

# Physical Visualizations

Group 2

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## Abstract

Physical visualizations encode data in properties of physical objects, thus they bring information visualization into the physical world. Throughout history physical visualizations have been used to store and communicate data, examples of early and also more recent physical visualizations are presented in this work. Contemporary physical visualizations are discussed in more depth by looking at examples of static, dynamic, interactive and collaborative physical visualizations. Potential challenges that can arise when using physical objects for visualizations are investigated, as well as available tools that facilitate the creation process. While it is possible to argue for benefits of physical visualizations, it is necessary to provide scientific evidence in the form of user studies. Existing work in this area is also surveyed.

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# Chapter 1

## Introduction

### 1.1 Motivation

Since humans are social beings, the need of expressing oneself and ones thoughts and opinions as well as spreading and gathering information to and from others - with other words the need to communicate - is self-evident.

In order to communicate humans use different types of communication, which can be grouped in two main types: Verbal communication (spoken language) and non-verbal communication (signs, gestures, facial expression etc.). [Rosengren, 2000, page 38]

Visualization as a non-verbal form of communication is usually placed on surfaces, either on digital screens or printed on paper. Physical visualizations bring visualizations from 2D into the 3-dimensional real world - data is encoded in properties of physical objects.

While the history of physical visualizations goes back as long as 75,000 years, research on this topic has only started in recent years. However, physical visualizations seem to have great potential. Zhao and Vande Moere argue in Zhao and Moere [2008] that physical objects provide a more enjoyable and engaging experience. Jansen, Dragicevic, Isenberg et al. [2015] argue more extensively about the advantages of physical visualizations, mostly due to the skills humans have in interacting with real world objects. The following is a summarization of their discussion:

Interaction with a physical object comes natural to humans, the active perception skills can be used on physical visualizations. Since a real world object is 3-dimensional, the spatial perception skills get the full range of information about shape and volume. The object can not only be looked at, but also touched, thus it is not only the visual sense that is involved. Involving other senses can also help visually-impaired to explore visualizations. From educational psychology it is known that physical representations can be helpful in learning, a characteristic that may extend to physical visualizations. Another inherent property of physical objects is that they are always “on”, they do not rely on screens for presentation. Therefore it may be easier to bring physical visualizations to public places. Finally the use of physical representations to engage audiences (like Hans Rosling in *Global Population Growth, Box by Box* [2010]) is taken as an indication that physical visualizations are more engaging than traditional visualizations.

Some of the most ambitious projects involving physical visualizations even allow interacting with the physical object to alter the underlying data. These kind of physical visualizations are part of a vision described as *Tangible Bits* in Ishii and Ullmer [1997] and as *Radical Atoms* in Ishii, Lakatos et al. [2012] and Lakatos and Ishii [2012]. While a tangible user interface (TUI) is a physical object used to control (parts of) a digital system, the idea of radical atoms goes even further: All the data of the digital system is represented in a physical object and this object can be directly manipulated.

## 1.2 Outline

In Chapter 2 the historical development of physical visualizations is discussed. Types of physical visualizations are presented in Chapter 3 - static, dynamic, interactive and collaborative physical visualizations are illustrated with numerous examples. After a discussion of challenges of physical visualizations in Chapter 4, existing tooling is presented in Chapter 5. In Chapter 6 some user/case studies are presented that support various benefits of physical visualizations. Finally, Chapter 7 summarizes this work with concluding remarks.

## Chapter 2

# History

This chapter focuses at the very beginning on the question “why physical visualization has become necessary”, to continue with a short chronology of their historical development - where some important examples will be briefly described and finally closes with our resume.

### 2.1 Why Physical Visualizations?

Communication as an activity for exchanging information and messages has already taken place about one hundred thousand years ago, as our prehistoric ancestors used nonverbal gestures and an evolving system of spoken language to communicate. With increasing complexity of their world, they needed a memory outside of the body which led to the development of media to store and retrieve the growing amount of information. Reinterpretation of found archaeological artifacts led to the conclusion that before the emergence of writing, several Old World societies were recording economic transactions through the use of fired clay tokens. Such examples confirm that communication has also taken place via visualization of information. [Crowley and Heyer, 2015, pages 2-3]

Friendly has also the same opinion, as he describes that “*information visualization takes us back to the earliest scratches of forms on rocks, to the development of pictoria as mnemonic devices in illuminated manuscripts, and to the earliest use of diagrams in the history of science and mathematics*” Friendly [2009, page 2]. That is why this time period is also considered in this chapter and in the chronological description of the history of physical visualizations it will provide the starting point.

### 2.2 Chronology

This section describes some of the most important examples of physical visualizations coming along with the rise of human civilization. Visualizations made in paper or parchment will be excluded, because physical visualizations are defined as visualizations that map data using physical form of items or artifacts of different size and shape and not visualizations which map data only using pixels or ink. [Jansen, Dragicevic and Fekete, 2013]

- 75000 BC - Blombos Ocher Plaque  
The Blombos Ocher Plaque (Figure 2.1), discovered by Christopher Henshilwood in Blombos Cave in Republic of South Africa probably was used for counting or storing information. The markings made on this object are clearly organized and that leads some researchers to presume that they represent information and are not only of decorative nature[DeSalle, 2008, pages 197-198].



**Figure 2.1:** Blombos cave engraved ochre [Image credit: Chris. S. Henshilwood - Wikimedia under the terms of the CC BY-SA 3.0 Licence]



**Figure 2.2:** Lebombo Bone [Image extracted from Jansen [2014, page 10] and used with kind permission of Yvonne Jansen]

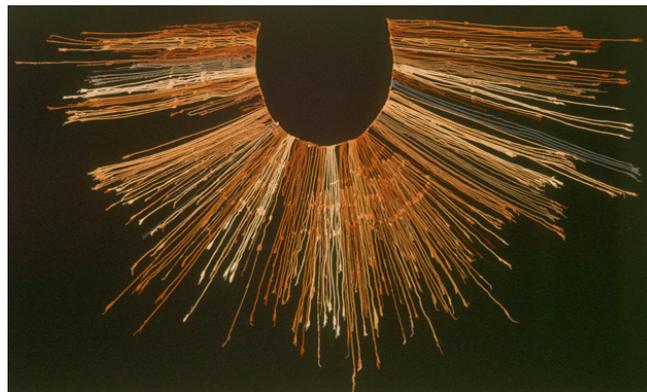
- 35000 BC - Lebombo Bone  
The Lebombo Bone (Figure 2.2), discovered in Lebombo Mountains located between South Africa and Swaziland, displays 29 engravings resembling tally marks. Based on the amount of engravings researchers assume that it was probably used as a lunar calendar.[Jansen, 2014, page 10]
- 22000 BC - Ishango Bone  
The younger Ishango Bone (Figure 2.3), found by Belgian Jean de Heinzelin de Braucourt in the area of Ishango near the Semliki River on the border between modern-day Uganda and Congo might have already been used as a physical instrument for reckoning. It shows various engravings on its front and on the back side with several multiples and prime numbers between 10 and 20. [Schmandt-Besserat, 1979] [Jansen, 2014, pages 10-11]
- 4000 BC - Mesopotamian Clay Tokens and Envelope  
The Mesopotamian clay tokens and envelope (Figure 2.4), used as counters to keep track of goods, were the earliest code - a system of signs for transmitting information. Each token shape was semantic, referring to a particular unit of merchandise. [Schmandt-Besserat, 1977]
- 2600 BC - Inca Quipus  
Quipus (Figure 2.5) were complex assemblies of knotted ropes of various colors that were used in South America as a data storage device and played an important role in the Inca administration. They were probably used among others as an accounting system. Despite the color of the rope, the position and type of the knot was relevant to decode and encode information. [Jansen, 2014, page 12]
- 1862 - Marshall Islands Stick Charts  
Stick Charts (Figure 2.6) are a kind of “native” cartography used in the area of the Marshall Islands to facilitate canoe navigation and show ocean swell patterns or wave masses caused by winds. The charts were made of the midribs of coconut fronds and were tied together with locally grown fiver plants. The approximate position of islands are marked by shells of coral. [Thrower, 2008, page 5] Unlike the traditional navigation techniques those charts were memorized before the trip and had no function or usage during a voyage. [Metropolitan Museum of Art (New York and Kjellgren, 2007, page 280)]
- 1898 – Crookes’ Vis Generatrix



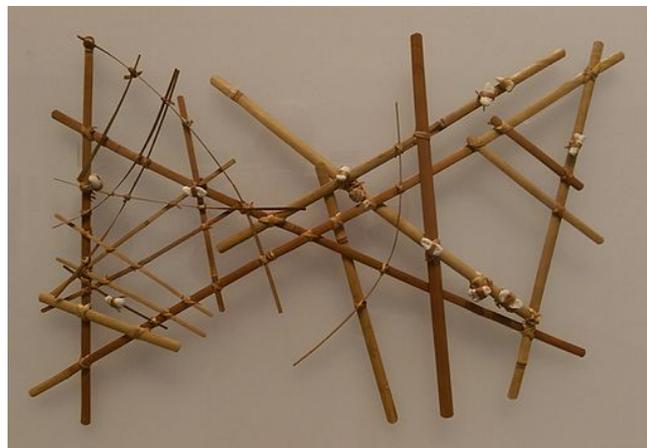
**Figure 2.3:** Ishango Bone [Image credit: Ben2 commonswiki - Wikimedia under the terms of the CC BY-SA 3.0 Licence]



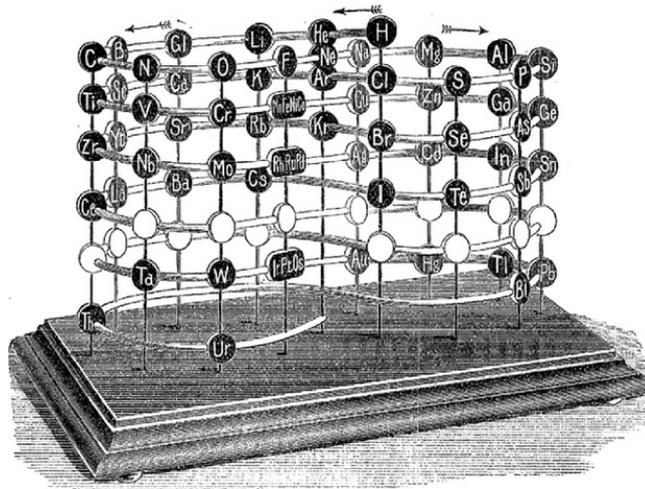
**Figure 2.4:** Mesopotamian clay tokens and envelope [Image extracted from <https://sites.utexas.edu/dsb/tokens/the-evolution-of-writing/> and used with kind permission of Prof. Denise Schmandt-Besserat]



**Figure 2.5:** Inca Quipus [Image credit: Lyndsaruell - Wikimedia under the terms of the CC BY-SA 3.0 Licence]



**Figure 2.6:** Micronesian navigational chart [Image credit: Jim Heaphy - Wikimedia under the terms of the CC BY-SA 3.0 Licence]



**Figure 2.7:** Crookes' Vis Generatrix [Image extracted from Gschneidner et al. [2010, page 45]]

Crookes' Vis Generatrix (Figure 2.7) is the 3-dimensional physical visualization of the periodic table in which the ordinate scale represents the atomic weight of the elements beginning with the lightest ones on the top and ending with the heaviest elements on the bottom. Each layer of the continuous spiral is shaped as an eight. White circles in the model represent missing or undiscovered elements. Similar elements are positioned underneath each other. [Gschneidner et al., 2010, pages 44-45]

- 1913 – Frankfurt Streetcar Load

This model (Figure 2.8) represents a map of Frankfurt a. M. Germany, enriched with the number of passengers carried in Twenty-four hours on the Tram Lines of Frankfurt a M.. The model uses wooden stripes glued on each street having a Tram line. In order to show the average frequency, wooden stripes (one stripe is equal to 4.000 passengers) are glued above each other. [Brinton, 1914, pages 224-225]

- 1935 – 3D Visualizations of Power Consumption

The 3-dimensional model (Figure 2.9) shows the electricity consumption for the year 1935. Data about the energy consumption was collected daily in a half-hour interval. Every slice of the model represents the energy consumption of one day. The half-hour interval creates a curve of 48 values and can be compared to the other days as well as to the other consumption values throughout the year. [Brinton, 1939, pages 354-355]

- 1968 – Jacques Bertin's Reorderable Matrices

The key idea of Bertin work on the reorderable matrix (Figure 2.10) uses the fact that reveal patterns can be visually represented if both dimensions are reorderable (Figure 2.11). For Bertin, the matrix was the most general and most important visual construction. Building and rebuilding of the matrix and the corresponding dataset makes it possible to perceive hidden relationships. [Perin et al., 2015, pages 2-3]

## 2.3 Summary of Historical Development

As mentioned at the beginning of this chapter, increasing world complexity of our prehistoric ancestors and information growth has led to the creation of physical visualizations. If the shown examples are examined more carefully, it can be seen that not only the complexity and amount of data and information, but also their quality keeps on growing throughout the history and this affected the evolution of physical visualizations, since they had to deal with it.

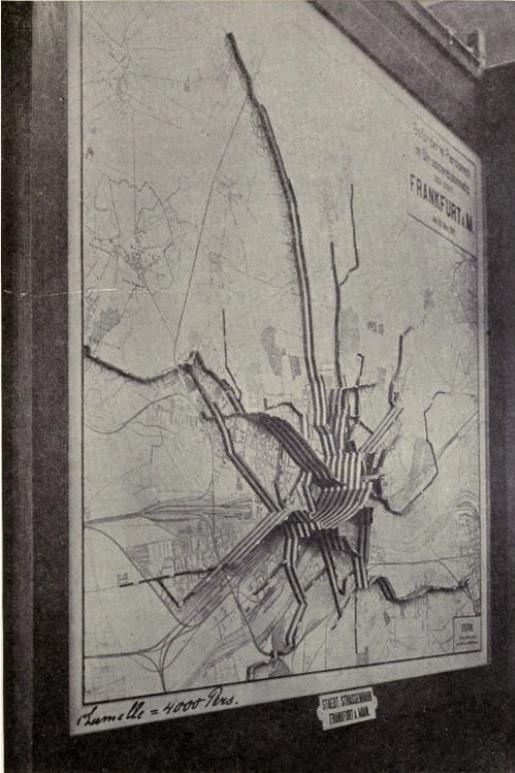


Figure 2.8: Frankfurt streetcar lines load [Image extracted from Brinton [1914, page 225]]

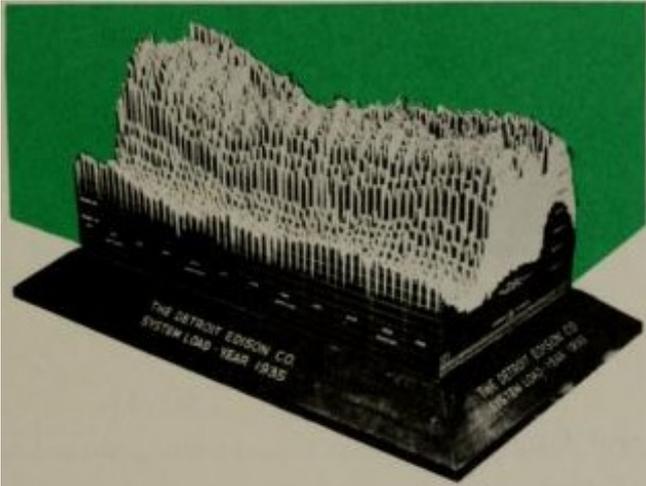
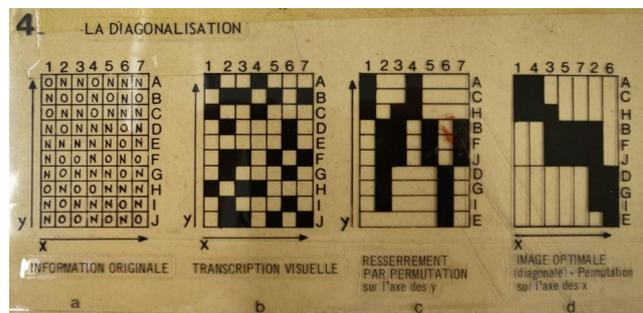


Figure 2.9: Detroit Edison company - power consumption 1935 [Image extracted from Brinton [1939, page 355]]



**Figure 2.10:** A wooden recreation of Bertin's reorderable matrix [Image credit: Robert Kosara - eagereyes.org under the terms of the CC BY-SA 4.0 Licence]



**Figure 2.11:** Revealing patterns by reordering the rows and columns of a matrix. [Image extracted from Perin et al. [2015, page 2]]

The quantity of data makes it sometimes necessary to compress them in order to be able to extract possible trends/patterns within the dataset, so despite the initial role of physical visualizations to record and share raw data they have to ensure that extracted information can also be easily understood.

The following chapter will offer more information about contemporary physical visualizations, by taking a closer look on some interesting examples.



## Chapter 3

# Types of Physical Visualizations

Physical visualizations have many different types. The underlying dataset can be fixed or change, user input may be supported and the visualization can be created by a dedicated group or as a collaborative effort of otherwise independent people. This way four different categories can be identified:

- **Static:** Data set is always fixed and can't be changed after building the model.
- **Dynamic:** It can represent multiple datasets. Usually the physical shapes seem to dynamically move.
- **Interactive:** The physical visualization acts according to user input, selecting a specific parameter or a specific part of the dataset.
- **Collaborative:** Users collaboratively build the visualization, it is built step by step with respect to other users' input, based for example on their taste, opinion or state of mind.

In the following sections, we discuss several examples for each type of physical visualization. These and many more examples can be found on Dragicevic and Jansen [2017].

### 3.1 Examples of Static Visualizations

#### 3.1.1 Wooden Model of a 3D MRI Scan

A project created by Neil Fraser, a software engineer at Google (described in Ouellette [2008]). He took 9 cross sections from an MRI scan with the aim to create a 3D model by gluing the MRI scan pictures on 1-inch wooden blocks (see Figure 3.1). The model consists of 60 1-inch wooden cubes where 94 faces are blank and 266 internal faces feature a slice of the MRI images. This visualization is a great example of an educational visualization where one can explore the brain and carve out custom shapes.

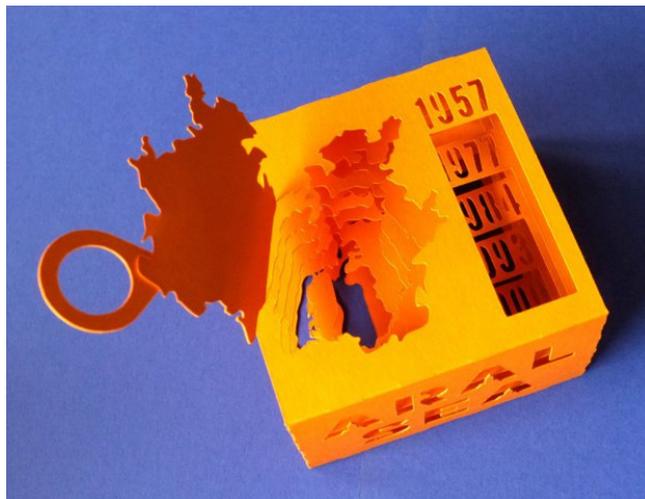
#### 3.1.2 3D Paper Model of Shrinking Aral Sea

The Aral Sea was one of the largest lakes in the world. Since 1960, it has been drying up. Today the size of the lake is 10% of its original size.

In Figure 3.2 it can be seen that the top paper layer presents the original size of the lake on the left and the year 1957 on the right. And consequently, over the next layers the size of the layer and the year can be seen for each of them until 2007.



**Figure 3.1:** 3D wooden model of MRI scan [Image extracted from Ouellette [2008] - Image credit: Movable Type 4 under the terms of the Creative Commons Attribution-Share Alike 3.0 Unported]



**Figure 3.2:** Paper model of the shrinking Aral Sea [Image extracted from Vojtek [2015] under WTFPL license]



**Figure 3.3:** General Motors' Lego model [Image extracted from Wilson [2012]]

### 3.1.3 General Motors' 3D Lego Visualizations

One of the manager's at General Motors realized that most of the data that comes to him is in 2D format. He wasn't able to reshape, grasp or work with the data. Therefore, alongside his colleague Dennis Pastor, they realized that the problem is that their reports come in 2D form and they want it in 3D form.

They started using Lego bricks for problem resolution tracking (see Figure 3.3). If a problem occurs they file a traditional paper report, but the problem is also added to the Lego board. On this board each type of problem has a different color and the brick size reflects the severity of the problem.

### 3.1.4 How Much Sugar do You Consume?

Nutrition labels are usually difficult for people to apprehend. Therefore, multiple campaigns started to make people aware of how much sugar they ingest while eating or drinking. The campaigns use physical visualizations to make it easier for people to comprehend. In Figure 3.4 multiple drinks are compared against each other by filling a plastic bag in front of each drink with the amount of sugar this drink contains. This is a great example of how physical visualizations can help making data more memorable as people tend to remember the amount of sugar in the bag better than just being told a plain number (like 40g).

## 3.2 Examples of Dynamic Visualizations

### 3.2.1 Actuated Prism Map of Italy

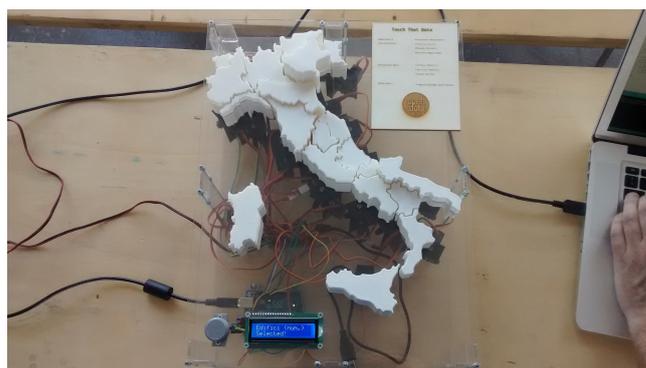
In this project an actuated prism map was created by Alessandro Masserdotti. It visualizes regional statistics by changing the height of each region according to the data. In Figure 3.5 the building count from the regional extracts is shown.

#### **Materials:**

1. Arduino
2. 3D Printing



**Figure 3.4:** Comparison of sugar amount in multiple beverages. The plastic bags in front of the drinks contain the same amount of sugar as the drinks. [Image extracted from Dragicevic and Jansen [2009]]



**Figure 3.5:** Actuated Prism Map of Italy [Image credit: Alessandro Masserdotti, [http://wiki.openstreetmap.org/w/images/8/86/Touch\\_that\\_data.jpg](http://wiki.openstreetmap.org/w/images/8/86/Touch_that_data.jpg), Creative Commons Attribution-ShareAlike 3.0 license]



**Figure 3.6:** Web behavior shown with a dynamic bar chart [Image extracted from Dragicevic and Jansen [2007] - Image credit: Physical Interaction Lab (2007), [http://asset-3.soup.io/asset/0987/0646\\_333c.jpeg](http://asset-3.soup.io/asset/0987/0646_333c.jpeg)]



**Figure 3.7:** Tempescope simulating mist [Image credit: Dovas [2016]]

### 3.2.2 Wable: Web Behavior Shown with a Dynamic Bar Chart

The project shows the personal feeds from a dynamic range of web applications like Flickr, Twitter or Facebook as a bar chart on a table (see Figure 3.6). The main idea is to visualize the web identity over time and create a physical link between the virtual and the real identity.

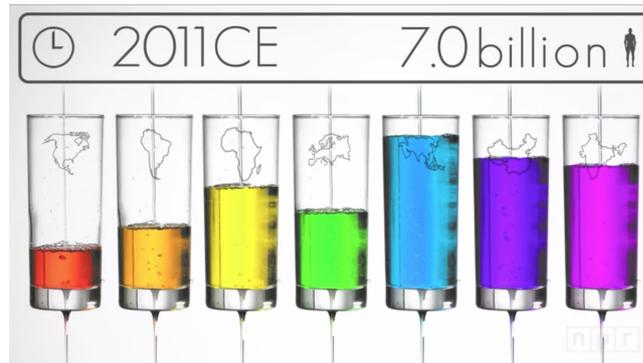
The project consists of two parts. The first part is a table where the user can see the visualization of the web identity. The second part is a web interface used to collect the data. The feedback is dynamic and can be changed using any RSS feed. Development of Wable 2 is currently in progress.

### 3.2.3 Tempescope

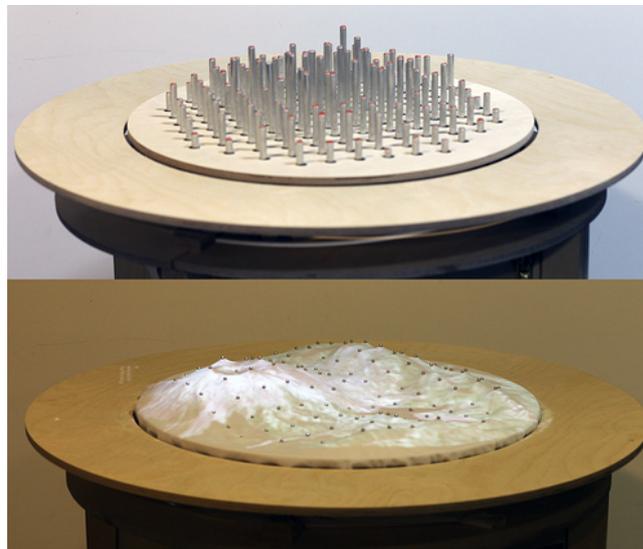
Tempescope is a product made to represent the various weather conditions indoors according to a forecast. The system can also show the forecast of other locations. It is connected to a weather service on the internet via smartphone or a PC. The model simulates raining by water dripping down the box, temperature is represented by color-changing LEDs and cloudiness is conveyed by a mist diffuser.

### 3.2.4 7 Billion: How Did We Get So Big So Fast?

The project Radio [2011] visualizes how the global population was and how it developed. It uses 7 glasses, each represents one continent of the earth. The amount of liquid in the glasses represents the population size. Adding liquid represents births and liquid dropping out represents deaths.



**Figure 3.8:** Population growth simulation using liquids. [Image extracted from Radio [2011] and used with kind permission of NPR]



**Figure 3.9:** The top picture shows 120 motorized pins - the bottom picture shows the model in action with a textile over it. [Image credit: Leithinger and Ishii [2010] under MIT license]

Medicine and nutrition are be represented on the glasses using a sticker on the bottom of the glass. This reduces the amount of liquid dropping out, thus the glasses get filled quicker.

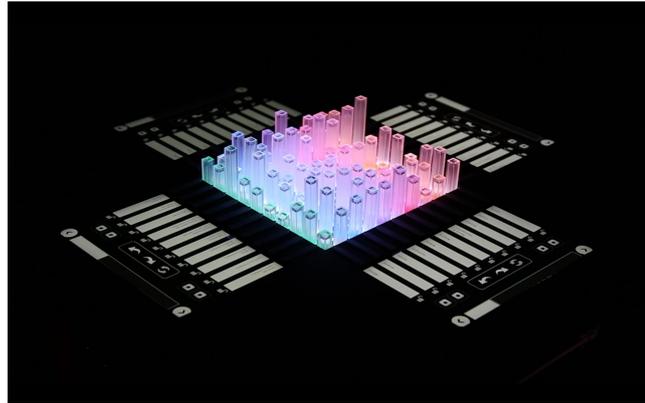
### 3.3 Examples of Interactive Visualizations

#### 3.3.1 Relief

The project is a tabletop display, the aim of the project is to allow the user to experience and form a digital geographic terrain using 120 motorized pins controlled by software (see Figure 3.9). Pins can sense user input (pulling and pushing), user can also zoom in and out on a specific part of the surface.

#### 3.3.2 Dynamic Shape-Changing Displays

In Taher et al. [2015] it was explored how non-experts made use of a dynamic physical bar chart with an open-ended data exploration and presentation task (see Figure 3.10). Users perform the following actions:



**Figure 3.10:** Dynamic physical bar chart for data exploration [Image extracted from Taher et al. [2015] and used with kind permission of Yvonne Jansen]

- **Highlighting:** Highlight and select a data points by pulling the bars (dims the deselected data).
- **Scrolling:** Navigate through data axes items by dragging the scroll-bar slider or pressing arrow icons on the touchscreen panels.
- **Locking:** Axis rows can be locked by pressing a lock icon.
- **Hiding:** Irrelevant data can be removed by pressing individual data points to hide them or press two data points around the edges to compare two rows (this hides all other rows except the locked ones).
- **Snapshot:** Save a ‘view’, and restore it later with the same settings as before (highlights, reorganized data points).

## 3.4 Examples of Collaborative Visualizations

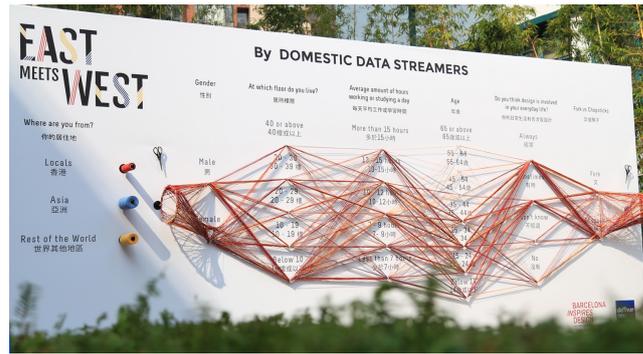
### 3.4.1 Data Strings

During a business of design week in Hong Kong a setup was made for 2 weeks (see Streamers [2017a]). It allowed the users to use a rope with three colours that represents the origin of the participants during the conference. Locals were red, Asian people were blue while the rest of the world where yellow.

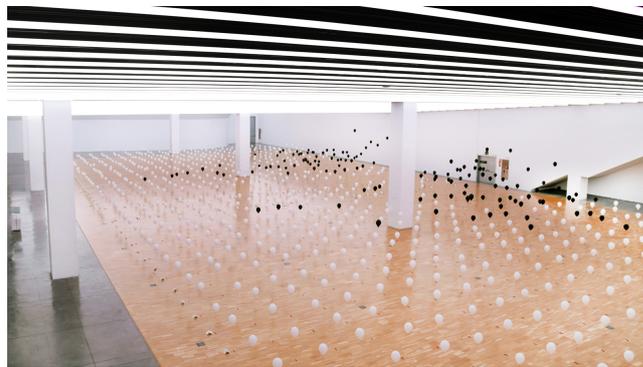
The audience had to answer the graph questions using the rope to select and answer the following questions:

- Gender?
- At which floor do you live?
- Age?
- Do you think design is involved in your everyday life?
- Fork or chopsticks?

The aim of the project was to allow the audience to perceive, understand and communicate with an organization in a more free way. The fabric sculpture grew more complex structure over time, yet the audience was able to engage and easily visualize and read the data from the parallel coordinates visualization. The result can be seen in Figure 3.11.



**Figure 3.11:** East meets west physical visualization [Image extracted from Streamers [2017a] and used with kind permission of Domestic Data Streamers]



**Figure 3.12:** Balloons representing until what age the participants want to live. [Image extracted from Streamers [2017b] and used with kind permission of Domestic Data Streamers ]

### 3.4.2 Lifeline

This installation was created during an event called *DEMO* at the Design Museum in Barcelona (see Streamers [2017b]). More than 2000 people were asked the question: Until what age would you like to live? The answers were collected into a giant 3D scatterplot, consisting of balloons in a space of 90x30 meters. White balloons were placed at a uniform height close to the floor, representing those people that do not know at what age they want to die (see Figure 3.12). Black balloons represent those people that know at what age they want to die, the height of the balloons corresponds to the desired age of death.

### 3.4.3 The Prudential Magnets Experiment

The participants of this project were first asked to write down things that happened in the past. Positive events were placed on yellow magnets, negative events on blue magnets. Afterwards the same was done for future events. The magnets for past and future events were collected on separate walls. As can be seen, in the past positive and negative events were quite balanced, but the forecast for the future was mostly positive.



**Figure 3.13:** The two boards showing people’s experiences from the past and their expectations for the future. [Image extracted from Dragicevic and Jansen [2015] - Image credit: Pruco Securities, LLC ]



## Chapter 4

# Challenges of Physical Visualizations

As seen in the numerous examples in the previous chapter, physical visualizations have great potential. However, there are also drawbacks to physical visualizations. This chapter discusses some challenges like costs, physical limitations and other disadvantages compared to virtual visualizations.

### 4.1 Costs

In the digital world, the main cost of a visualization is the creation time. The digital resources needed for the presentation are usually a small factor. For physical visualizations this changes. The material for the physical object as well as the space for presentation can both become significant factors.

### 4.2 Physical Limitations

Since the object of the physical visualization resides in the real world, it is also subject to its limitations and constraints. For example if a data sculpture needs to be able to stand by itself it can not be of arbitrary shape - it is subject to forces like gravity. Another simple example that is difficult to realize in the real world is a 3D scatterplot. Easy in the digital world, but gravity makes it hard to suspend objects in midair.

However, people may find ways around some limitations, as in the case of the 3D scatterplot. The group *Domestic Data Streamers* created a collaborative 3D scatterplot using balloons (Streamers [2017b]), and in Lee et al. [2011] magnets were used to control a sphere in midair, including interactivity.

If a physical visualization changes over time (either due to changes in the underlying data or due to user input) it also needs to be ensured that no material "runs out". This means for example, that a bar in a bar chart can get as high as needed at all times (see for example Jansen, Dragicevic, Isenberg et al. [2015]).

### 4.3 Production

Since producing a digital visualization is such a common task, many tools have been created to facilitate the process. Equivalent tooling for physical visualizations is not (yet) available (although there exist some efforts, see Chapter 5). Bringing a visualization of digital data into the physical world adds conceptually another step to the creation of a visualization: Fabrication. Thus it typically takes more time to create physical visualizations in comparison to comparable digital visualizations.

## 4.4 Distribution and Portability

A digital visualization, once created, can be easily distributed over digital communication channels. All that is needed by the recipient is the appropriate software to display the visualization. If standard formats like Scalable Vector Graphics (SVG) are used, then the majority of personal computing devices is equipped to handle the visualization. In case of physical visualizations the distribution becomes much more complicated - it is not possible to just copy a physical object and send it over the internet. Even moving a physical visualization may be challenging in practice, for example if the object is very large.

# Chapter 5

## Tooling

For digital visualizations there are many tools available. The tooling for physical visualizations is not so advanced. However, there are some initial efforts in this area, as well as inventive utilizations of existing technologies.

### 5.1 Lego

Several people discovered Lego bricks as a technology for physical visualizations. Its modularity supports the creation of arbitrary shapes, and with 3D printers it is possible to add custom bricks. Lego has been used for time-tracking (Hunger [2012]), bug tracking (Kakeda [2008]), visualization of production problems at GM (Wilson [2012]) or a thesis project board (Schneider [2015], with custom bricks, see Figure 5.1).

### 5.2 Physical Visualizations for Photographs

A more artistic approach to physical visualizations is to put data into a physical context. This seems to be often used by photographers to create unique visualizations, bringing the physical visualization back into 2D. The photographers Marion Luttenberger and Peter Ørntoft have used this approach to create beautiful visualizations, see Luttenberger [2017] and Oerntoft [2011], respectively. Characteristic of these visualizations is that the photographs are digitally edited to add labels to the physical objects that represent statistical data. See for example Figure 5.2.

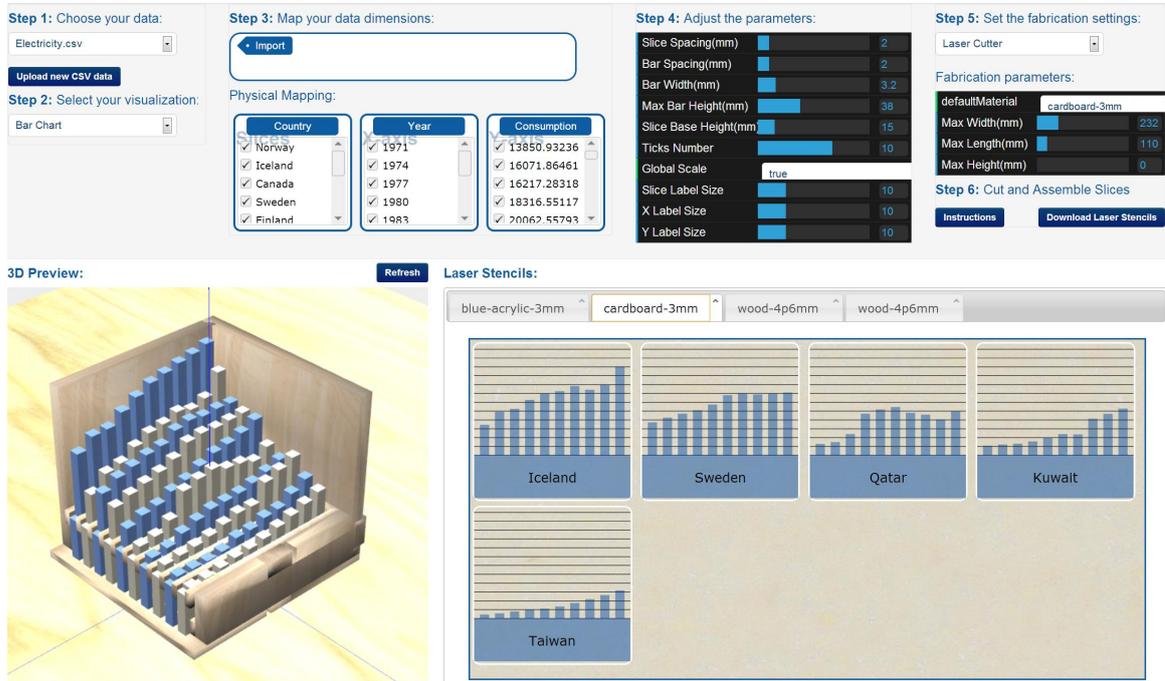
### 5.3 Handmade Visualization Tool-Kit

To support the creation of visualizations in the spirit of the previous section, the Colombian designer Jose Duarte devised a toolkit (named *Handmade Visualization Tool-Kit*, see Duarte [2017]). The toolkit consists of a few simple tools and items, bringing the cost of physical visualizations nearly to zero. See Figure 5.3 for the toolkit and a visualization created with it.

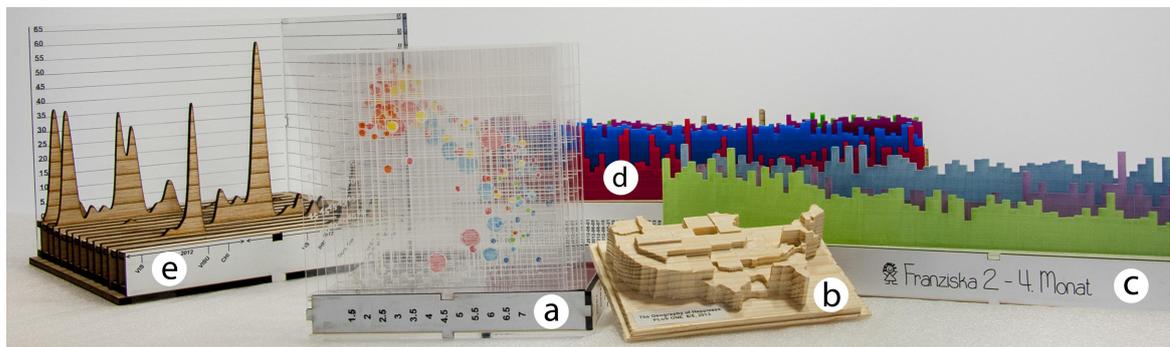
### 5.4 MakerVis

While the *Handmade Visualization Tool-Kit* is low-cost and simple, a sophisticated tool called *MakerVis* (described in Swaminathan et al. [2014]) is on the other end of the spectrum. It is a software that supports the creation of layered bar charts, layered line charts, layered scatterplots and prism maps. The input to *MakerVis* are raw data tables, it supports the user in modeling their visualization (see Figure 5.4 and produces output files ready for fabrication. The paper describes how 3 users tested the prototype and were able to create their own physical visualizations (see Figure 5.5. The paper mentions plans to open source *MakerVis*, however it does not seem to be available at the time of writing.





**Figure 5.4:** MakerVis supports the modelling of 3D physical Visualizations. When the modelling is finished it produces files for the fabrication of the visualization. [Images extracted from Swaminathan et al. [2014] and used with kind permission of Yvonne Jansen]



**Figure 5.5:** Examples of physical visualizations produced with MakerVis. All types of visualizations that can be produced with MakerVis (layered bar and line charts, layered scatterplots and prism maps) are shown. [Images extracted from Swaminathan et al. [2014] and used with kind permission of Yvonne Jansen]



## Chapter 6

# Benefits of Physical Visualizations

Physical visualizations take visualizations away from the traditional 2-dimensional setting (computer screen or paper) into the real 3-dimensional world. It seems intuitively attractive to enable real world interaction with a visualization, even if interaction is limited to the touching of a static visualization. However, do these intuitive advantages hold up under scientific investigation? This chapter discusses existing research about benefits of physical visualizations.

### 6.1 Memorability

In Stusak, Schwarz et al. [2015] a user study was conducted to evaluate the memorability of physical versus digital bar charts. The used bar charts can be seen in Figure 6.1 The 40 participants of the study were asked to remember certain information about the bar chart, like minimal or maximal values. While the results immediately after the handling of the charts did not depend on the type of the chart (physical or digital), the participants that worked on the physical bar chart recalled more information after 2 weeks had passed. This indicates that the physical representation is more memorable than the digital version.

Stusak, Hobe et al. [2016] investigates similar aspects, comparing the memorability of 2D paper bar charts to 3D wooden bar charts (see Figure 6.2). In this user study 16 participants were instructed to assemble and use the physical visualizations to complete simple tasks. Immediately afterwards as well as one week later, it was tested how much of the data the participants recalled. The 3D model performed slightly better (in particular the participants could recall extremal values better if they used the 3D model), but the results depended more on the underlying datasets. If the data set was more easily understood, the participants' performance was better.

### 6.2 Efficiency

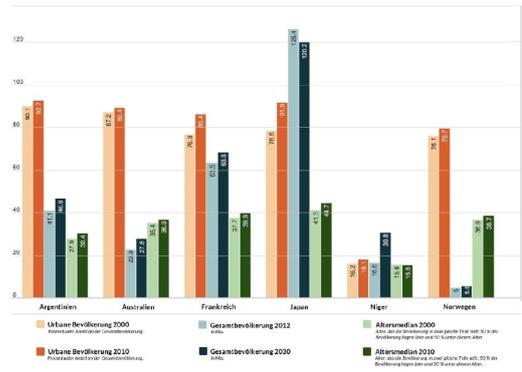
For the user study by Jansen, Dragicevic and Fekete [2013] a physical 3D bar chart was created and compared to digital 2D and 3D bar charts with respect to the efficiency in completing a set of tasks. The bar charts are shown in Figure 6.3. The 16 participants were timed during the completion of the tasks. While the 2D bar chart was more efficient than the 3D versions, the physical 3D bar chart performed better than the digital 3D bar chart. Despite the 2D version performing best, the users' feedback on the physical 3D bar chart was positive with respect to the handling of the chart.

### 6.3 Support Communication of Statistical Data

Physical Visualizations of statistical data were used in Gwilt et al. [2012] to communicate statistical data (see Figure 6.4. In this user study 30 people participated from 3 different user communities: Designers, scientist-s/engineers and the general public. After initial skepticism from the scientific group there was consensus on the usefulness of the physicality ("tactile nature") of the objects.

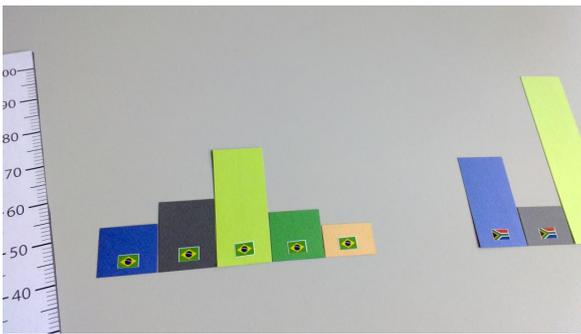


(a) Physical bar chart



(b) Digital bar chart

Figure 6.1: Physical and digital bar charts used in user study to evaluate memorability of physical visualizations. [Images extracted from Susak, Schwarz et al. [2015] and used with kind permission of Simon Susak]



(a) 2D paper bar chart



(b) 3D wooden bar chart

Figure 6.2: Physical bar charts used to compare memorability of 2D and 3D bar charts. While the 3D model performed better, the results depended more on the understandability of the underlying data set. [Images extracted from Susak, Hobe et al. [2016] and used with kind permission of Simon Susak]

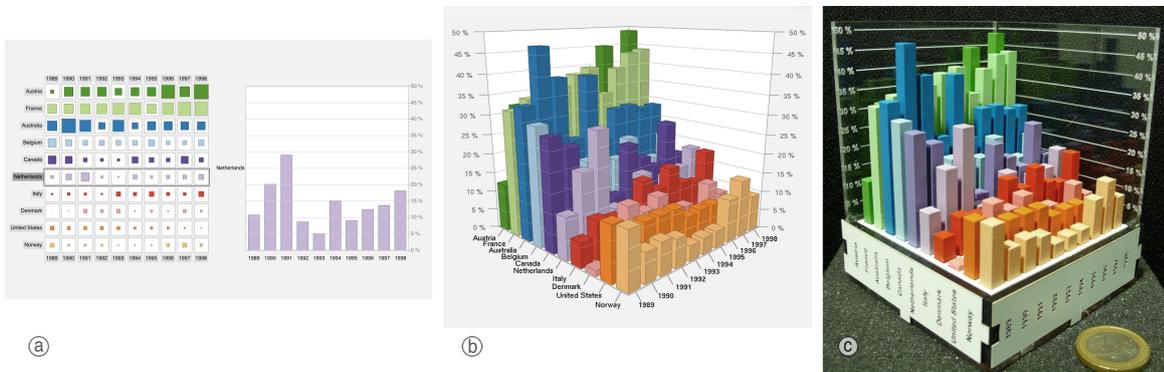


Figure 6.3: Physical and digital bar charts used in user study to evaluate the efficiency of physical visualizations. [Images extracted from Jansen, Dragicevic and Fekete [2013] and used with kind permission of Yvonne Jansen]



**Figure 6.4:** Physical Visualizations to support the communication of statistical data. [Image extracted from Gwilt et al. [2012] and used with kind permission of Ian Gwilt]

## 6.4 Motivate Physical Activity

In Stusak, Tabard et al. [2014] data on physical activity was used to create data-driven *Activity Sculptures* (something similar was also done in Khot and Mueller [2013]). Over 3 weeks 14 participants recorded their running activity, and the authors used these data to create the activity sculptures (see Figure 6.5 for examples). These sculptures were designed to encode the running data in their shape, for example the diameter of one part corresponds to the average running speed. The sculptures were well-received by the participants and caused motivation and self-reflection. Some participants even tried to change their running activity to consciously shape the corresponding *Activity Sculpture*.



**Figure 6.5:** Activity Sculptures encoding running data. The parts of the sculptures encode different metrics, for example the diameter of an arm represents the average running speed. [Images extracted from Stusak, Tabard et al. [2014] and used with kind permission of Simon Stusak]

## Chapter 7

# Conclusion

Physical visualization is a nice tool for encoding and presenting information that has been used for thousands of years. In this work contemporary physical visualizations have been grouped into four different types: dynamic, static, interactive and collaborative. Due to intuitive advantages (for example physical objects are easier to perceive and are more engaging) physical visualizations are often used over digital visualizations. However, the physical nature also introduces new challenges like physical limitations, a more involved construction process and a lack of mature tools. It is likely, that this situation will improve in the future (as projects like *MakerVis* show).

Scientific research on physical visualizations is still sparse, but the existing user studies show encouraging results. To better understand physical visualizations and to be able to create physical visualizations that are valuable to the users, more research will have to be done - the scientific foundation of digital visualizations is far ahead in this area.



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