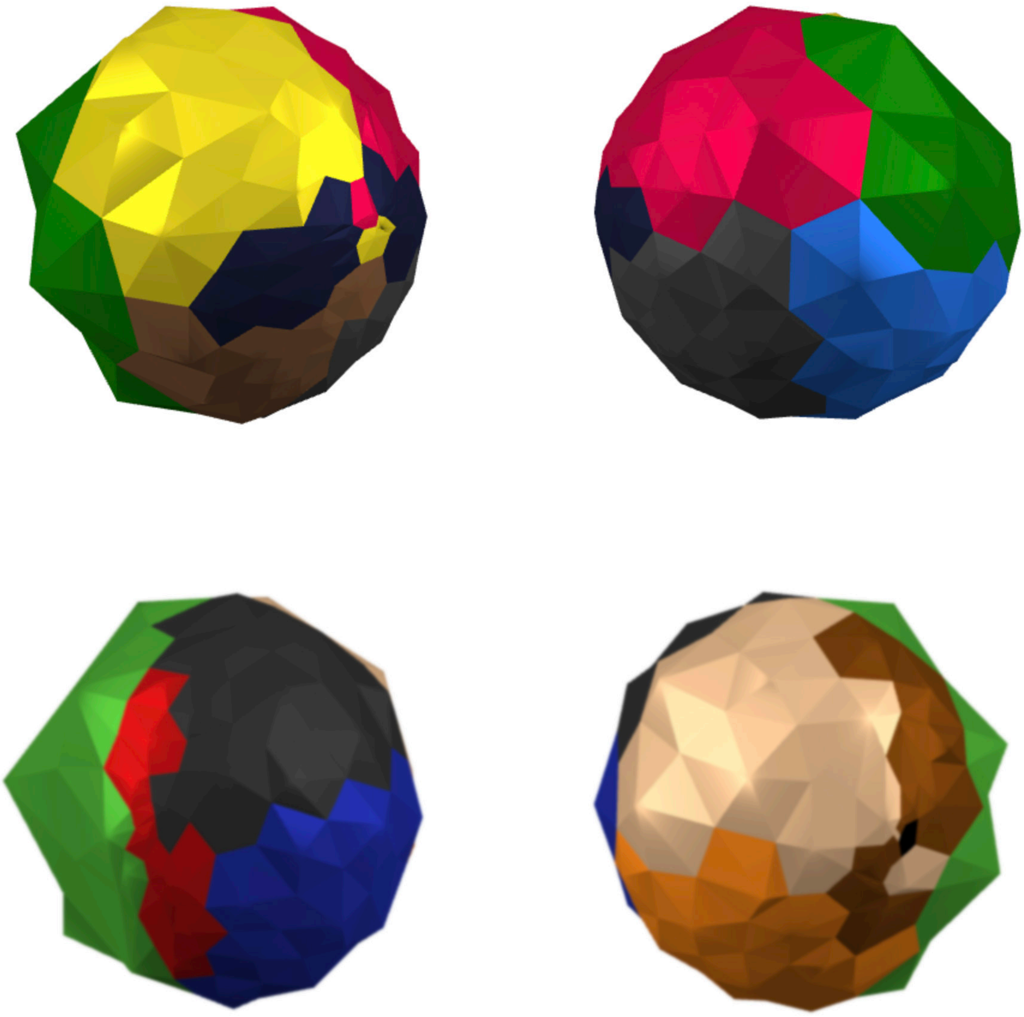
Table 6.2.1 visualizes the color palettes, and in Figure 6.2.18 we can see them applied to the artefacts.

Table 6.2.1

The fourteen attributes and their respective colors.

Attribute	HEX Code	Color
CO2 Emissions	#1a1f3d	
Fertilizer consumption	#885935	
Forest area	#007b00	
Meat production	#be0a41	
Population	#246bd0	
Renewables %	#decb21	
Fossil Fuels consumption	#464646	

Attribute	HEX Code	Color
Surface temp. anomaly	#ea1818 #2298cb	
Agricultural land	#713d0d	
GDP	#49a133	
Deaths by Air Pollution	#303030	
Precipitation	#202C9C	
Poverty	#dcb186	
Red List Index	#ec7f1a	



This marked the end of the development of the visual data artefact. From here, we advanced into applying the artefacts onto a platform where the user could navigate between datasets besides exploring the data behind them.

Figure 6.2.18

The colour palettes were applied to the artefacts. The top shows the Causes palette and the bottom shows the Consequences palette.

6.3 Visualization platform

The first step in the platform development was to set up the web technologies it would use. Naturally, the development of the project up to this point revealed different necessities and goals than the technologies studied in the preliminary work stage. The fact that the data artefact was entirely able to be generated client-side, and no further communication needed to happen with external platforms, a need for a server-side application was invalidated. Therefore, there was no need to use Node.js, however, we still used its package manager, npm[26], as well as browserify[27], which allows

[26]**npm**
https://www.npmjs.com

[27]**browserify**
https://browserify.org

us to "require" modules client-side like we would server-side. This made managing the dependencies, mainly D3.js and regl.js, very straightforward. Initially, we used budo.js[28], which is a live development server, to develop the platform. Further ahead we used Apache[29] to set up an webserver so that the developed platform could be online.

Having set up the technologies necessary, we moved on to the development of the platform itself, starting by designing the mockups in the Adobe Illustrator software, allowing us to envision what the front end of the platform would look like. We did this by first establishing our goals of the aesthetic and functionality of the web platform. In terms of aesthetics, we wanted it to have at least some personality and thought put into it (also because it would be the first visual development of the work outside of the artefact, so the design here was eventually going to be explored in the visual identity context), but without taking the attention of the leading actor, the data artefact. Regarding the functionality, the main objective was naturally allowing the user to navigate between the different artefacts/data sets. However, we also wanted to offer the opportunity for the user to read further and analyze the data. Figure 6.3.1 shows our final mockup for the front page.

[28]**budo.js**

https://www.npmjs.com/package/budo

[29]**Apache**

https://www.apache.org

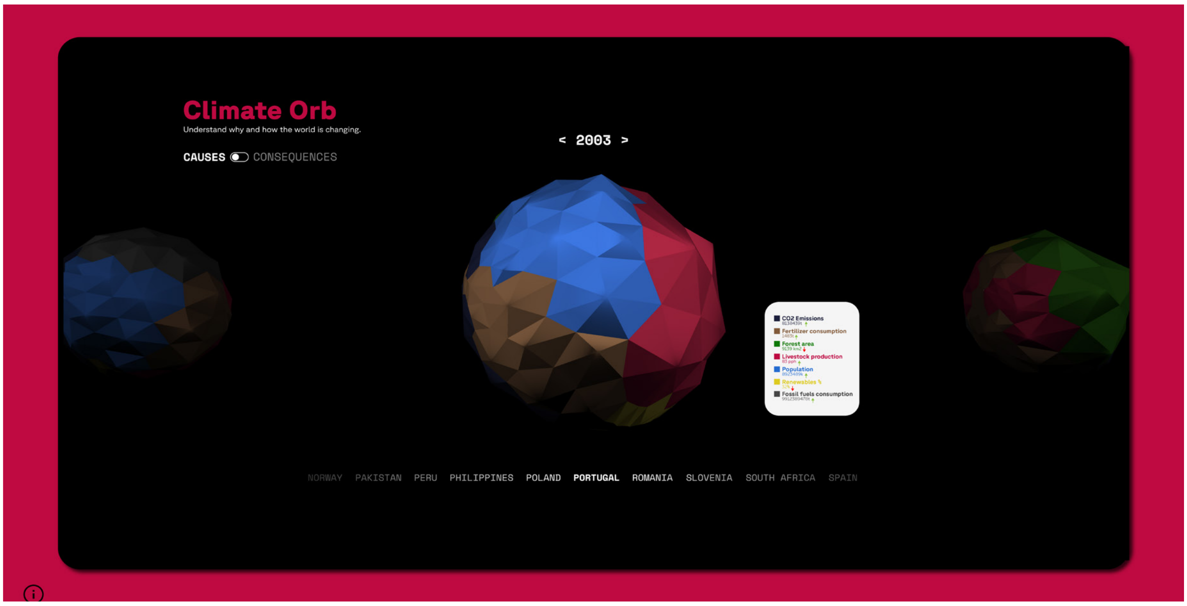


Figure 6.3.1

Mockup developed for the frontpage of the web platform.

Let us start by analysing the navigation. On the top-right, under the solution's title (which will be explained in a further section), is a Causes-Consequences toggle button. The objective was that the user could toggle the button to switch between a Causes visualisation mode and a Consequences visualisation mode. When clicked, it would trigger an animation where the artefacts displayed would pan out of the screen, and the opposite mode artefacts would pan in. In either mode, the user can explore the years and the countries of the datasets. In the top middle, the current year is shown, as well with two buttons that allow you to go forwards or backwards one year. The envisioned animation was for one of the directional lights drawn onto the artefact to rotate. Once the light was behind the artefact (and hence it is slightly obscured), it would be replaced by the chosen year. In the bottom middle, a horizontal scroll with all the countries available can be seen, just like two, slightly obscured and smaller artefacts on the side of the screen. These are the two previous and next countries, and the objective was to be able to scroll horizontally between countries, selecting them in the menu below.

Concerning the aesthetic, as said before, we kept it simple. The platform has a coloured background, with the colour changing to the most predominant colour of the primary artefact (also helping the user understand the principal factor regarding the data). A dark overlay presents the rest of the visualisation and its title, navigation menus and caption. The caption is another essential aspect: in a small overlay next to the artefact, we can find each attribute's labels and the data's actual numeric value. The objective is also to show a small green/upwards or red/downwards arrow, representing if the value has increased or decreased. We also wanted to implement a sideways popup that prompted more information on the attribute when clicking on the caption, as seen in Figure 6.3.2.

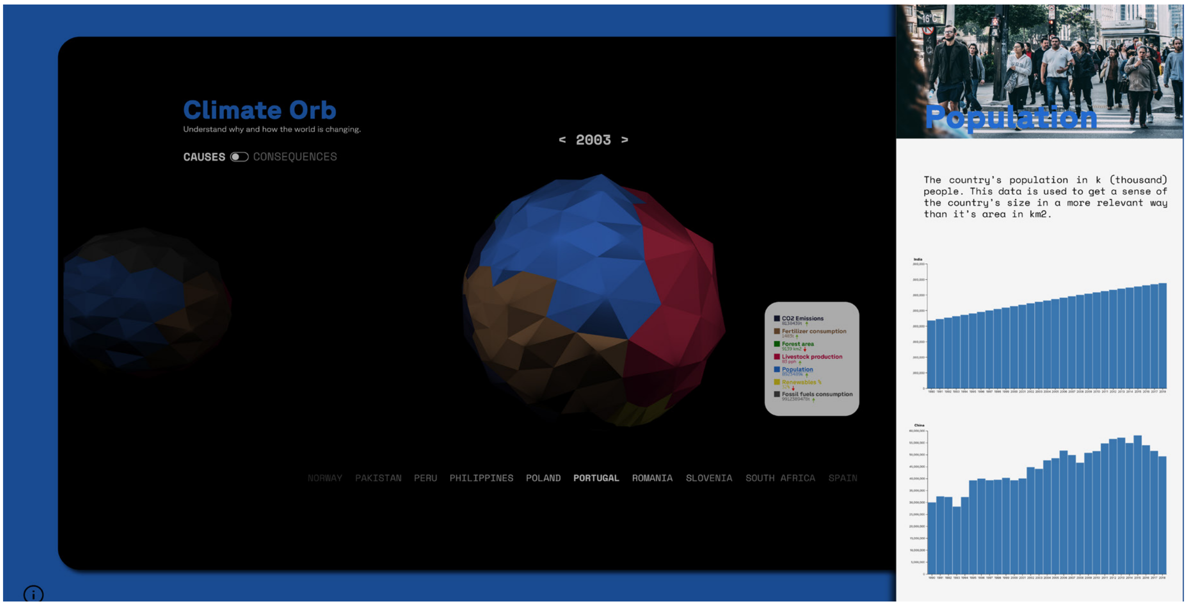


Figure 6.3.2

Mockup for the sidebar which shows more information on the attribute selected.

The goal here was for the user to explore each attribute of the data thoroughly, including a brief description, a more detailed explanation, more visualisations, including how it evolved through the years and how it compares to other countries, and links to the sources.

Bearing these mockups and their ideas and objectives, we advanced on implementing them into the web platform.

We started by developing the most crucial aspect of the platform, which is the navigation between datasets. Since the python script returned two datasets for each combination of year & country, we had to choose between integrating the python script so that the dataset desired would be generated on-demand client-side or loading every dataset file at site load. After testing the loading of the platform with every file and researching python web integration, we concluded the slightly increased load time was a better alternative than integrating the python script. We also implemented a loading screen so that the platform had time to load the data before presenting itself while making the user aware that the website was loading, as shown in Figure 6.3.3.

Figure 6.3.3

A screenshot displaying a frame of the loading screen.

Initially, the mechanism loaded one file at a time, saving its data to an Object variable. We made the multi-file load possible by saving them to a multidimensional array, where the *c* dimension equals the country, and the *y* dimension equals the year. This array made navigating between the data very easy, as, for example, loading the previous year meant loading *data[c][y-1]* or loading the following country meant loading *data[c+1][y]*.

Implementing the years' navigation was straightforward. Clicking on the buttons triggers a light animation, and halfway through the animation, the following/previous year is loaded (by adding or subtracting one value to the *y* variable). Implementing the countries' animation was somewhat more complicated because of the animation, due to the simultaneous rendering of the next and previous countries' artefacts, besides the selected one. The animation works because when triggered, the selected country moves into the main stage, but until the last frame of the animation, the platform still sees it as the following country. Only in the last frame is one value added or subtracted from the c variable. This fact also means that when the animation is triggered, a fourth hidden artefact is rendered, so it can take the place of the artefact selected while the animation finishes. A diagram explaining this animation is shown in Figure 6.3.4.

As to the Causes-Consequences mode switch, a boolean variable was implemented that, when toggled, switched between getting the causes dataset and the consequences dataset for rendering the artefacts. The animation works because the artefacts pan out of the screen and in the frame after they disappear, and

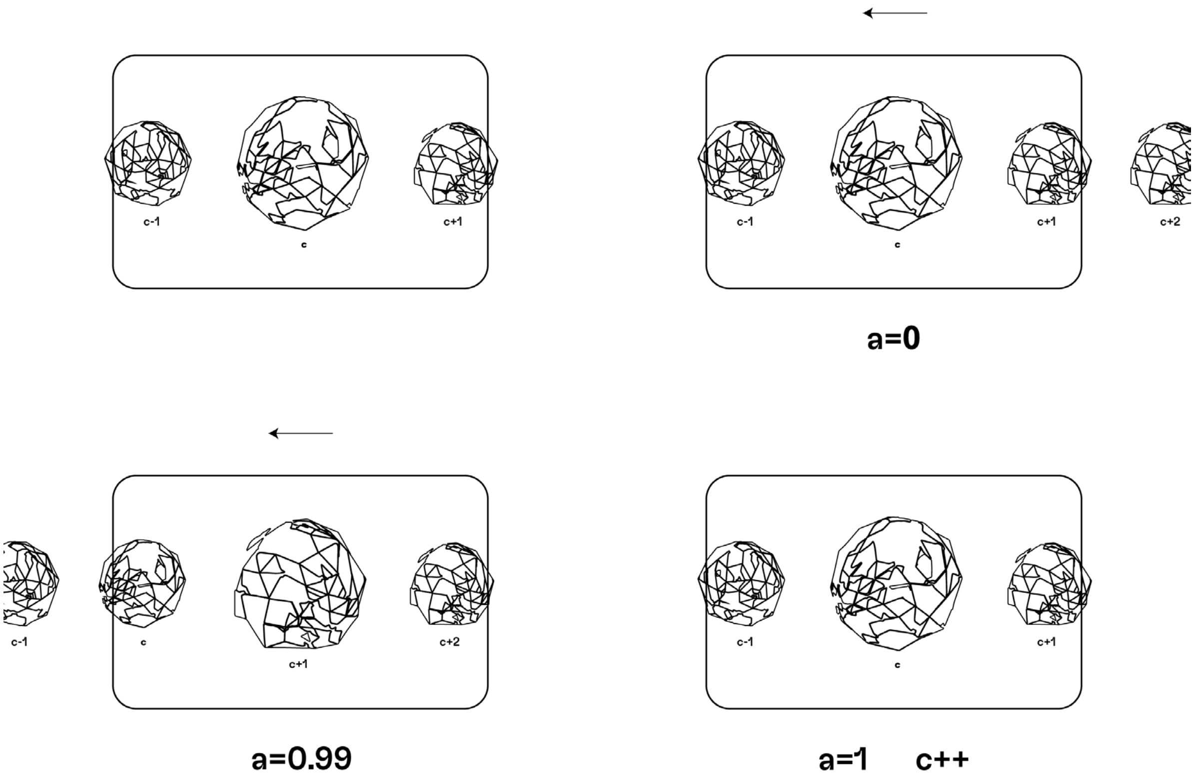


Figure 6.3.4

Diagram explaining the animation for the countries change.

before appearing again, the boolean is toggled. Finally, we implemented the Regl.js Camera module, allowing the user to control the sphere's rotation freely. We also added a download button, which saves a copy of the artefact (including a title and caption) to the user's device. An example can be seen in Figure 6.3.5.

Figure 6.3.5

An example of the image obtained when downloading an iteration of the artefact.

The caption was also a very straightforward implementation. Every time the primary artefact gets updated, the HTML elements get updated with the corresponding value of the attributes while also updating the arrow, indicating an increase or decrease from the previous year. Selecting one of the attributes triggers an animation which slides a sideways popup from the right, showing more information on the attribute selected.

In Figure 6.3.6 we can see what the final result of the platform looks like.

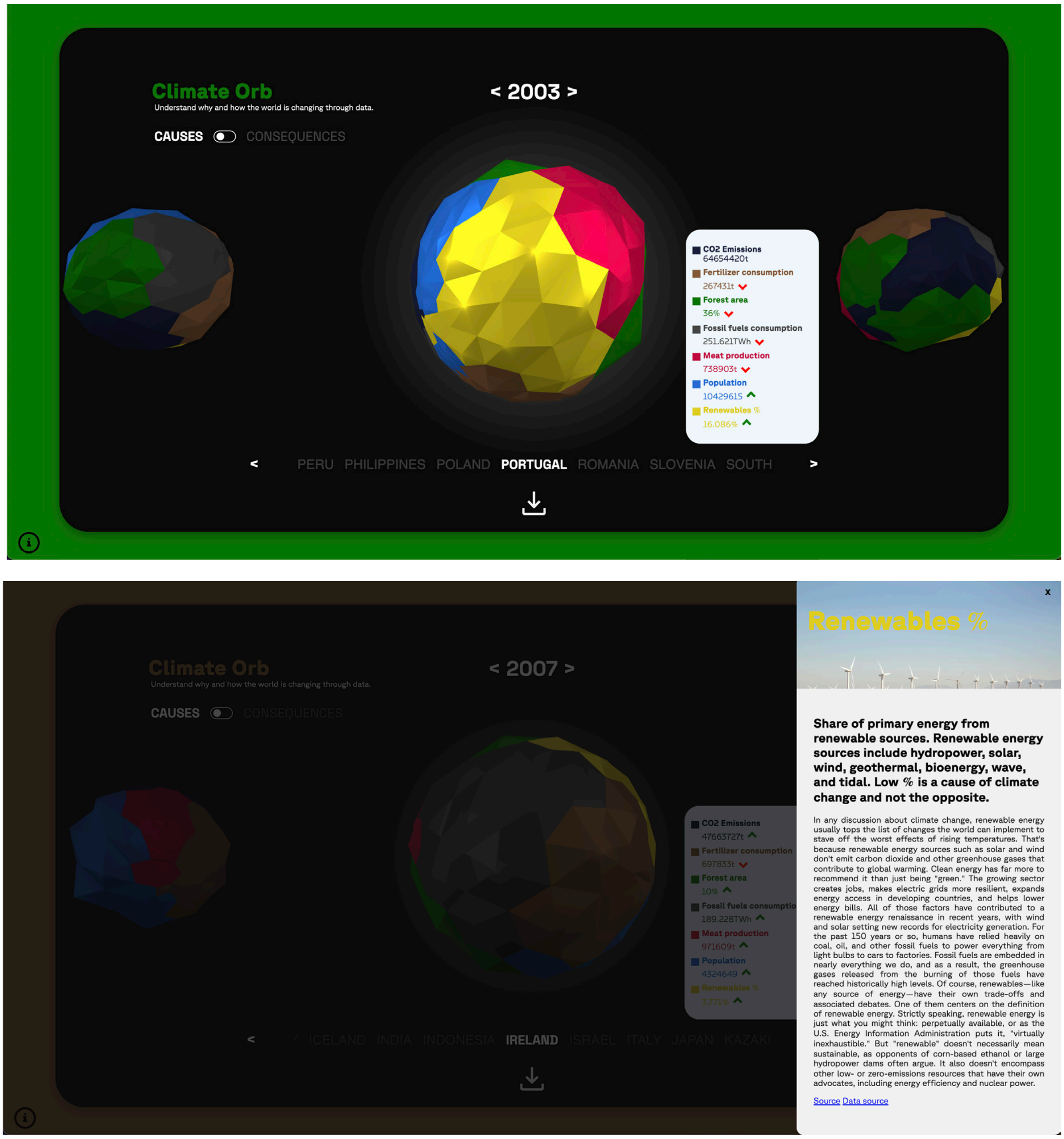


Figure 6.3.6

Two screenshots examplifying the web platform developed.

6.4 Campaign

A critical objective of the work developed was to take the data art created and the platform implemented and develop an awareness campaign that strived to raise awareness and educate the audience about climate change. The goal of this campaign would be not only to disseminate climate change but also to educate its viewers about its causes and consequences through the information that everyone could relate to, and with the aid of the data artefact as a means of drawing attention and interest. Its audience would mainly be the younger generations as they are both the most likely to find value in these types of solutions and the most influential in the combat against climate change. We named the work "Climate Orb", taken from the data artefact, as in, each pair of country and year generates a Climate Orb. The purpose was to centre the campaign around the artefact, in the belief that it would serve its purpose to grab attention as a data aesthetics work and that emphasising the "collectables" aspect of the solution would captivate the audience even more.

The campaign was divided into the web platform and digital and physical divulgation. Naturally, as it centres around the data artefact, the main stage was the web platform, and every other divulgation's primary purpose was to lead the viewers onto it. In the platform, the viewers can get into the depth of the work, interact freely with the Climate Orbs, and explore the data involved more deeply. We wanted the divulgation to invite its viewer to do this, so apart from the data artefact, a strong emphasis was put on the data involved. This means that most of the divulgation would use excerpts of the data that were educational on their own but also arouse curiosity and leave the viewer wanting to explore more. Allowing the platform users to download an instance of a Climate Orb also allows the campaign to "gain a life of its own" and be self-sustained by the people interested in it.

As for the visual identity and characteristics constructed for the campaign, like the rest of the work, they were based on the data artefact. The visual identity was kept simple so as not to take too much attention from the data artefact, and its applications essentially consist of the data artefact, a dark background and typography. We chose two typefaces, *GT Planar*[30] and *Space Grotesk*[31], which gave us a significant margin of opportunity for the type design and some personality to the identity but not enough to take centre stage from the artefact. In Figure 6.4.1, we can see the typography and an instance of the artefact constructed into a logotype. We also used the colour palette chosen for the artefact as another application for the identity, specifically the typography, to create a connection between the colour and attribute and to emphasise the data further.

[30] **GT Planar Typeface**
https://www.gt-planar.com

[31] **Space Grostesk Typeface**
https://fonts.floriankarsten.com/space-grotesk

Climate Orb

Figure 6.4.1

Logotype created for the campaign.

An example of the application as a social media post can be seen in Figure 6.4.2.

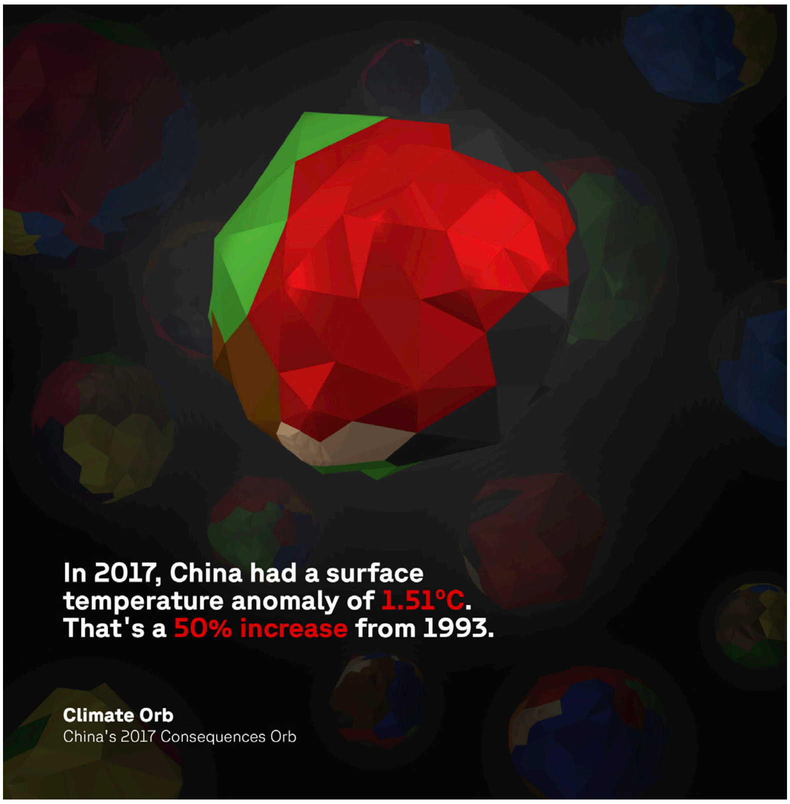


Figure 6.4.2

An image representing an example of dissemination material.

As previously mentioned, the dissemination would fall into two categories: digital and physical. Regarding digital dissemination, the critical component is the web platform, which was put available on an online server so that it was available to everyone worldwide, at *climateorb.dei.uc.pt*. Naturally, virtually every other divulgation would have an "invitation" for the viewer to visit this URL. The other component would be social media applications, specifically Instagram, as it is currently the most popular social media amongst the younger generations and the most widely used for these type of campaigns. Therefore, an Instagram profile was created with the handle *@climate_orb*. Because of the versatility of a social media profile, this would also play a key role in significantly spreading the campaign, explaining the work behind it, and emphasising critical points from the data. In Figure 6.4.3, we can see what the Instagram profile currently looks like.

Concerning the physical divulgation, the work's geographical aspect was critically valued. This means that the developed

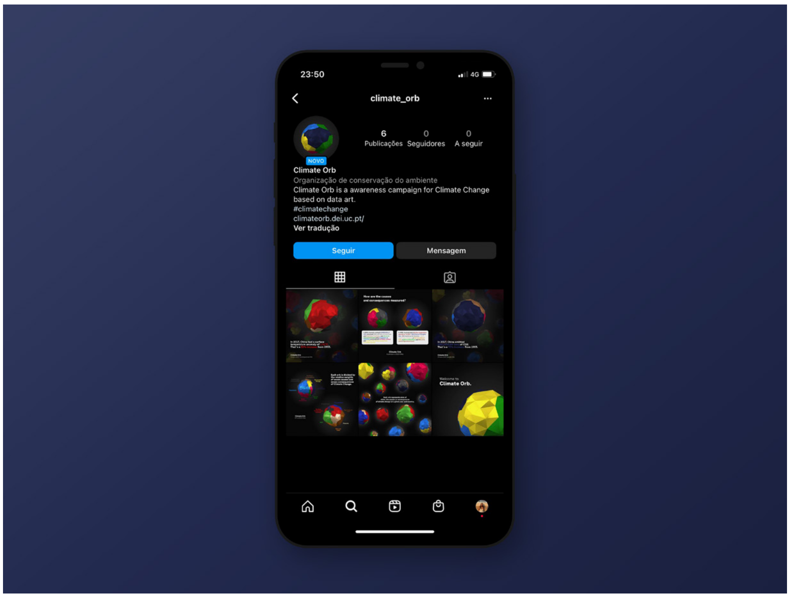


Figure 6.4.3

Mockup representation of a smartphone showing the Instagram profile.

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material would adapt to where it is physically located and what data key points are more relevant in said location. For instance, for a very industrialised country, an urban application regarding the CO2 emissions, renewable energy percentage could have the highest impact. In Figure 6.4.5 & 6.4.6, we can see two conceptual instances of this application in New York City and London.

Figure 6.4.4

Mockup representation of dissemination material shown in New York City's Times Square.

Figure 6.4.7 also exemplifies how the application's physical context can further emphasise the data. On the other hand, Figure 6.4.6 demonstrates a rural application regarding the agricultural land data, which could be, for example, placed on highways near those.

Figure 6.4.5

Mockup representation of dissemination material on the side of a London bus.

Figure 6.4.6

Mockup representation of a highway billboard with dissemination material

Figure 6.4.7

Mockup representation of a large-scale billboard on the side of a building.

Figure 6.4.8 shows an example of a poster applied on a "*mobilier urbain pour l'information*" (MUPI).

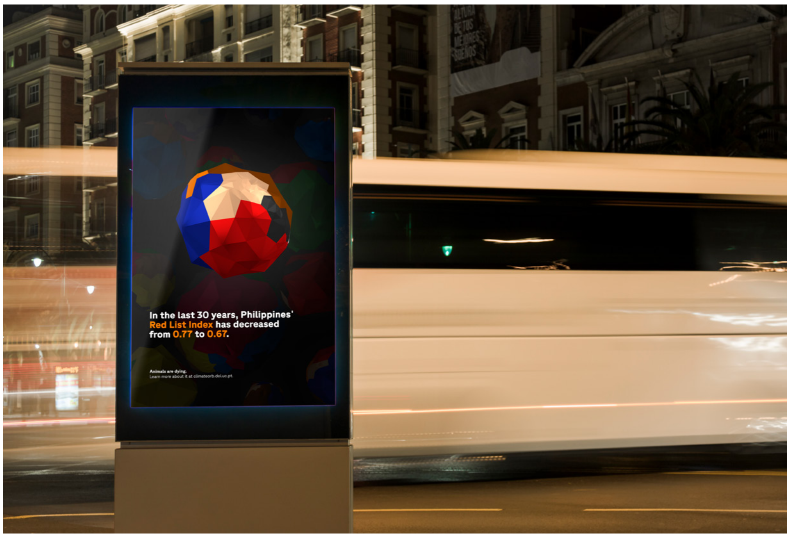

Figure 6.4.8

Mockup representation of a poster applied to a MUPI.

Figure 6.4.9 shows an example of how dissemination material could work on multiple instances tied together physically.

Figure 6.4.9

Mockup representation of three posters applied in an urban setting.

Another possible component of the physical divulgation would be merchandising. Merchandising could also be an interesting way of spreading the campaign as the "collectables" aspect of the data artefact would make it very appealing, environmentally-friendly merch items could be used, which adds more depth to the solution, and captivated viewers would have the opportunity to help spread the campaign on their own. Figure 6.4.10 shows how this could work on a bag.

Figure 6.4.10

Mockup representation of a bag with a data artefact and an excerpt of the data.

Figure 6.4.11 shows an example of an artefact imprinted on a mug, which could be a potential application of a collectable item, meaning mugs could be produced with different artefacts each.

Figure 6.4.11

Mockup representation of a mug with an instance of a data artefact.

In Figure 6.4.12 we can see multiple data artefacts rendered on a recycled notebook, also showcasing the "small multiples" potential of the data artefact.

Figure 6.4.12

Mockup representation of a notebook with multiple data artefacts.

7. Discussion and Future work

In this section, we address and discuss the work developed in its entirety and individual parts. The purpose is to analyze the work critically, how it fares compared to early ideas and conceptualisations, and what future work could be done.

Starting with the data work and the resulting artefact. We were overall satisfied with the data found, analyzed and processed. We figured that the logic of finding and pointing to the causes and consequences of climate change — and specifically the indirect ones — is one of the best paths we could have taken regarding making climate change data easy to understand and accessible to the general audience. Regardless, this does not mean that it was the most accessible it could have been, and a way of further processing the data to make it even more understandable could be analysing the causes of the causes and the consequences of the consequences. For example, instead of measuring CO_2 emissions in its conventional measure of tonnes, we could look at the number of cars that are causing them, and how it would compare if it were public transport instead. Alternatively, instead of looking directly at the loss of agricultural land, we could analyze how it is causing food prices to rise. Developing these types of "translations" into the platform and divulgations could be very effective at grabbing the attention of the viewers even more and further driving the point home. The data artefact itself left us both satisfied and unsatisfied in various ways. We judge it to succeed as an instance of data art and aesthetics in the way it can provoke an emotional response from the viewer and, hence, creating an attachment to the viewer. However, we are not completely satisfied with the final visual result and concluded that further work could be done to amplify its aesthetic value. Additionally, because of how the data is processed to compare each attribute relatively, its readability can be questioned from a data visualisation point of view. The same value of an attribute can yield very different relative weights and consequently very different visual outputs in different artefacts. Also, there are not many conclusions to be taken from comparing the relative weights of the attributes, leaving us with an artefact that has little value for reading and understanding the data. In essence, the data artefact has value simply as a bold piece of data art or data-driven design. The data reading should be based on the platform or the examples shown in the instances of divulgation. Nonetheless, this does not invalidate some possible further development on the data artefact so that actual data can be read from it.

Regarding the web platform, it is not as functional as we would have liked the final product to be. It is not responsive, meaning it cannot be accessed by smartphones, for example. This is an important factor to allow individuals to immediately visit the platform after encountering a piece of physical divulgation or after visiting the Instagram profile which is mainly used on smartphones. Also, some specific data artefacts cannot be generated because of problems with the D3 Voronoi Treemap module.

Finally, due to a lack of time, we didn't implement additional visualizations that would allow the viewer to further analyze the data on the data attribute sidebar, as it was planned on the mockup developed. Accordingly, there is further work to be done in advancing the web platform technically.

The visual identity is an aspect of the resulting solution that is lacklustre compared to the goals set in previous stages of development. Our initial objective was to push the boundaries of a dynamic visual identity from its generative construction with data-driven elements. Essentially we wanted to explore what could be considered a "fully-dynamic" visual identity, where instead of only the usual visual mark being dynamically generated, other elements, like typography, background, and colours, would also be. We diverged from this path, and as other projects addressed, we too focused on our data artefact as the primary visual mark of the visual identity. Since an unexpected amount of effort was put into developing the data artefact, not much work was put into developing the visual identity. This means we did not develop some material we originally intended to, such as a visual identity guideline and more applications of the identity for the campaign. Hence, there is space left for future work to develop other data-driven elements further and develop a dynamic visual identity to continue the work intended for this aspect of the work.

As for the campaign, although not an essential part of the solution, we would have preferred to develop it more from a social communications point of view. This means developing a more in-depth concept of an awareness campaign, with a mission, goals, means and plans to use them. We also believe there are more features we can develop into the web platform that would allow the campaign to spread more autonomously by everyone interested in it. Having the platform automatically create images depicting randomly-chosen Climate Orbs and selected data key points and publish them to social media would be very useful to make the work self-sustained. Making the source code for the data artefact open source would invite individuals to create their own iterations of the "Climate Orb" and create smaller-scale, more specifically located implementations of the Climate Orb work, thus increasing its overall scale and significance. To further emphasise the "collectables" aspect of the data artefacts, making them available as NFTs would draw significant attention to the solution from an already trendy market and increase the credibility of the Climate Orbs. Therefore, future work can be put into developing the campaign and how it ties in with the rest of the solution.

8. Conclusion

This dissertation has set the foundation for a climate awareness project that stems from a campaign with a data-driven visual artefact. We started by explaining our motivation on why this is one necessary work: from the framework point of view, we concluded that there while climate change is a dangerous situation that requires immediate action from society globally, there is little work done that aims to truly explain all its aspects from a scientific perspective but aimed at the general audience; from the academic point of view, we argue that data-driven design is not only a powerful grabber of attention of the public, it also can be viewed as the future of communication and brand design. The goals for the dissertation were set, them being essentially a data aesthetics engine capable of producing visually appealing and informative visuals, with those visuals culminating in an awareness campaign. Because of the nature of the project, we also felt that a very brief introduction to climate change was essential.

To set the theoretical basis of the solution, we started by exploring dynamic data-driven visual identities. The main takeaway from this chapter is that while dynamic visual identities are a proven concept, there is a lack of identities that don't focus only on the graphic mark, and data-driven identities fail to transmit data clearly. We progressed by defining the broad aspects regarding information design, and making the case for the use of data aesthetics as an alternative that although can be less efficient at transmitting data clearly, can be a powerful tool in making artworks that appeal more to our intended audience. The conclusion of this basis rested on the exploration of climate data visualisation and aesthetics, particularly on how to make climate data and visualisation accessible to everyone. To understand where the work sits when compared to other works, there was also some research into related work, essentially concluding there are some works that share some details with the intended solution, but none with the exact same nature and intentions.

In order to lay the ground for the next stage of development of the solution, we also detailed some of the preliminary work that was put into place before delving into the actual development, specifically a brief study of a few datasets, and some investigation into the technologies that we could use.

Informed with the knowledge acquired from the Literature review, we set out to develop the solution. The first step was to research, collect and process the data that would be used for the data-driven artefacts. The research led us to choose the data on the causes and consequences of climate change, specifically the direct and indirect ones, in the belief that primarily the indirect causes and consequences would provide a more direct connection to the general audience. We chose seven attributes for each factor and collected the datasets that best represented them, before processing them and aggregating them into a single dataset.

Having concluded the data work, we proceeded into conceptualising the data aesthetics artefact. We started by searching for inspiration and drawing some early sketches on paper of what we would like the result to look like. After defining this initial idea, we researched techniques and technologies to accomplish it, eventually getting to a Spherical Voronoi Diagram. Once we further processed the data to accommodate this visualization technique, we developed our iteration of the diagram using a "Voronoi Planet" code, ending with our own artefact which matched the solution's expectations and objectives. After developing the system which would receive the data from a certain country & year and return an artefact, we adapted it onto a web platform so it could be accessible to the general public. The development of this platform also comprised a user interface so that the viewer could interact with the artefact and explore the data that generates it. In the final step, we adapted the platform onto an awareness campaign, creating divulgation material both physically (by creating conceptual billboards, MUPIs, and others) and digitally (by creating an Instagram profile). The objective of this campaign was not only to create awareness by itself but also by inviting the viewer onto the platform.

We finalized this dissertation by critically analysing the work done and taking some conclusions in the process. Mainly, we concluded that while we succeeded in the creation of a data-driven design artefact that can effectively grab the viewer's attention the way art would — more work can be put into improving it visually. Additionally, more work can be put into translating the data into more understandable and impactful measures, and into improving the campaign so it can be more self-sustainable as well as grasp greater audiences.

9. References

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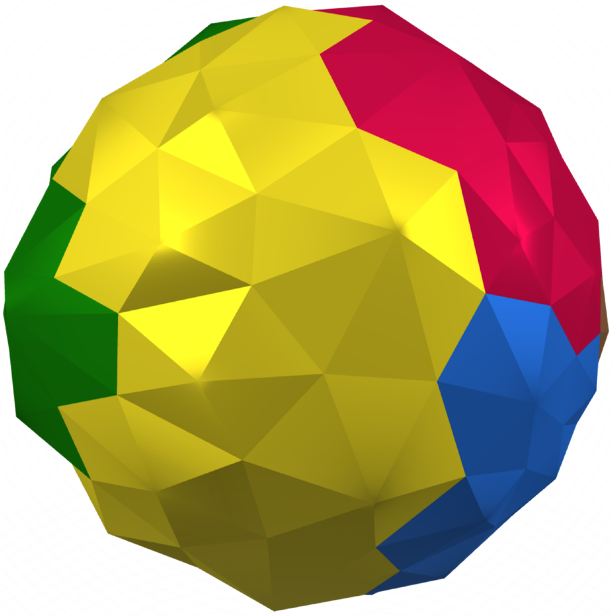
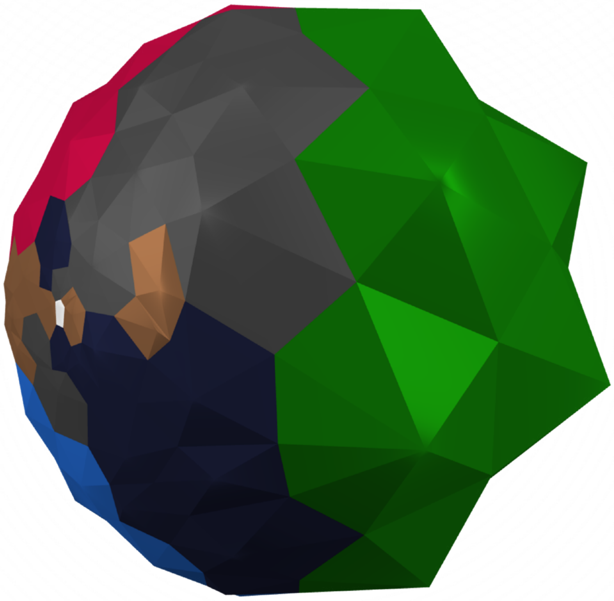
References

Appendix

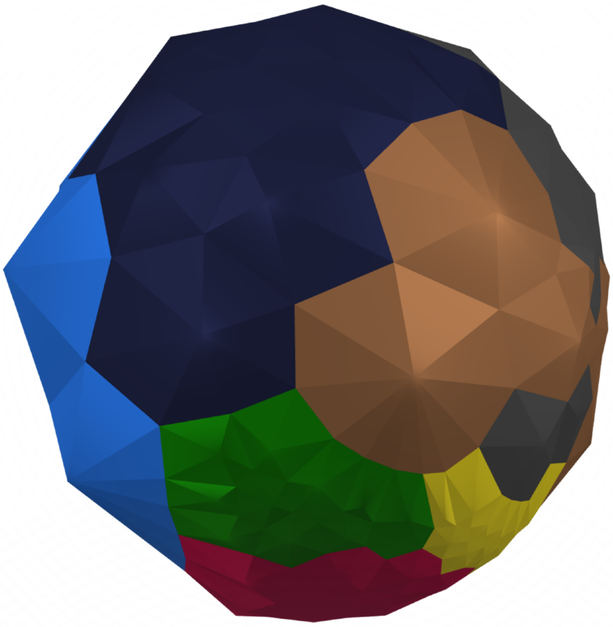
Appendix A
Data artefact system outputs

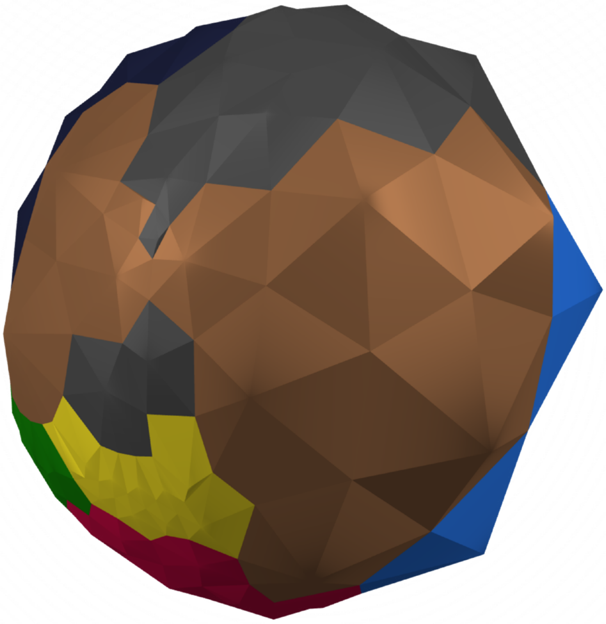




Country: Portugal
Year: 2003
Dataset: Causes

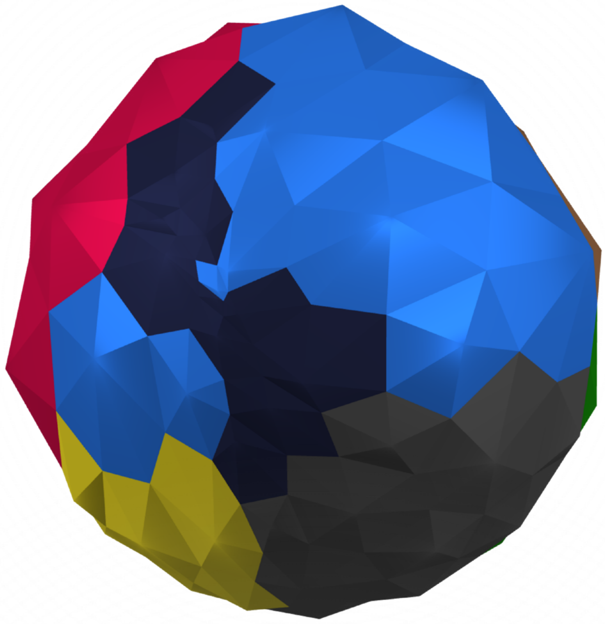
CO2 Emissions: 64654420t
Fertilizer consumption: 267431t
Forest area: 36%
Fossil fuels consumption: 251.621TWh
Meat production: 738903t
Population: 10429615
Renewables %: 16.086%

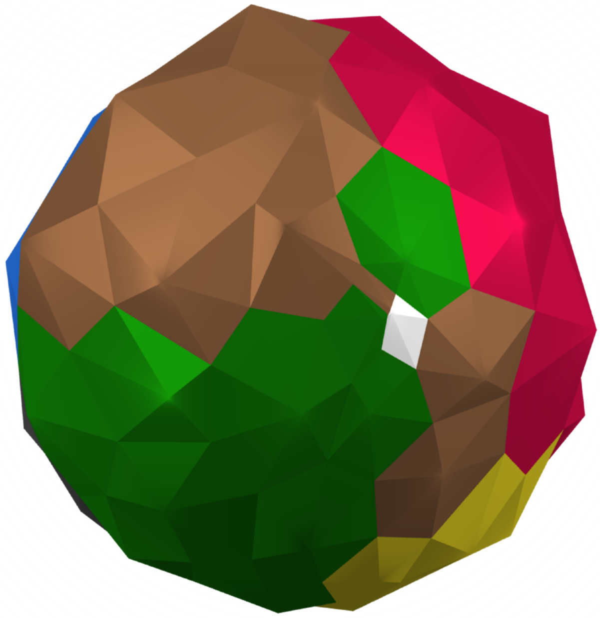




Country: India
Year: 2010
Dataset: Causes

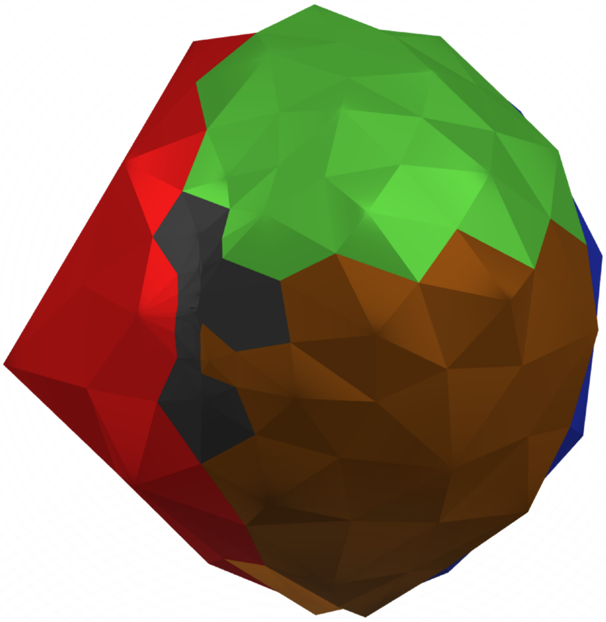
CO_2 Emissions: 1677887585t
Fertilizer consumption: 30308673t
Forest area: 25%
Fossil fuels consumption: 5833.073TWh
Meat production: 6088912t
Population: 1234281163
Renewables %: 5.937%

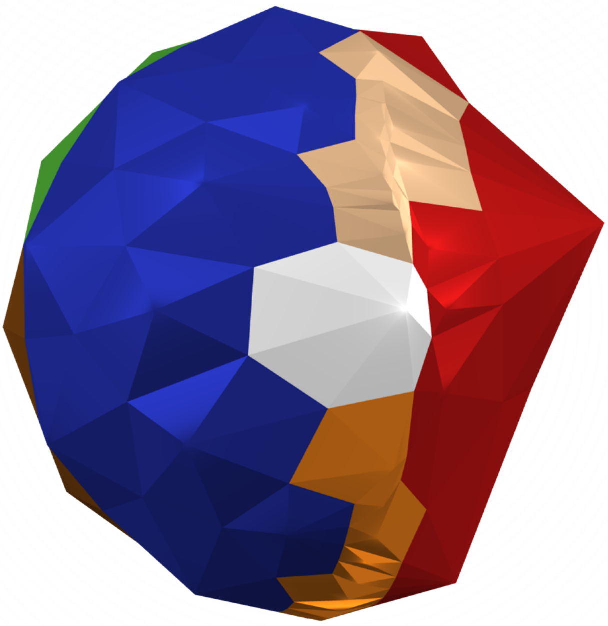




Country: Brazil
Year: 1995
Dataset: Causes

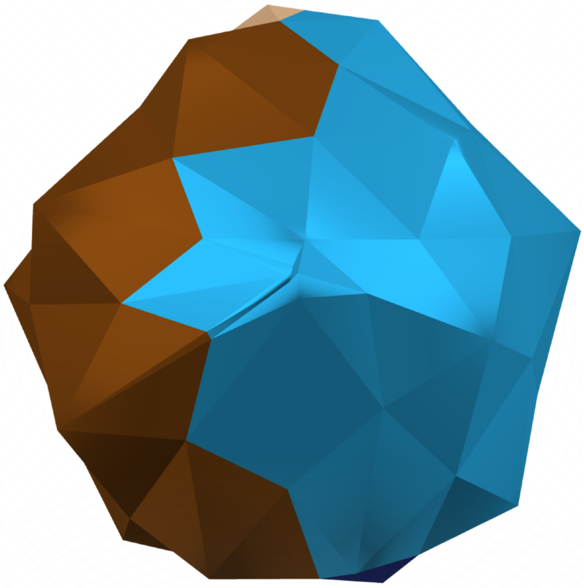
CO2 Emissions: 268678000t
Fertilizer consumption: 5974447t
Forest area: 68%
Fossil fuels consumption: 1057.746TWh
Meat production: 11816818t
Population: 162019889
Renewables %: 42.923%

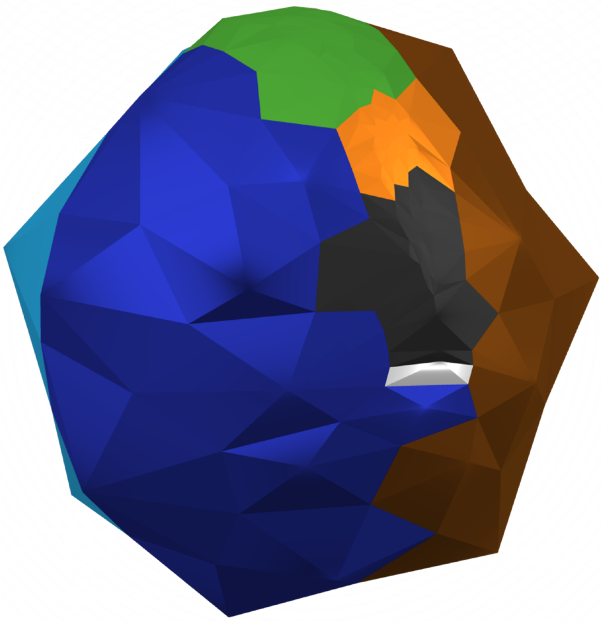




Country: Canada
Year: 1997
Dataset: Consequences

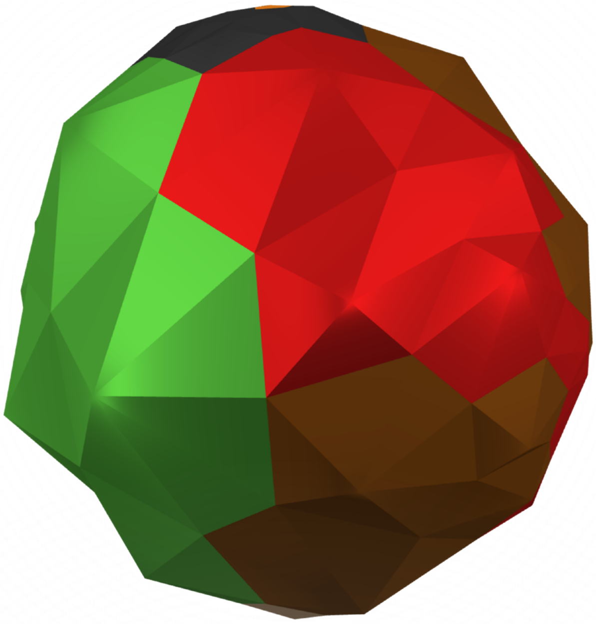
Agricultural land: 7%
Surface °C anomaly: 0.67 °C
GDP: $980486389760
Deaths by Air pollution: 6365
Precipitation: 542.8mm
Red List Index: 0.96991
Poverty: 149311

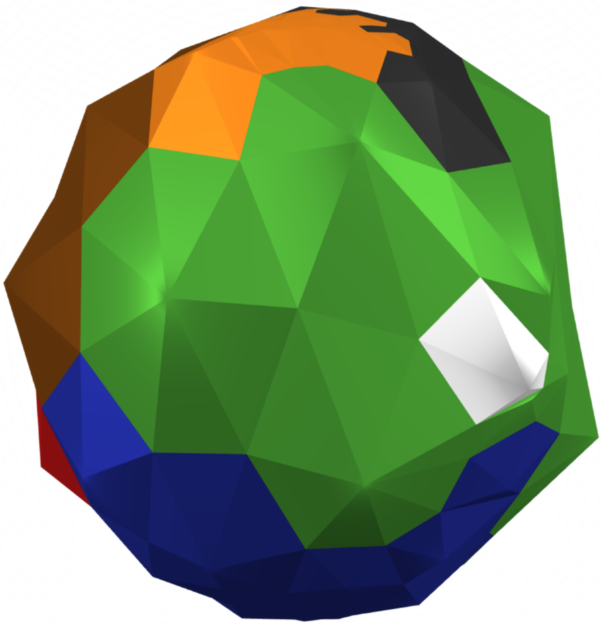




Country: Chile
Year: 2000
Dataset: Consequences

Agricultural land: 20%
Surface °C anomaly: -0.37 °C
GDP: $161457668096
Deaths by Air pollution: 5068
Precipitation: 593.43mm
Red List Index: 0.83322
Poverty: 656968

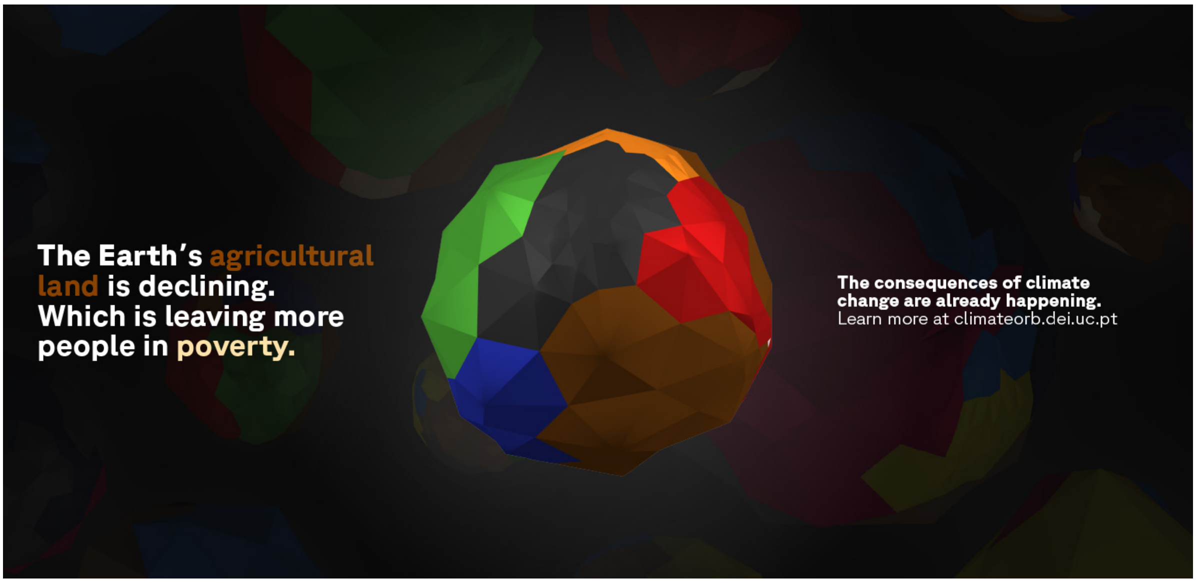




Country: United States
Year: 2017
Dataset: Consequences

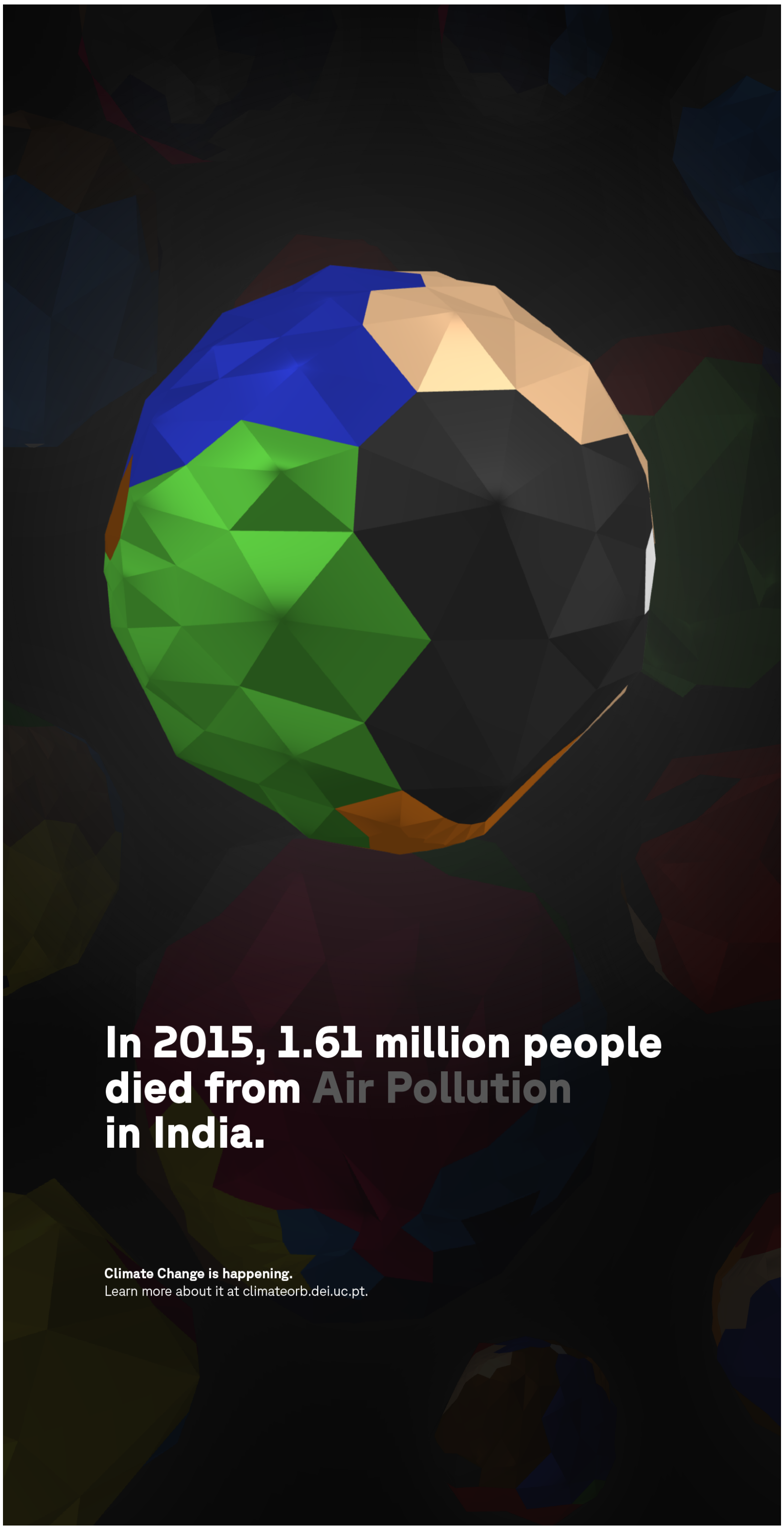
Agricultural land: 44%
Surface °C anomaly: 1.71 °C
GDP: $17778679480320
Deaths by Air pollution: 57765
Precipitation: 755.19mm
Red List Index: 0.83446
Poverty: 4062069

Appendix B
Dissemination material

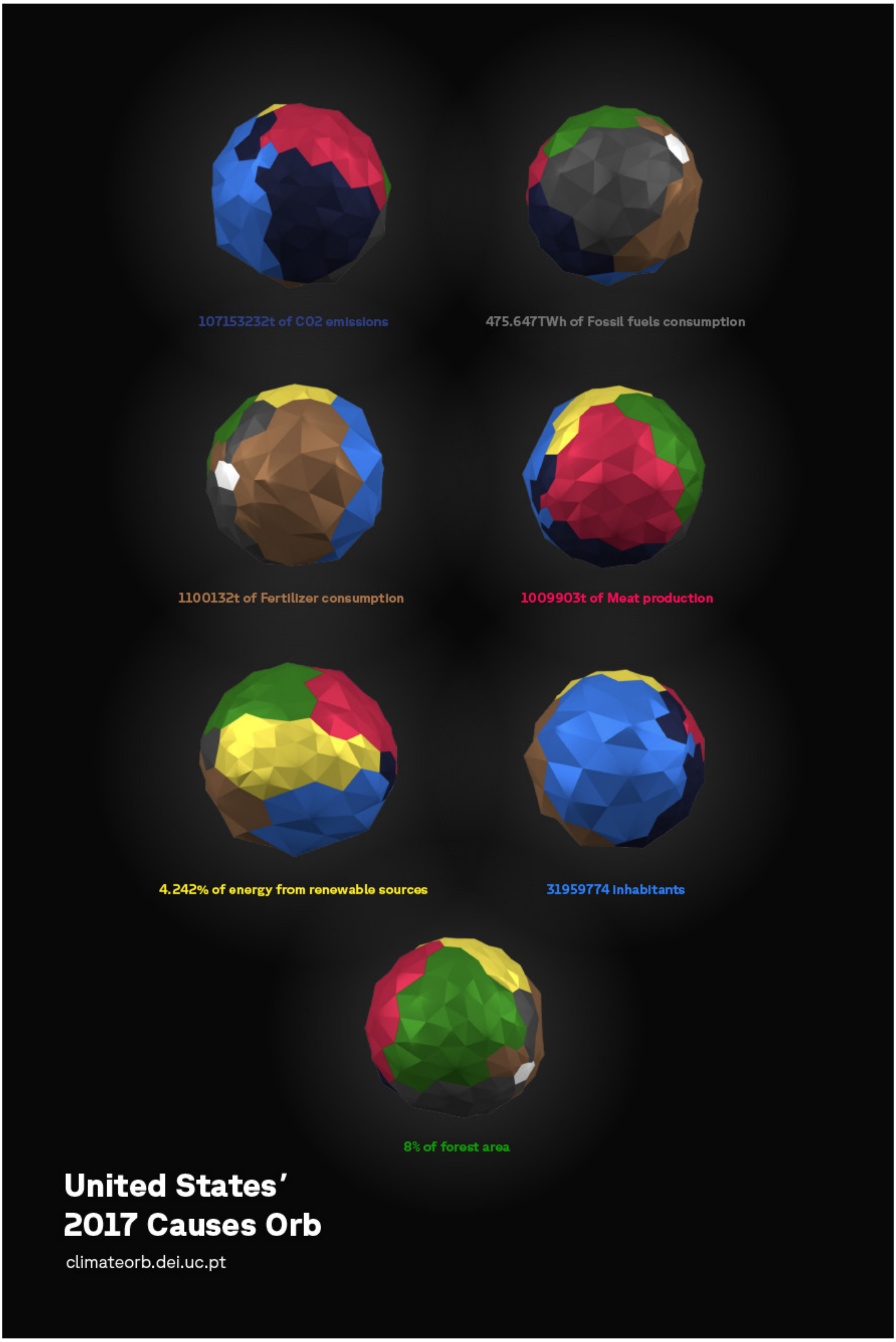


B.1 Horizontal poster designed for highway billboard

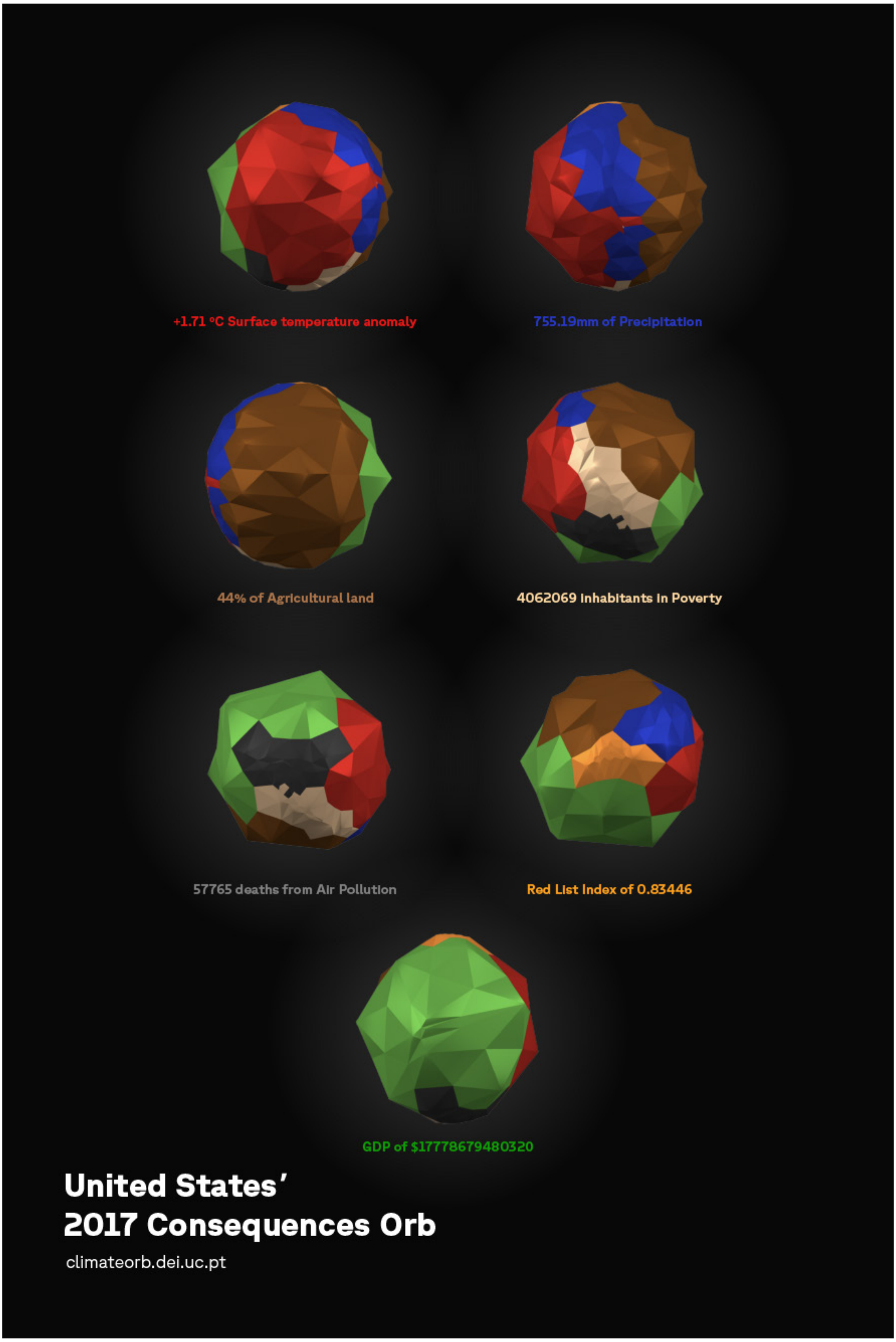
B.2 Poster designed for MUPI



B.3 Poster designed for building-sized billboard

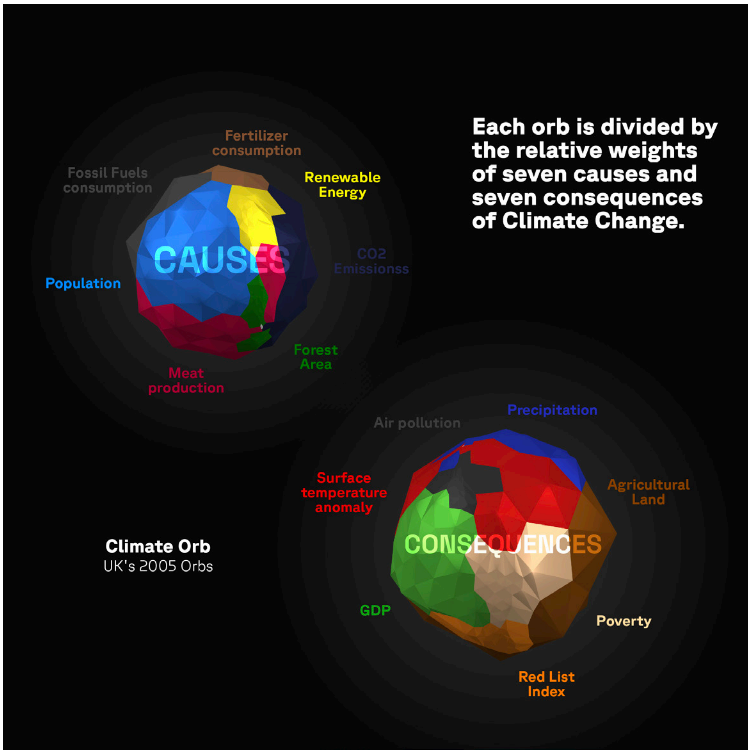


B.4 Poster designed for urban application

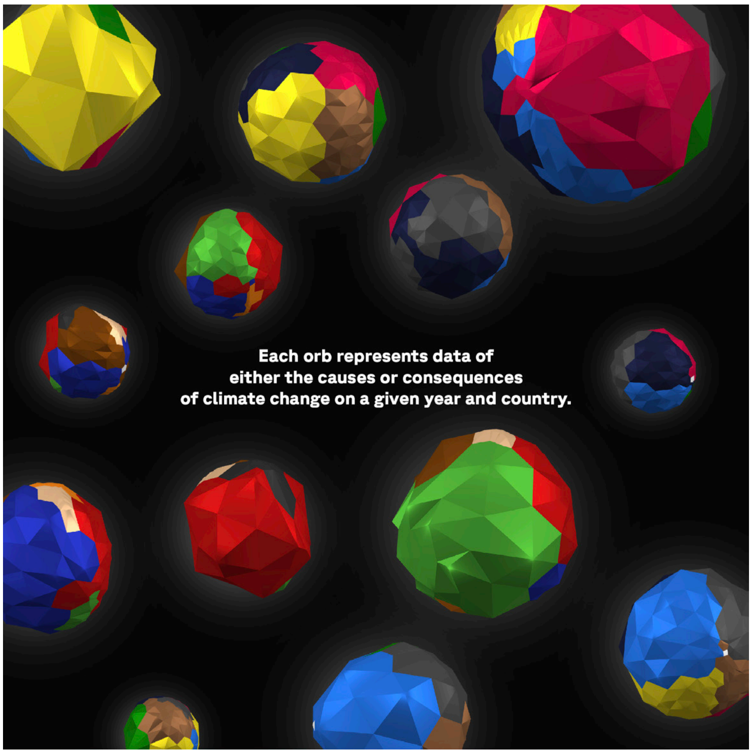


B.5 Poster designed for urban application

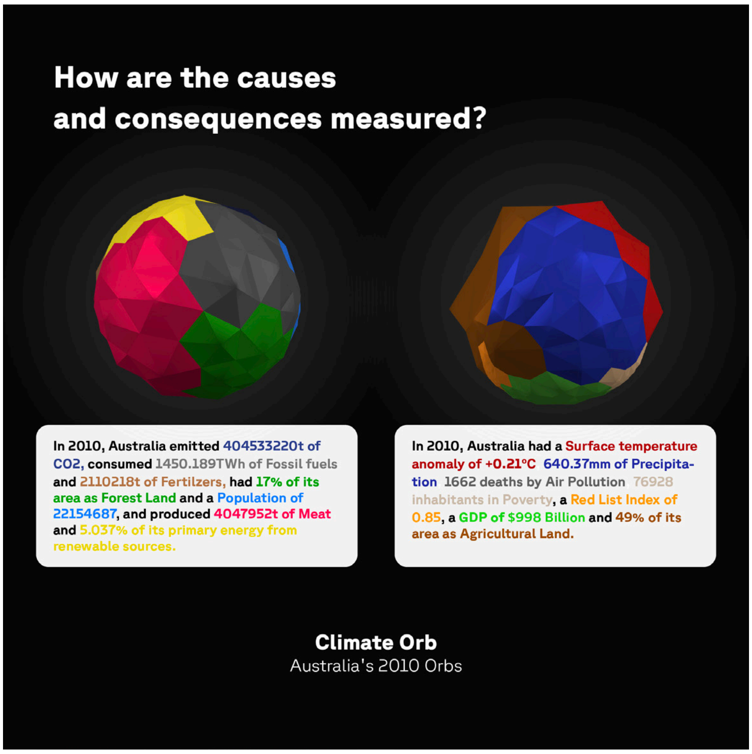
B.6 Image designed for social media post



B.7 Poster designed for urban application



B.8 Image designed for social media post



B.9 Poster designed for urban application