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UNIVERSITY OF CALGARY

Glass: Opportunities in Design and Technology

by

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A THESIS

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Abstract

The objective of this thesis research is to identify and explore the design opportunities and the potential capabilities and applications for new glass products, given recent advances in glass material and the incorporation of digital technologies.

In order to accomplish this objective, different issues, such as the history of glass, the state of the art in glass, the technology in its broadest sense, the relationships established between people and technology were explored. Analysis and insight into these issues allowed a focus on semiotic pollution, which in turn informed an industrial design response.

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To Axel, thank you for your unconditional support.

Table of Contents

List of Tables

List of Figures and Illustrations

List of Symbols, Abbreviations and Nomenclature

Abbreviation	Definition
EPV	Enframed Point of View
DPV	Dazzled Point of View
MP	Meeting Point

"It is only through facing technology that we will ultimately understand it and transcend both its fascination and insidiousness" (Ihde 1979)

Chapter One: **Introduction**

Glass is a man-made material that can be found in several aspects of our lives, in different forms and varieties. Glass has been developing for thousands of years, and its manufacturing processes have evolved through history.

Therefore, a current mandatory question is: given recent advances in glass material and the incorporation of digital technologies, what are the potential capabilities and applications for new glass products?

It is important to note that glass development is not an isolated process, it is part of economic, historical, cultural contexts; and then, in order to answer this question it is necessary to address other issues such as: what is glass? What are the features and characteristics of glass? How is it made? How has it evolved through history? How people relates with glass? What is the state of the art in glass?

Methodology

To answer these questions literature reviews will be necessary in a number of areas. Because glass is a product of technology, the scope will be enlarged to encompass the technology issue in its broadest sense, as well as to understand what kind of relationships can be established between people and the products of technology.

After conducting these literature reviews and the appropriate analysis, it is anticipated that some problematic areas will become evident. These are then anticipated to form the basis and opportunity for a possible design intervention. Finally, a design process will be used to obtain a design response. This design response will likely incorporate a synthesis of the different subjects approached in this research.

Chapter Two: **Glass, a Background**

One of the most important tools for industrial designers are materials, because even if one can make use of virtual tools, an industrial designer is, at the end, a designer of objects with a material support.

For the first 5 million years of our existence, human beings mainly used five materials to make all our objects, tools, and structures: wood, stone, bone, horn, and leather. Those were materials that were found in our environment. Over time, as Enzio Manzini says, materials were no longer just "found", and they began to be "manufactured": for example, ceramic. Currently, we can now engineer materials to achieve almost any desired performance (Manzini 1986). Sometimes designers use materials at their fingertips, and sometimes they create specific materials to fulfill a need.

Currently there are an overwhelming number of materials, and designers should make a conscious effort to connect the properties of the thousands of materials available today, with the daily needs of users. (Thackara 2005).

According to Toshiko Mori, an essential role of design is to understand the basic properties of materials and push their limits to achieve better performance, and simultaneously, designers should be aware of their aesthetic and psychological effects (as cited in Kolarevic 2008).
In addition to being the indispensable basis for the creation of objects, materials also have a certain narrative. As Juhani Pallasmaa stated, materials have their own language. Stone speaks of its distant geological origin, its durability and suggests permanence. Bricks tell us about heat and

fire and the ancient tradition of construction. Bronze evokes the extreme heat of its manufacture, wood talks about its two lives, first as a tree, and then as an object made by man (Kolarevic 2008).

The correct choice of appropriate materials when designing an object not only improves its performance, it also helps to create a multisensory experience. Speaking about materials, one can say that there is a close relationship between effect and affect. Peter Eisenman said that "effect" is something produced by an agent or a cause and "affect" is a response to a physical environment. Some material effects can engender powerful feelings (Kolarevic 2008).

After talking about materiality in a broad sense, now I would now like to talk specifically about glass.

2.1 What is glass?

Glass is an inorganic solid material that is usually transparent or translucent as well as hard and brittle. This material is made by the fusion of a mixture of materials such as sand (silica SiO_2), limestone, soda and other minerals at a very high temperature to form a liquid and then cooling to obtain a certain shape (Frank 1982).

2.1.1 Uses of glass

Glass was probably one of the first materials to be manipulated on a large scale, and it can be found in different fields of application, from packaging to prostheses and from the construction industry to the telecommunications industry.

There are types of glass properties which can be adapted to meet almost any imaginable requirement, but the main restrictions are normally commercial considerations; i.e., whether the potential market is large enough to justify the development and manufacturing costs. According to Lefteri, glass, or the comparatively new family of materials known as glass ceramics, may be the only practical material for the engineer to use for many specialized applications in chemistry, pharmaceuticals, the electrical and electronics industries, optics, and the construction and lighting industries (Lefteri 2002).

Different forms and varieties of glass are used in almost every conceivable aspect of human life like architecture, food and drink, laboratories, equipment, instrumentation, the chemical, nuclear, and electrical industries, lighting, optics, etc. For some areas of application, one type of glass predominates; for example, soda-lime glass is used in the building and packaging industries, while borosilicate tends to be standard in the chemical processing industry (Lefteri 2002).

Image 1: *Glassware by Kosta Boda*

Image 2: *Optical fiber*

Image 3: *The Netherlands Institute for Sound and Vision*

Common uses of glass

The following chart presents some common uses of glass.

Product	Specific qualities	Method of manufacture	Typical formula (approximate composition)
Glass containers, bottles and jars	Relatively cheap when mass produced, resistant to mechanical shock, capable of being filled at very fast rates, can be re-used and recycled, can be sterilized, inert, does not impart taste or toxic substances	Automatically blown at high speeds	Soda-lime silica SiO 74% Na_2O 14% CaO 11% Al_2O_3 1%
Flat glass	Relatively cheap, can be toughened, weather resistant, can be coated	Float process Cast and rolled	Soda-lime silica SiO_2 71% Na_2O 16% CaO 9% Al_2O_3 1% MgO 3%
Domestic glassware for everyday use in the home and catering	Pleasant appearance Ability to stand up to constant use Does not affect contents	Mouth blown, pressed or fully automatic mass produced.	Soda-lime silica SiO_2 74% Na_2O 16% CaO 5% Al_2O_3 3% MgO 3% K_2O 1% B_2O_3 1%
Radiation shielding	High density to absorb radiation	Extrusion and casting can be ground and polished to optical precision	SiO_2 5% PbO 82% B_2O_3 10% Al_2O_3 3%
Thermometer tubing	Thermal stability over a wide temperature range, retaining transparency	Automatic or hand drawing	Soda-lime silica Borosilicate Lead glass Depends on temperature range required.
Laboratory glassware	High chemical	Lampworking (made	Mainly borosilicate or

	durability, low thermal expansion	from tubing by heating and skilful manipulation), mouth and automatic blowing, sintering	fused silica for extra low expansion coefficient
Full lead crystal domestic glassware	Particularly suitable for artistic hand shaping and mouth blowing, brilliant finish, attractive when full or empty, comparatively soft; easy to cut and polish or engrave	Handmade by skilled craftsmen	Lead glass SiO_2 55% PbO 33% K_2O 11%
Heat-resistant oven to tableware	Resistant to thermal shock, attractive, easy to clean, can be used in microwave ovens	Automatically pressed or blown	Borosilicate glass SiO_2 55% PbO33% K_2O 11%
Optical glass	Wide range of refractive indices, wide range of dispersion coefficient, perfect homogeneity, complete transparency	Casting, pressing, blowing	Wide range of compositions. Depend on applications
Electrical components: cathode-ray tubes, capacitors and resistors, computer components, printed circuits	Good dielectric properties, low electrical losses over a wide range of temperatures, high operating temperatures.	Blowing, drawing in rod form and sheets, sintering and pressing. Glass is ground to fine grains and then subsequently pressed into required shape and fired	Wide range of compositions
Glass building blocks	Resistant to normal temperature changes, resistant to atmospheric conditions, mechanically strong, attractive, translucent	Automatic pressing. Pressed in halves and joined together	Soda-lime silica Similar to flat glass
Ballotini: minute glass spheres (1-60 microns) which reflect light	High reflective properties, mixed with paint for road signs and cinema screens	Flame drawing. Velocity of flames draws particles of glass up tower. As the softened glass falls on	Soda-lime silica Similar to flat glass

		the outside, spheres are formed by surface tension effects	
Glass fiber	High strength-to-weight ratio. Resistant to corrosive substances. Resistant to high temperatures, flame resistant, high electrical resistance.	Filament drawing, continuous filament, white wool, crown process. Can be woven into textiles or incorporated with plastics to form insulating materials, boat hulls, and car bodies.	Soda-lime silica and where resistance to weathering is necessary, a borosilicate glass is used.
Lighting glassware Electric light bulbs	Economical to produce, easy to manufacture by mass production methods, resistant to shock, impermeable and inert to gas, steam, and liquid. Durable. Transparent or translucent.	Ribbon machine produces bulbs at the rate of over 100 per minute. Blanks used in the manufacture of vacuum flasks are also produced by this machine	Soda-lime silica SiO_2 72.5% Na_2O 15.9% CaO 6.5% Al_2O_3 3% MgO 1.3% K_2O 0.3%
Special glass: high pressure mercury vapor lamps, glass for encapsulating electric components	Low melting point. Resistance to intense chemical activity of mercury vapor.	Special glass can be formed by using manufacturing processes, or, in some cases, laminated on to ordinary glasses, i.e., sodium discharge lamps	Wide range of compositions
Tubing for fluorescent lighting	Low melting point. Resistance to intense chemical activity. Electrical discharge generates UV light which then causes fluorescent powder to emit visible light. High efficiency. Long life: 3000 -5000 hours, i.e., about one year of continue use.	Automatic drawing	Soda-lime silica SiO_2 72.5% Na_2O 14.5% CaO 5.7% Al_2O_3 2.6% MgO 3% K_2O 1.2% B_2O_3 0.3%
Domestic and industrial shades and	Resistant to high temperatures, resistant	Mouth blowing Hand and automatic	Soda-lime silica Laminated with opal

bulkhead lights: includes lenses for traffic lights, car lights and railway signal lights	to thermal shock, resistant to weathering, Accurate and non-fading color. Subject to strict BS specifications	pressing depending on quantities required	glass. Borosilicate glasses and opal glass
British Glass Ltd., as cited in Lefteri. (Lefteri 2002)			

Some authors, such as Macfarlane, have divided the uses of glass into: verroterie (glass beads, etc), verrerie (glass vessels and other domestic ware), vitrail (window glass), and mirrors, lenses, prisms (Macfarlane 2002).

2.1.2 Properties of glass

General properties of glass

Glass has a combination of features we do not find in any other material; for example, glass is excellent to use for physical and chemical experiments because it is easy to clean, seal, transform into the desired shape for the experiment, and strong enough to make thin apparatus and to withstand the pressure of the atmosphere when a vacuum is created within it. It is resistant to heat and can be used as an insulator (Macfarlane 2002).

Although many of the properties of glass arise as a result of their composition, there are some properties that are common to most types of glass; for example, the compressive strength of most glass is approximately 10.000 kg / cm ^{2}, and the density is 2500 kg / m^3. Also, it is necessary to say that in general, glass is a poor conductor of electricity and heat.

Other general characteristics of glass are:

Brittleness

Glass, when newly formed with a perfect surface, is very strong: about 5 times as strong as steel. In theory, glass should be very strong because of the nature of its inter-atomic bonds. However, in practice, there are several factors that make glass brittle. One of the main causes of this loss of strength is the presence of surface defects, such as those caused by chemical corrosion or mechanical abrasion. Under these conditions the strong bonds break and fracture occurs. Once started, the fracture has a high probability of spreading right across the material because there are no internal grain boundaries to stop it, and then a piece of glass will often shatter suddenly when subject to stress (Frank 1982).

It is also important to control the cooling of glass during the manufacturing process, because if the glass is cooled too rapidly it does not have time to release the stresses set up during cooling, and the glass will shatter. In order to avoid these internal stresses, glass articles are subjected to a controlled heat treatment after manufacture, a process known as annealing. The temperature is raised to that which allows internal stresses to be relaxed by flow within the glass (but not so high that the article will deform) and held there for an appropriate time.

Then temperature is then slowly reduced to a certain point. This controlled heating and cooling process is known as “curve of control of temperature” (Frank 1982).

Hardness

The hardness of soda glass is 6 to 7 on the Mohs scale (the Mohs scale is a definition of hardness in materials).The resistance of soda glass to being scratched (hard surface) is approximately equal to quartz.

Resistance to corrosion

Glass is very durable and extremely resistant to corrosion, and its composition can be chosen to enhance this property. However, ordinary glass, when placed in contact with water (as may be the case at an archaeological site or in a damp atmosphere), can suffer corrosive attack because the water leaches out some of the components (usually sodium or potassium) from the surface.

Potash glass (glass where potash is the major component) is in general much less durable than soda glass, and this has important consequences for archaeology because medieval glass is usually a potash glass, which is scarce in comparison with Roman glass; the Romans produced a relatively stable glass containing soda as the major alkali (Frank 1982), as I will explain further.

Transparency

Apart from certain single crystals and plastics, solids are not generally transparent; transparency is much more characteristic of a liquid than a solid. In a crystalline solid, which is usually made up of many tiny crystals, light, in its passage through the solid, is reflected at each internal boundary. Some light is lost at each reflection, with the result that the material is effectively opaque. Glass (and liquids) has no internal surfaces or discontinuities having any dimensions approaching the wavelength of visible light. The light can pass through the glass almost unhindered and as a result, glass is transparent (Frank 1982).

This characteristic of glass, transparency, allowed the development of optical instruments, and therefore allowed new ways of seeing and understanding the world. Transparency also made possible the development of experiments in physics and chemistry, because researchers could see what was happening in the container.

If some substances are added to glass, it can achieve almost any color. A large description of glass and color can be found in Appendix B.

It is important to point out that glass is transparent in visible light, but soda glass is in fact opaque at infrared and ultraviolet wavelengths because at these wavelengths the frequencies of molecular vibration within the glass result in its absorption by the glass.

Viscosity

Viscosity means the resistance of a liquid to flow. As the glass heats and softens, it becomes less viscous. The point at which glass begins to deform is around 730 ° C or so (depending on the composition of the glass), and is known as the softening point. The strain point is when the internal stresses vanish, and the yield point occurs when the glass is a rigid solid and can be cooled quickly without internal stresses (Frank 1982).

Glassy state

Solids are composed of crystals: a crystal is a substance which has solidified from a liquid state into a definite geometrical form reflecting the arrangement of the constituent atoms. These are packed together in a perfectly regular manner to form a repeating network, or lattice. However, glass is a material which never crystallizes, and it becomes rigid whilst still retaining its liquid structure. When most liquids are cooled, a sudden change occurs in their structure at a particular temperature and they freeze to form crystals. In a liquid, the atoms are joined to one another but not in any regular extended three-dimensional pattern; they form a random structure. When the liquid becomes a solid, the structure changes from random disorder to regular order, and the material no longer flows (Frank 1982).

However, as we cool liquid glass from very high temperatures to room temperature we see no discontinuous changes taking place. It simply gets stiffer and stiffer until it is rigid and effectively a "solid", but still with the internal structure of a liquid. Because it has been cooled to far below the temperature at which thermodynamic considerations indicate freezing should take place, it is known as a “supercooled” liquid (Frank 1982).

A supercooled liquid exists in what it is called a “metastable” state. At its freezing point, an ordinary liquid changes to a solid because in this way the internal energy is minimized, and the system is stable. The energy of the system is appropriate to the temperature of the system (Frank 1982).

During fabrication, the fused mix of silica, soda, and other components is cooled to ambient temperature at a rate fast enough to prevent crystallization; i.e., the molecules cannot arrange themselves into a crystalline pattern. The fast rate of cooling to prevent crystallization applies to transparent glass, whereas in the case of translucent or opal glass, the rate of cooling is such as to produce a predetermined level of crystal formation (Frank 1982).

A liquid which may form a glass shows a very rapid increase in viscosity as the temperature drops below that at which the glass is “melted”, typically 1350°-1600°C. Just below the melting temperature is the most dangerous region for crystallization and the glass must be cooled very quickly through this range, giving crystals no chance to form and grow. The way in which the glass-forming liquid will pass from the metastable state to the stable, crystalline state is by breaking the intermolecular bonds in the liquid, making new bonds to form a regular crystal lattice. But the original bonds are too strong for this to happen: not enough energy is available to break them, and the glass-forming liquid fails to crystallize. This difficulty increases as the temperature falls, and by the time that the glass reaches room temperature it may be said that it is a liquid which has become too cold to freeze. The faster the glass is cooled, the higher the temperature at which configurational rearrangement effectively ceases. In general, glass can be thought of as a “slow-motion” liquid, having flow properties which are similar, on a vastly increased time scale, to those of ordinary liquids(Frank 1982).

2.1.3 Glass composition

The main constituent of practically all commercial glass is silica (SiO2). Silica comprises approximately 44% of the earth´s mantle, making it by far the most abundant compound, and this allows glass to be made in almost any part of the world.

In order to reduce the melting temperature, silica (SiO2), usually in the form of washed white sand, is melted with another chemical compound such as soda (sodium carbonate, or Na2CO3, which melts at 851°C) or potash (potassium carbonate, which melts at 901°C) (Lefteri 2002).

Adding other chemicals to sand can considerably reduce the temperature of fusion, but in order to give the glass stability, other chemicals like calcium oxide (CaO) and magnesium oxide (MgO) are needed. Current glass-making is done in furnaces at 1500 to 1600°C, at which temperature the glass is very fluid and the larger bubbles can rise to the top. In addition, small amounts of arsenic oxide or antimony oxide can be added, which assists in the removal of the very small bubbles (Lefteri 2002).

It is important to say that oxides are not added simply as fluxing agents to lower the melting point; for example, lime (CaO) and magnesium oxide (MgO) are added to improve the chemical resistance, and many desired physical and chemical properties are obtained by altering the glass composition (Frank 1982).

The chemical composition of the most common types of glass is shown in the chart titled "Common uses of glass".

Sometimes broken glass, also called cullet, is added to the mixture of chemicals. Cullet melts at a lower temperature than any of its separate constituents, and then it speeds up the melting process. It is important to point out that cullet can form a significant proportion of the total batch. It can come from factory rejects, or it can be collected by the public in bottle banks or from the bottling industry (Lefteri 2002).

Almost any proportion of cullet can be added to the mix, known as batch, which serves to manufacture new glass. Although the glass collected from bottle banks may come from several manufacturers, it can be reused without problems as long as the colors do not mix and the cullet is free from impurities, especially metals and ceramics (Lefteri 2002).

Depending on the final use, the composition of the glass and the rate at which it is allowed to cool will vary, as these two factors are crucial in obtaining the properties the manufacturer is seeking to achieve.

An interesting fact is that most of today´s glass is essentially the same glass of ancient times; both are made of silica fused or melted together with other ingredients such as soda and lime. A description of glass composition and raw materials through history can be found in Appendix D.

So far, I have made a review of the characteristics, composition and properties of glass. In summary, it can be said that glass presents a number of features that make it unique; for example, the humble raw materials used in its manufacture, its high recyclability, its characteristic of being inert (in that it reacts whit few other substances) and its transparency, among others. These features are very useful in many fields, for example, because due to both the transparency of glass and its characteristic of being inert, it has been an excellent material for the manufacture of tools for the study of chemistry. This relationship has been symbiotic: as advances in glass technology field carried advances in experimental sciences, so advances in sciences involved advances in glass technology.

Moreover, the raw materials for glass are so common on the Earth's surface that glass can be made in almost any part of the world, at low cost, and using basic technologies. An important thing to note is that materials used in glass making process do not always need to be raw, as a high percentage of cullet (recycled glass) can be used in the manufacture of glass objects.

However, although due to its chemical composition glass can be made almost anywhere in the world, it is necessary to clarify that context has a big impact in any technological development, and the glass field is not an exception. In Appendix C a brief history of glass can be found, from pre-roman glass to mechanization processes. In this Appendix it is stated that the development of glass through history has been marked by various cultural, social, political, economic, and even geographic aspects.

A clear example of how context has influenced the development of glassware is the following: drinking habits of a particular place influence glass production. For example, according to Diamond, in England different kind of glasses were made to match the wide variety of English drinks: beers, ales, ciders, wines, whiskeys, and gins (Diamond 1953); and on the other hand, according to Macfarlane, there was not a large development of glass in China and Japan (at least not until the 20th century) because both countries traditionally drink tea, and are also great potting nations, and pottery holds hot liquids very well. A tea-drinking nation is unlikely to develop the same kind of drinking glasses as the heirs to Roman glass (Macfarlane 2002). Some historians have even developed their theories based on drinking habits; for example, Standage has divided the history of the world through the consumption of six beverages: beer, wine, spirits, coffee, tea, and Coca-Cola (Standage 2005).

But the cultural context was not the sole condition for glass to develop in a certain place. Factors such as climate, for example, also influenced the development of flat glass for windows, which were unnecessary in warm climates. What I wish to point out is that there are a lot of cultural, political, social and even geographical factors which are important in glass development, but in any case, it was not necessary for a country to be a glass producer as long as it could buy glass from somebody else, and this trade influenced the exchange of knowledge, which in turn boosted the development of glass technology. It is also important to point out that many of the glass manufacturing processes have scarcely changed throughout history and they are still being used.

A large description of the traditional techniques of glass manufacturing can be seen in Appendix F.

It is possible to identify some milestones in glass field:

The first milestone in glass technology was the development of glass-blowing. This process allowed making more objects in less time, resulting in a reduction in the price of glassware.

The second milestone in glass field was the development of lead glass for optical purposes. This advance enabled the manufacture of more accurate lenses, which in turn boosted the manufacture of telescopes and microscopes, basic instruments in the development of modern science.

The third milestone in the glass field was the mechanization of production processes in the 19th century, which changed working methods and caused handicraft workshops to become factories. The mechanization of production processes also changed the relationship between worker and glass: the craftsman was not longer in direct contact with the glass object, but became a worker who operated machines. As a reaction to this shift there was a revival of handmade glass in Scandinavian countries, and in Holland, England, France, the Czech Republic, the USA, and Italy.

And finally, we are currently living a fourth milestone in the glass field: the development of digital tools. In the next chapter I will explain the state of the art of glass as well as the use of digital tools being applied to the glass field.

Chapter Three: **Glass Today**

In the previous chapter I talked about glass as a material: its characteristics, features, and behavior. The relationship between people and glass through history was also mentioned. In this chapter I will talk about the state of the art in the glass field, and I will also mention some emergent processes.

Glass may be devised to meet almost any imaginable requirement. A large variety of glass with different chemical and physical properties can be made. Diamond mentioned that in 1950 there were about 30,000 different kinds of glass (Diamond 1953).In this chapter I will mention only the types of glass that are of the most importance, either for their applications or their innovation. I have separated the types of glass into 4 main areas: the most commonly-used glass, specialized glass due to its composition, different types of glass products, and some examples of emerging glass. In Appendix E a detailed description of these types of glass can be found.

But some mandatory questions are: how is glass made? What is the state of the art in the glass field? As I mentioned earlier, several ancient processes of manufacture of glass are still being used, even though skilled workers have been replaced by machines, as can be seen in Appendix F.

Now, I will list the most common processes being used today in the glass manufacturing industry. The complete description of these processes can be found in Appendix G.

3.1 Most common manufacturing processes in the glass field

In this part I will describe the most common processes being used today in the glass manufacturing industry. In Appendix F a description of traditional processes through history can be found.

3.1.1 Preparation of raw materials

The first step in glass making is the preparation of raw materials. In this step, silica sand is cleaned and sorted and then it is mixed with other components. Currently, recycled glass is added to the mix at 20 to 40%, but the mixture can be 100% recycled glass.

3.1.2 Deformation: molding and casting

These methods describe ways in which material can be cast directly into a mold as a liquid; pressed into a mold as a “plastic” material; deformed under pressure using dies, forming tools, or molds; or otherwise made into shapes different than that of the original material without directly removing or adding material (Schodek 2005).

Casting is a semi-automatic or manual process used for low or medium production. This process is not normally used in high production because it requires a long cooling time in order to avoid thermal shock. Furnaces for melting glass can use refractory or electric tanks.

3.1.3 Making glass containers by an automatic process

Until the second half of the 19th century, bottles were made by hand processes, mainly blowing glass. A semi-automatic method of bottle-making was developed after 1850, but this has since been replaced by the fully automatic process. All bottles and jars are now made automatically by one of two methods: “Press and Blow” or “Blow and Blow” (Lefteri 2002).

3.1.4 Making flat glass

The main flat glass products are for high-quality glazing in homes, offices, hotels, shops, vehicles, public buildings, wired glass for fire resistance, patterned glass for decoration, and a wide range of glass for environmental control and energy conservation.

Other uses for flat glass include toughened glass doors, suspended window assemblies, cladding for the exterior of buildings, mirrors, and low-reflection glass for pictures and instrument dials. The current two main manufacturing processes for producing flat glass are the float glass and rolled glass processes (www.britglass.org.uk, 2011).

3.1.5 Glass fiber manufacture

Continuous glass fiber is a continuous strand made up of a large number of individual filaments of glass. Glass fiber is produced in a range of filament diameters and strand dimensions to tight tolerances for different end uses (www.britglass.org.uk, 2011).

3.1.6 Glass tubing

Glass tubing is used in many products including scientific instruments, fluorescent lights, and many other lighting applications. Glass tubes are made by the Danner process or the Vello process.

3.1.7 Secondary glass processing

As part of the production process, some types of glass are subjected to secondary processing such as annealing, toughening, coating, and decorating. Formed and annealed glass may be further processed. This may be done by taking away from or adding to the surface of the glass. It may also be heated, manipulated, and reshaped. If it is reshaped, it would need to be re-annealed and be toughened again (www.britglass.org.uk, 2011).

3.2 Digital technologies in glass manufacturing

So far I have talked about the most common manufacturing processes in the glass field, however, all of them have been around for decades, or even centuries. As I mentioned in previous Chapter 2, a milestone in the glass field is currently happening: the development of digital technologies. It is necessary to point out that this milestone is not only affecting the glass field, but it is a global phenomenon, unlike other milestones, such as blown glass development.

This topic is very broad, so I will just list those digital technologies that could be used in the glass field.

Digitally-based technologies have introduced new capabilities in architecture and design. According to Fabio Gramazio and Matthias Kohler, the digital revolution has changed the ways architecture and objects are designed, built, and used (Kolarevic, 2008). One of the more radical consequences of the digital revolution in the field of industrial design is the computer-controlled fabrication, or digital fabrication, as well as CAD / CAM.

3.2.1 Digital design

According to Marta Malé-Alemany at this time there is an emergence of a new tool, the computer, and a new medium, digital. Since the 1990s, CAD, CAM, CAE (Computer Aided Engineering) and CNC production have been progressively integrated. These technologies were often adopted from other disciplines. Digital tools have influenced the development of building materials, components, and structures through the design, analysis, and manufacture of customized materials, customized forms, and customized properties. Some examples of digital tools are : parametric design, scripting and programming, and CNC machining and prototyping (Krar and Gill 2003).

Computers have created a revolution in manufacturing processes and procedures. Computer-based technologies have made it possible to manufacture goods faster, improve product quality, and reduce manufacturing costs. A few of the technologies made possible by computers are:

NURBS interpolation

NURBS interpolation is used to define a 3D object in mathematical terms. It can be used in the high-speed and high-accuracy machining of very complex forms. NURBS is an acronym that stands for Non-Uniform Rational B-Spline. It is an accurate and flexible mathematical model used to represent the curves and surfaces of random shapes. NURBS interpolation is a relatively new function of modern CNC and CAM systems. NURBS is used to define a 3D object in mathematical terms. It is widely used in various industries, such as CAD/CAM, mold work, computer graphics, and 3D animation (Krar and Gill 2003).

The main elements of NURBS, namely the control points, knot vectors, and weight factors, can now be transferred from the CAD software directly to the CNC system in the form of NURBS interpolation. The machining program is generated by the CNC software, and produces a special G code output (Krar and Gill 2003).

For example, the following image was digitally made using NURBS. Having this digital model, one can fabricate the real thing without any problems.

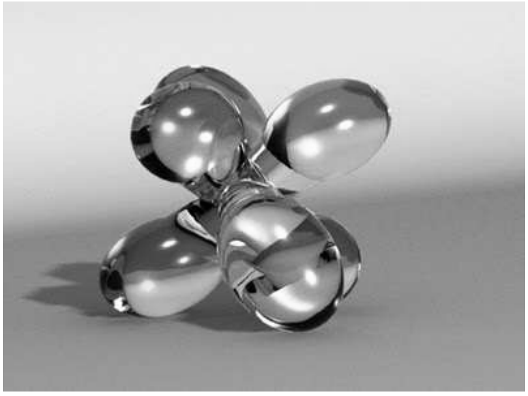

Image 4: *A digital shape made using NURBS*

Use of the internet in CAD processes

The ability to quickly and accurately communicate technical information and drawing designs to suppliers and manufacturers allows developing a strong collaboration in an iterative process, no matter the geographical distance (Krar and Gill 2003).

Immersive virtual reality

Virtual reality (VR) uses computers and other special hardware to create objects and even alternative worlds. It allows a person to become immersed and interact with the simulated environment (Krar and Gill 2003).

Immersion provides users the ability to believe that they are present in the virtual world and that they can navigate through it and function within the simulated environment as if it were physical reality. Interaction gives them the ability to manipulate objects encountered in a virtual environment. The professional and scientific applications of VR are actually more widespread than recreational applications: there are medical applications, engineering applications, military simulations, and educational applications (Krar and Gill 2003).

Virtual product design is a process that saves time and materials which are necessary in making physical models by traditional methods. Users can design and analyze the shape and construction of a product, and inspect any potential problem (Yan et al. 2009).

3.2.2 Digital fabrication and manufacturing

The digital tools mentioned so far are focused mainly on the design stage, and now I would like to talk about digital tools that can be applied to the manufacturing stage. It is important to point out that digital technologies explained on the following pages are very useful design tools, but they are not necessarily being used in glass manufacture.

According to Makai Smith, the term "digital fabrication" is a catchall very useful to group many different technologies which involve a manufacturing process that can only be done by machines, not by human hands. In practice, the distinction is not so clear; digital manufacturing processes tend to mix computer-enabled methods and hand-labor methods, and each of them offers different limitations and potential (as cited in Kolarevic 2008).

Some concepts linked with digital fabrication are: Computer Aided Design (CAD), Computer Aided Manufacture (CAM), and Computer Numerical Control (CNC). While CAD/CAM is the union of the computerized forms of drafting/design and manufacturing, CNC technologies allow automated equipment to be controlled and operated in real time through the use of a symbolic language (Schodek, 2005).

I wish now to present some digital processes that can be applied to glass manufacturing.

Non-material removal processes: fabrication or addition to elements

Fabrication processes occur when material is added to a base element, layers of materials are built up, or small elements connected to one another to produce a larger item. This may be done by welding, screwing, riveting, squashing, gluing, mechanically engaging, or using any number of other methods (Schodek, 2005).

Non-material removal processes use a blank of material, and by bending, forming, or shaping create a finished product. Other processes combine CAD and laser technologies to produce a part using raw materials such as metal powders. Currently in the glass industry, these processes are used mainly to fabricate prototypes or molds. Some of the most common non-material removal processes are:

Non-material removal processes used to fabricate prototypes

Fineblanking

Fineblanking is a high-tech forming process closely resembling cold extrusion, and provides new options for improved part quality, and greater detail. It can form accurate parts which require only minor secondary operations (Krar and Gill 2003).

Rapid Prototyping

Rapid Prototyping (RP) is the name of a number of computer-based technologies that make it possible to quickly build a 3D model directly from a Computer Aided Design (CAD) file. These models are a key step before the manufacture of most industrial and consumer products and parts. The process starts with software that slices the CAD model into thin layers. The computerized RP machine builds the cross-section one layer on top of the previous to produce the finished prototype (Krar and Gill 2003). Rapid prototyping is a tool that can be used in several manufacture fields; but it does not necessarily apply to glass manufacture; however aspects of rapid prototyping can be used to study the form and functionality of potential designs yet they may not accurately portray the true qualities of a glass product or object.

There are dedicated glass rapid prototyping technologies available and these are discussed below.

The various RP technologies differ in the way the cross-sections are produced as well as the materials that can be used. The most common rapid prototyping processes are Stereolithography, Selective Laser Sintering, and Laminated Object Manufacture (Krar and Gill 2003).

Stereolithography (SL) is the most widely used rapid prototyping and manufacturing technology. It can quickly and accurately take a CAD or CAM design or a 3D-scanned object and produce solid three-dimensional objects. SL uses a laser to selectively polymerize a liquid resin to form the part cross-sections(Krar and Gill 2003).

Selective Laser Sintering (SLS) is a powder-based fabrication technology that uses a CO2 laser beam to fuse (sinter) layers of plastic, metal, ceramic, and composite powdered materials into 3D parts, patterns, and tools using information from CAD files. By mixing powder particles with thermal binders, a wide variety of materials such as polycarbonate, nylon, polystyrene, sand, and direct metal powders can be used. The powders offer several key advantages over resin-based technologies as well, including higher strength and durability. This process is used for building functional parts that are extremely durable and accurate, have high tensile strength, and are resistant to many chemicals. The SLS process provides a broad range of flexibility in materials and applications because of its ability to work with a variety of powdered materials. The key areas where this technology applies are in prototypes and manufacturing (Krar and Gill 2003). Also, molds for glass products can be made using this process.

Laminated Object Manufacture (LOM) is a process where a computer image of the solid object is sliced with a laser out of paper, plastic film, ceramic, or composite sheet-form material, into parallel, two-dimensional cross sections. The sheet-form material is laminated (layered) together to form the 3D model. LOM can be used to produce parts for design purposes, visualization models, patterns or molds, casting, rotational molding, blow molding, and rubber molding (Krar and Gill 2003).

Solid Ground Curing (SGC) is a rapid-prototyping physical imaging technology process where each layer of the part or multiple parts is generated in a multistep process from a 3D computer design. This process makes it possible to fabricate one piece or an entire functioning assembly with parts that move in relation to each other, such as a set of rotating meshed gears. The SGC is well-suited for building any geometric shape and very large prototypes(Krar and Gill 2003).

Because Rapid Prototyping (RP) engineering can shorten the design stage and minimize some risks when developing a new product, it is an effective and popular method to manufacture prototypes. As well, RP engineering applied in product molding design has also become an important part of manufacturing processes (Zhou Yan). Specifically in the glass field, a printer that uses glass powder in place of resin is currently under development. This printer would produce semi-finished products, as shown in Image 17.

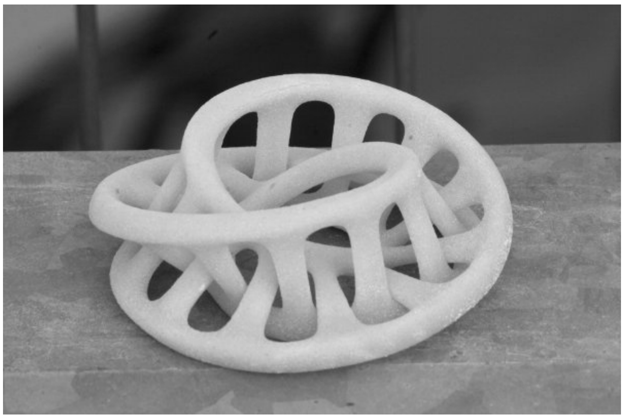

Image 5: *A 3d glass printer product*

One important consequence of Rapid Prototyping is that this technology will make it possible to manufacture products at home, revolutionizing the way in which objects are designed, produced and, consumed (Quinn 2011). It is interesting to note that some designers think that in the near future, objects will be sent as CAD files, and the final user will 3D-print them at home.

Non-material removal processes that can be used to fabricate molds for glass products

Direct metal deposition (DMD) is a form of rapid tooling process that makes parts and molds from metal powder that is melted by a laser and then solidified in place. DMD uses five common technologies: lasers, computer-aided design (CAD), computer-aided manufacturing (CAM), sensors, and powder metallurgy (Krar and Gill 2003).

Direct Shell production casting (DSPC) is a patternless casting process for metal parts in which complex ceramic molds are created automatically from 3D CAD data. This process uses three-dimensional printing technology developed at the Massachusetts Institute of Technology to produce ceramic casting molds using a layer by layer process. There is no need for physical patterns, core boxes, or other tooling, and no part-specific setups. The only pattern is the CAD design itself. The DSPC process can produce functional parts in a few days for complex products such as cars (Krar and Gill 2003).

Investment casting is a process that can be used for all types of components, especially complex parts with thin-walled sections. In conventional investment casting, a metal part is produced from an identical wax pattern made from a precision-machine mold. The wax pattern is coated with refractory layers that form a shell mold around the pattern. The wax pattern is eventually removed from the shell, leaving a clean ceramic mold into which molten metal can be poured. (Krar and Gill 2003). Today, RP models can easily replace wax patterns.

Near-net shape casting (NNS) is used for the high-volume production of small, engineered iron castings weighing one-half pound or less. These malleable iron and gray-iron castings are characterized by very tight tolerances, complex designs, high-tensile strength, and an ultra-smooth surface finish. Near-net shape casting produces a casting that is in or near its final shape and size, producing a completed part that requires little or no machining or finishing(Krar and Gill 2003).

Soft tooling: RP models can be used directly in investment casting to produce soft tools by pouring silicon rubbers, epoxies, or other soft tool materials around the RP model. This forms a temporary transfer tool that can be used to produce wax patterns. Since multiple wax patterns can be produced from a single RP model, this technology is suited for short production runs (Krar and Gill 2003).

Other processes

Lasers and robotic processes, as well as mass customization, also use CAD/CAM and CNC technology and can be used in glass manufacturing.

Robotic Processes

An industrial robot is a programmable, multifunctional manipulator designed to move material parts, tools or devices through various programmed motions for the performance of a variety of tasks (Krar and Gill 2003).

There are literally thousands of different operations currently performed by industrial robots. They are often used in situations where tasks are dangerous, tedious, or highly repetitive, or in some cases, where special precision is required (Shodek et al.). To be effective in a variety of applications, robots must meet the following criteria: they must be adaptable for many applications, be reliable, easy to program, safe to operate, and capable of working in hazardous places (Krar and Gill 2003).

There are many different ways of characterizing typical industrial robots. The primary components that make up a robot include a basic arm assembly and related manipulators (e.g., wrists), end effectors, programmable controllers, feedback and sensory input devices, a drive unit, and associated servomechanisms. A robot may have differing degrees of mobility (stationary fixed base, track-mounted, vehicular-mounted, and legged). Power sources may be electric, hydraulic, or pneumatic (Schodek, 2005).

Lasers

The laser (light amplification by stimulated emission of radiation) is a tool that can cut, weld, drill, produce cavities, heat treat, and mark a wide variety of materials. The laser beam is a very narrow, intense beam of coherent (united) light that can be controlled over a wide range of temperatures at the point of focus. There are several types of lasers: solid lasers, gas lasers, and YAG lasers. Lasers are finding ever-increasing applications in manufacturing because of the unique features of the process. The beam can be focused to a precise spot, making it possible to perform operations such as measuring, machining, welding, part identifications, and many other operations associated with manufacturing, like machine alignment, measurement and inspection, laser caving, laser hardening, laser making/bar coding, and laser welding. Lasers can also be used for medical uses, military applications, communications applications, and consumer applications (Krar and Gill 2003).

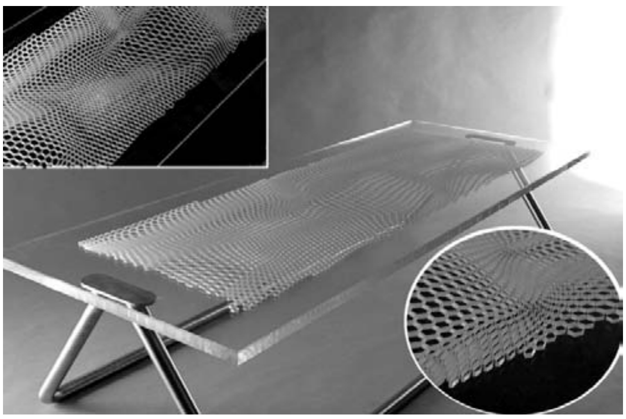

Image 6 *Laser engraving on glass*

Personalization/ mass customization

technology developments change manufacturing processes; one of the changes that digital technology has allowed is so-called mass customization.

When using CNC and CAM technologies, it is almost the same to fabricate 100 identical pieces or 100 slightly different pieces. With these technologies, production processes become adaptive.

According to Kolarevic, shaping and reshaping CNC processes which are based on cutting, subtracting, adding, and forming allow designers to have more control over production. This is the base of a non-standardized production mode, which in turn can be used to produce mass customization objects (Kolarevic 2003).

Chang stated that mass customization is a range of complex strategies that capture some of the features of craft production and mass production. Mass customization enables the manufacturer to produce and market a product that can be customized according to the costumer´s desires and still be offered at a reasonable price, which is not too far from that for the standardized product (Cheng 2005). The fundamental premise of mass customization is to no longer manufacture products "blindly" according to a predicted demand, but instead allow production to be directly driven by actual orders. This reduces the cost for storage of unsold items and for costly discounts. Using mass customization fabrication, a customer can order small quantities of a product, and many individual variations can be made to it (Schodek, 2005).

Schodek stated that generating individualized orders in significant quantities is only feasible if the corresponding manufacturing system is actually able to handle this individualization efficiently; that is, without the downtimes, setup times, and high tooling costs normally associated with a change in a product model or a model variation in high-volume production. Since these manufacturing systems are inevitably expensive to set up, it is important to point out that the success of mass customization hinges on large production volumes, but the systems can achieve an impressive variety of products (Schodek, 2005).

Finally I should mention that there are some emerging processes which as applications in the field of glass are still at an experimental stage, such as cryogenic tempering. A description of these processes can be found in Appendix H.

3.3 Chapter conclusions

To conclude, I would like to emphasize that, as mentioned in the previous chapter we are currently experiencing a milestone in the glass field: the use of digital tools. This milestone is affecting both the manufacturing processes (and therefore the appearance of objects) and the relationship between designer and glass.

It is important to point out that one of the consequences of any new technology is to have a dazzled point of view. Designers should always be aware of this attitude towards technology, and should always keep in mind that digital advances are just a tool which in no case can replace the designer’s judgment; digital advances are a tool which can be used to modify materials, and which allows designers to manipulate materials in a variety of complex shapes unattainable by hand, but in the end digital technology is just a tool

These new technologies are, as McDonough and Braungart stated, just hyper-efficient machines that expand the possibilities of creation (McDonough and Braungart 2002). But the interesting thing about all these new technologies is not what they are doing, but their possibilities. As David Erdman said, after all, it is about what you are doing with the technology, not the technology itself (as cited in Kolarevic, 2008).

However, as always with innovative and influential technology, digital tools have led to a series of reactions and some movements of rejection, with some designers even calling for a return to the traditional forms of production: Bradley Quinn stated that as opposed to rapid manufacturing, craft practices are becoming increasingly popular with contemporary designers, and they seem to be a central part of product design in the next decade (Quinn 2011). But even this possible return to artisanal practices cannot ignore digital advances; for example, one of the advantages of digital technologies is the possibility of hybrid workshops, where one person, using tools of CAD / CAM, can produce hundreds of objects in a short time.

As William Zahner mentioned, designers should always ask themselves: Is there always really a need for advanced and often complex technologies? Does the final product really pay off? What are the benefits of the technologies involved? (as cited in Kolarevic, 2008).

For example, one thing to think about is that despite the increasing amount of people in the world, companies are still cutting down on human labor through technology. This is logical in places where skilled labor is expensive, as in Europe and North America, but in developing countries, the opposite is true. However, both places can produce almost the same objects, using either available human labor or some sophisticated technology (Kolarevic, 2003).

Ideally, it should be a combination of traditional processes and emergent processes: we must remember that circumstances vary from place to place (as well as the cost of labor and the cost of technology varying by geographic location or type of company), and production processes that can be appropriate in one country may not be appropriate in another. Designers should use available resources; whether technology or human labor, but is also necessary to know the latest technology in order to avoid falling into digital illiteracy. Designers also must be aware of the latest developments, even if they do not have practical applications, because research that is at an experimental level allow us to forecast in some way the future of the glass industry.

As can be seen in Chapters 2 and 3, I started talking about glass, but I ended up into talking about technological development and how the relationship between designers and glass is affected.

I have talked about the characteristics, properties, uses, and manufacturing processes of glass, but at this point it has become clear that glass is more than just a material, it is a product of technological development.

Therefore, in order to understand glass beyond its material aspect, to understand its scope and its consequences, it is necessary to understand technology in the broadest sense.

Chapter Four: **Technology**

I began this thesis as a review of emerging glass technologies, but at some point I realized that the glass issue should be addressed from a broader point of view, not only from the perspective of glass as a material, but from a wide technological perspective.

Glass belongs to our technological world, and in order to understand its impact, we first need to consider technology in its broadest sense.

4.1 A discussion of technology

Several authors have explained the technology issue; but, why is it so important to define it? Why is it important to define its nature? Why are we giving so much emphasis to give a definition? As stated by Arthur, definitions matter because the way we approach to technology determines the way we think about its future and consequences (Arthur 2009).

But before presenting some definitions of technology, it is important to understand the differences between *a technology*, and technology in a broad sense.

A technology is just a feature or a collection of features captured and made to work. Namely, if we talk about glass technology, we understand it as a system of means of production, practices, and structures for carrying out a purpose; for example, blown glass technology, which refers to the processes required to obtain an object by using the phenomenon of heating the glass and blowing it.

According to Ihde, a technology cannot be purely theoretical. A technology must have some specific physical component, a material element. A technology must have a practical use, and there must also a relationship between technology and the human beings who use it, design it, make it, or modify it (Ihde 1979).

It is also important to note that technique is not the same as technology, and that several techniques do not need to use technology; for example, speech styles, habits of observation, etc.

Having said that, let us see how different authors have approached the issue of technology in its broadest sense.

According to the Oxford English Dictionary, technology is the collection of mechanical arts that are available in a culture to the service of the economy and society (Arthur 2009) .

Arthur defined technology in three different ways: 1) technology as a mean to fulfill a human purpose; 2) the technology as a blend of practices and components; and 3) technology as the entire collection of artifacts and engineering practices available in a culture (Arthur 2009).

According to Donald Norman, technology is the application of scientific knowledge to practical purposes of human life, to change and manipulate the human environment (Norman, 1993). However, the same thing can be said about other fields, such as design, engineering, or health.

As we can see, some similarities between the above definitions are: to consider technology as a means to an end, to consider technology as an application of knowledge, and to consider technology as a tool in the service of human beings.

While these points are correct, this view of technology is somewhat limited, and it is necessary to address this issue from a much broader point of view; it is necessary to understand what makes technology unique and to understand what the essence of technology is in order to understand its scope and its consequences.

4.2 Philosophy of technology: a brief overview.

The human desire to answer questions and define concepts has always been linked to the development of philosophy. There have been lengthy discussions to define concepts such as art, beauty, being, and knowledge, discussions that are still open and whose definitions have changed throughout history. But, what happened to the concept of technology? According to Don Ihde, the philosophy of technology as a recognizable sub-discipline of philosophy began to develop in the 20th century, although some important authors had talked about it earlier (Ihde 1993) .

What follows is a brief overview of some of the most relevant philosophic points of view regarding technology.

4.2.1 Ancient Greece

It is important to mention the point of view of the ancient Greeks on technology, as they are the ones who laid the foundations of modern Western philosophy as we know it.

Here I wish to present Plato and Aristotle´s concepts of technology. Plato and Aristotle are the two most representative thinkers in Greek philosophy.

For Plato, the word *techne* covered a broad spectrum of activities: both medicine and carpentry were considered *technai*; a physician and a sculptor both qualified as technicians. *Technai* generally referred to those human activities that produced things that were not there before, either tangible objects or intangible assets.

Aristotle discussed the technology issue in his *Nicomachean Ethics*, defining it as "*a rational faculty exercised in making something a productive quality exercised in combination with true reason*" (as cited in Nye 2006). The business of *techne* (or art) is to bring something to existence.

Similar to Plato, for Aristotle *techne* is equivalent to "a productive habit," productive in the sense that it brings into being something that did not exist in nature, something whose existence depends on the maker. Aristotle also included the production of the non-tangible; for example, health produced by the physician.

Both Plato and Aristotle theorized about technology, often giving it a negative sense. Aristotle said that technicians were worse than slaves, and Plato said that *techne* is "at best morally neutral, at worst marked by a dangerous propensity to upset the prescribed social order" (as cited in Smith 1981). According to Cyril Stanley Smith, the ancient Greeks admired the objects produced by craftsmen, but despised their material activities and their apparent unwillingness to engage in verbal exchanges on political or philosophical questions (Smith 1981).

This point of view of the ancient Greeks is curious, since in the same historical period there were great advances in various fields of practice such as medicine, engineering, and architecture, and there were also significant practice-focused characters, such as Archimedes and Hippocrates.

However, both Plato and Aristotle did not talk about the essence of technology, but about its characteristics and consequences.

4.2.2 Middle Ages and the Renaissance

After Ancient Greece, and as a prelude to the Middle Ages, the Roman Empire flourished. Although Roman thinkers were strongly and directly influenced by the philosophy developed by Plato and Aristotle, Romans valued what we now call technology more highly than the Greeks.

In the *Natura Deourum*, Cicero praised the human ability to transform the environment and to create a “second nature” (Nye 2006).

As the Roman Empire disintegrated in the West, the power, wealth, and influence of the Catholic Church increased, giving rise to the Dark Ages of the Middle Ages. In the Dark Ages the economy was based on agriculture, and feudalism emerged (McClellan 2006).

After the Dark Ages period, the high Middle Ages arose, and there was a strong technological development period. The basis of the economy shifted from agriculture to trade. The development of trade, in turn, boosted the development of industry. As a result of this relationship between trade and industry, there was an exchange of technological knowledge. According to some authors, like McClellan and Dorn, this synergistic relationship between trade and industry finally ended in the industrial revolution in the 18th and 19th centuries (McClellan 2006).

However, despite the great advances in practice, the philosophy of technology was practically inexistent. The thinkers of the time, such as Anselm of Canterbury and Thomas d'Aquino, were occupied with the study of theology, epistemology, logic, and the study of the ancient Greeks (McClellan 2006).

Roger Bacon was a thinker of this period who approached the technology issue to some extent. He was interested in the study of mathematics, languages, and experimental science. Bacon not only performed practical experiments, but also speculated about them, trying to unite practice with theory; for example, in his *Epistola de Secretis Operibus*, Roger Bacon foresaw the possibility of constructing mechanically-powered ships, automobiles, and airplanes (McClellan 2006).

For Ihde, the Middle Ages witnessed a revolution in technology, understanding the word technology in its broadest sense and not only as a synonym for technique. At that time there was a rise in universities, cities, and in the construction of cathedrals, and advances like the draining of the Lowlands of northern Europe were made possible by increasingly large machines such as cranes, windsmills, watermills, and artifacts using simple physical principles, some of which had been recovered from those used by the Romans, Ancient Greeks, and Asians (Ihde 1993). The Middle Ages, with all their changes in different areas, were the catalyst for the development of the Renaissance.

In the Renaissance there were large achievements in praxis[1], like advances in the field of navigation, the development of gunpowder, and the development of metal movable type for printing (Headrick 2009).

Meanwhile, the writings of some of the most emblematic Renaissance thinkers, like Galileo, Copernicus and Tycho Brahe, were based more in practice than in a philosophical reflection. Galileo was one of the first Europeans to develop a science-based technology, basing his studies on experiments using instruments and devices. According to Ihde, Galileo was not a "Greek" speculator, but a prototype of a modern technoscientist (Ihde 1993).

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[1] The Blackwell Dictionary of Western Philosophy defines *praxis* as the Greek term for action (Bunnin & Yu).

It is however necessary to mention Francis Bacon, in whose book *New Atlantis* we can spot a modern attitude towards technology. In this text Bacon imagined a world where the domination of nature by technology did not have any sinister side effects, but instead satisfied material needs, abolished poverty, and eliminated injustice (Nye 2006). Bacon began to be aware of the side effects of seeing the universe as a reservoir of energy that can be tapped and adapted to human use (McClellan 2006).

4.2.3 The 19th century

However, it is important to note that although in the Middle Ages and the Renaissance there were great advances in practice, there was not really deep thinking about the philosophy of technology (Ihde 1993). It was not until 1877 that Ernest Kapp used the term "*technikphilosophie*" (philosophy of technology). Kapp suggested in his essay *"Philosophie der Technik einer Grundlinien"* (Principles of a philosophy of technology) that technologies were material extensions of the body, with anthropomorphic features; for example, a stove to cook food could be seen as an artificial or "technological" stomach, a fork could be seen as an extension of the hand, and so that with every object, from the simplest to the most complicated machines, everything could be seen as tools to enhance the capabilities of the human body (Ihde 1993).

However, the problem with Kapp´s point of view about technology is that he still considered it purely as a means to an end, and he did not delve into the essence of it.

Another 19th-century philosopher who wrote about technology was Karl Marx. According to Ihde, before Marx, more emphasis was given to theory without praxis, or to praxis without theoretical thought. Karl Marx can be seen as one of the first thinkers of “praxis philosophy”; that is, a kind of philosophy that reevaluates the theory and links theory and praxis, or theory and materiality, or theory and action (Ihde 1993).

Before Marx and Kapp, the dominant trend in philosophy was the "immaterial": ideas, theories, the abstract, the ideal. Marx and Kapp began to discern a focal role in materiality, mainly the materiality of technologies, tools, and machinery,and a good example of this is Marx’s ideas regarding modes of production.

The modes of production were, according to Marx, systems of material products made by technologies arranged in different ways. Marx recognized that for long periods of human history, these production models changed very little and very slowly, but sometimes there were revolutions or changes in these modes of production. Marx gives the example of the feudal system over the capitalist system (Ihde 1993).

Although it may seem obvious, it is important to emphasize that materials modes of production are shaped by existing technologies, and that the final product is also shaped by existing technologies. Therefore, an object can speak of its historical moment in addition to its manufacturing process.

According to Ihde, Marx’s analysis based on praxis and modes of production, was one of the earliest sources for what would be later called the "philosophy of technology." Technology, in the hands of Marx, went from being a matter of background to an issue of foreground, and his vision towards technology outlined much of the 20th century´s philosophy on the topic (Ihde 1993).

4.2.4 Philosophy of technology in the 20th century

According to Ihde, the 20th century has been the greatest period of technological innovation in history. These technological developments have had a dual impact: on one hand there was a fascination with technological advances (many of which were developed during WW2), and on the other hand pessimistic reactions toward technology arose; for example, Jacques Ellul said that technology could not be civilized because the technological society is profoundly materialistic, and Marcuse said that what technology hides is dominant and political power (Ihde 1993).

Some philosophers, such as the Russian Berdyayev, the Spaniard Ortega y Gasset, the German Heidegger, and the American Dewey, made technology and technological civilization one of their main themes of reflection.

At this point I would like to delve into Heidegger´s theories, because I will use some of them to define technology.

In 1955, Martin Heidegger gave a lecture entitled "The Question Concerning Technology", where he presented his vision about technology. At this conference, Heidegger focused more on explaining the essence of technology and less on technology as a mean to an end or just as an extension of our body. Heidegger began to see it not as a tool but as a philosophical question, as a systematic way of seeing the world and as a way of being-in-the-world (Ihde 2010).

Heidegger said that if we want to be able to understand the phenomenon of technology, we must release it from subjective interpretations, based primarily on anthropological definitions (to see technology as a human activity) and instrumental definitions (to see technology as a mean to an end) (Ihde 2010).

According to Heidegger, technology is not just the collection of things and activities, but also the way in which these things and activities appear, and it is important to point out that the things of technology (instruments) and the activities (of subjects) appear always within a frame (Ihde 2010).

Technology is thus elevated to an ontological dimension. As stated by Heidegger, “*tekne* is a mode of aletheuein (*alethia* means unconcealedness). It reveals whatever does not bring itself forth and does not yet lie here before us, whatever can look and turn out now one way and now another. . . Thus what is decisive in *tekne* does not lie at all in making and manipulating nor in the using of means, but rather in the revealing mentioned before. It is as revealing, and not as manufacturing, that *tekne* is a bringing forth. . . Technology is therefore no mere means. Technology is a way of revealing. . .Technology is a mode of revealing. Technology comes to presence in the realm where revealing and unconcealment take place, where *alethia*, truth, happens." (Heidegger 1977).

But if technology is considered as a way of revealing, then is important to point out that the revelation does not occur in an isolated environment. Revelation always arises within a framework. Heidegger talked about this as *Ge-stell*, or enframing.

Heidegger took some ideas from Ancient Greeks, and said that "*tekne* is the name not only for the activities and the skills of the craftsman, but also for the arts of the mind and the fine arts. *Tekne* belongs to bringing forth, to *poiesis*" (Heidegger 1977). *Poiesis* is both making and bringing forth, and it is important to point out that *tekne* is linked to episteme as a way to reveal the truth.

In summary, there are two key concepts: one is the idea of technology as a way of revealing within a framework, and the second is the idea of poiesis (that means bringing forth). Therefore, for the purpose of this thesis, I will use Heidegger's definition of technology as poiesis within a framework.

This definition has several advantages: it takes into account the essence of technology, not only its applications, and it mentions that technology is not only a tool, but a systematic way of seeing the world and a way of being-in-the-world. Heidegger also mentioned that technology is a means of revealing, and he pointed out that this revealing always happens within a frame.

This idea of “frame” is important because if, according to Heidegger, the essence of technology is not itself technological but existential, then the response or relationship of the human being to the essence of technology will be in terms of the way the enframing appears.

But, if technology is considered as a way of revealing within a frame, then, as I have mentioned, this concept of frame is important, because on one hand it refers to the environment in which that technology arises, but on the other hand it can be the cause of having a biased point of view towards technology. I will be coming to this idea throughout the next chapters.

Having defined technology as "poiesis within a frame", it is now possible to analyze some of its features and consequences, and these will be discussed in the following chapters.

Chapter Five: **People and Technology**

In the previous chapter I defined technology in its broadest sense, and now I would like to address how human beings are connected with technology and technological products. This subject is important because technology is something fundamentally human, and thus to better understand its consequences we must also understand the relationship between people and technology.

According to Ihde, technology has always been present in human development, and he stated that there have been no human cultures that have been pre-technological. All human beings have a material culture with complex practices involving the use of artifacts. For example, in prehistoric times, a "first" technology may have been a found technology. This is also the type of technology used by many animals, but according to Ihde, animals, unlike humans, do not use technology, but prototechnology. To Ihde, the step from using found technologies that have an adequate shape, to designing tools, was a very important step, but a very short one (Ihde 1979).

It is important to point out that throughout the long history of the technology/human relationship, there have been some human-artifact relationships that are universal, but with a set of practices that are particular to each culture, even when they are developed around the same processes, like cooking, storage, and shelter (Ihde 1979).

So then, what are those human-artifact relationships? Or, in other words, what is the relationship between human being and technological objects?

5.1 Nature of the relationship between human beings and technological products

A product of technology can be seen as any man-made object used to achieve some end (e.g., either a pencil or a plane), and that operate as an extension of or support for the human body. For example, we can think of a musical work for example, which is done by man, and its end is aesthetic delight, but nevertheless, a musical piece does not work as an extension of the human body. By contrast, the musical instrument that is used to perform the musical piece works as a man-made extension of the human body and is intended to achieve a goal. It is made by man to achieve an end, so we can say that the musical instrument is an object of technology, while a musical piece is not.

It is also important to note that a product of technology must have a material part i.e., it cannot be purely theoretical, and this material part is the one that the user approaches first.

Image 7: *A musical instrument is a product of technology.*

Now, using some ideas from Ihde and Heidegger, I will analyze the relationship between human beings and objects.

According to Don Ihde, a human being connects with the world in 3 different ways: intentional correlation, embodied relationship, and hermeneutical relationship.

5.1.1 Intentional correlation

In this relationship, technological products are absent and the human being experiences his/her environment face to face, or "in the flesh", with no help from any object; or, as Ihde says, the shape of the experience comes via a reflection from the world (Ihde 1979).

For example, imagine a man plunging his hand into a creek, as seen in Image 2. When water comes into contact with his skin, some nerve endings are stimulated, and they send information to the brain. In this relationship, no object of technology is present, and the human being gets first-hand information instead. This is the most direct way of experiencing the world, and is shared by all living things. This experience differs from person to person, depending on their particular sensory capabilities.

Image 8: *"In the flesh" experience.*

In a schematic way, we can think on this relationship as: human → world (Ihde 1979).

5.1.2 Embodied relationship

According to Don Ihde, the second relationship between human beings and the world is the embodied relationship.

The embodied relationship is one where otherness is experienced through the object, and the object then is an element between the human being and his/her understanding of the world; that is, we experience the world through an object. For example, let us imagine a dentist exploring a tooth with his instrument, looking for cavities. Ihde notes that the final objective of this experience is not the instrument but the tooth. The instrument is the means to achieve this experience (Ihde 1979) .

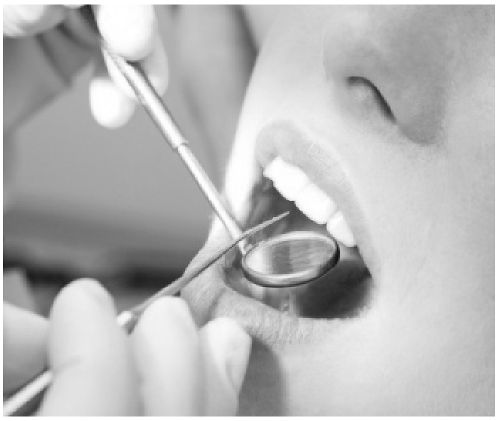


Image 9: *An embodied relationship is established.*

According to Ihde, when the user is no longer aware of the object, an embodied relation is established; for example, when an experienced driver parks without thinking about the process, just "feeling" the space. Heidegger also mentions a similar relationship, and he gives the example of using a hammer:

1: A hammer (object-as-such) belongs to a "kingdom of tasks", a relational context of specific uses. We can say that one task of this kingdom is to nail.

2: A hammer in use is not an "object-as-such". Once we have learned how to use the hammer, it is not an object anymore, and it becomes the means of experience itself; our attention is not on the hammer, but in the terminus, which may be the shoe (presuming that the author is speaking here of a shoemaker's hammer). It is important to note that here technology is taken for granted as long as it works well.

3: When the hammer is useless, broken, or lost, then it becomes an object again. It is in this interruption of the flow of praxis where Heidegger can see an opportunity for a different type of knowledge (Heidegger 1977).

Image 10: *Heidegger uses a hammer as an example.*

Ihde clarified that this experimentation of the world through an object is somehow transformed depending on the object used; for example, it is different to experience a blackboard through a piece of chalk than through a dentist's tool, or using a finger (Ihde 1979) .

However, Ihde also clarified that this embodiment relation is never entirely transparent, because when a human being is using an object to explore the world, the object (or machine, or tool, as we like to call it) never disappears.

It is also important to mention that, besides being more or less opaque, this relationship is a transformed experience, and is not the same experience when one touches something "in the flesh" (face to face); i.e., to Ihde, experience through the object causes a sensory-extension-reduction relationship (Ihde 1979) .

In a schematic way, we can think of this relationship as: (human / object) → world (Ihde 1979).

5.1.3 Hermeneutical relationship

The third relationship that Ihde described is the hermeneutical relationship.

Embodied relationships are given through the objects and so are embodied in the objects. Ihde called them "primitive" human-machine relations, and they have been present in the lives of human beings throughout history, but in the words of Ihde, we have moved from experiencing through machines to experiences of machines (Ihde 1979).

An example of a hermeneutical relationship occurs in a control center, where an operator monitors the machines that monitor temperature. In this relationship we rely on the interpretation of reality that the machines provide.

Image 11: *A control center*

In a sense, a hermeneutical relationship is established by making use of virtual reality, where the experiences of the senses are replaced by simulations. This, according to Slouka, is often rated as "more real" and of "more value" than real life experiences (as cited in Ihde 1979). In the words of Guy Debord, this is a phenomenon of hyperreality (Debord 1994).

Another way to establish a hermeneutical relationship is through the media. According to Ihde, one of the consequences of technological advances in media (radio, TV, etc) is the experimentation of the world through them. There is a phrase from Debord which says that the true is a moment of falsehood; it refers to media that build facts (which can be true or not) through fragments of truth. According to Debord, all that was previously lived directly is now experienced as far away, as a representation (Debord 1994).

In a schematic way, we can think of this relationship as: human → (object / world) (Ihde 1979).

5.1.4 Background relationship

Ihde mentioned that besides these three direct relationships with objects, in an increasingly complex society (technologically speaking) there are other types of relationships, such as background relationships. For example, one can talk about a coffee machine: the user turns it on and forgets about it, but the machine keeps working. If successful, this background technology is rarely noticed. We do not realize that it is working, but we experience its results. Other examples of background relationships with technology are services such as lighting, heating, etc.

I wish to point out that that in these relationships that involve the use of objects (embodied, hermeneutical, and background relationships), there comes a point at which the object goes into the background, and the activity being performed becomes more important than the object.

Normally we are surrounded by objects, as they form a technological texture that is always present, but at the same time the relationship is invisible, as these objects are generally taken for granted. It is at this point, when the object goes into the background and is taken for granted, that we cease to be aware of everything that this object carries: its hidden costs and consequences.

It is also important to mention that we return to our awareness of objects only when an object fails to work. Heidegger defined this as the disruption of the flow of praxis. It is in these moments when the object comes back to the foreground, however, and once the object is working properly again, it goes back into the background.

It is impossible to be constantly aware of the objects surrounding us, but the danger of taking these objects for granted is that we are not aware of all the consequences they carry.

5.2 Some attitudes towards technology

After the analysis of the relationships established between human beings and technology´s products, I must mention that these relationships carry a range of attitudes towards technology, such as: reliability and enframed point of view, fascinated point of view, and seeing nature as a standing reserve.

Reliability is a consequence of the relationship established between people and objects; it means that technology is taken for granted as long as it works well. When technology works, we cease to be aware of it and all of its costs.

As users, it is impossible to be always aware of the objects around us, and a high degree of reliability on these objects is desirable; however, the latent danger of this reliability is to have a biased point of view.

Moreover, as designers we should be aware of the hidden costs behind the objects we design. I will analyze this point in more depth in the following chapters.

Another consequence of the relationships between people and technology is the fascinated attitude towards technology. Throughout history we can see the fascination of people towards technological developments, but few people are aware of technology´s costs and consequences.

A current example is the use of electronic devices: there are advances in this field every day, and the user feels compelled to change his or her device for a newer and faster model. Usually, however, the technical characteristics of the newest devices exceed the needs of the common user. We then can say that the user is dazzled by technological developments, but he is not aware of all the hidden costs that they entail.

A third consequence of the relationships established between people and technology is seeing nature as a standing reserve to serve man. This idea was mentioned by Francis Bacon in his book *New Atlantis*, where he talked about the side effects that entail seeing the universe as a reservoir of energy that can be tapped and adapted to human uses.

Heidegger also referred to this subject, and his major criticism was the behavior enframed by technology. According to Heidegger, the problem is not the technology itself but the attitude it has brought: instead of adapting to the world and nature, human beings expect the world and nature to adapt to them, and then the problem is to consider the world and nature as a standing reserve at the service of human beings. French sociologist Jacques Ellul also referred to this subject and said that technology is now directing human life; technology has become one thing that human life must revere and adapt to (as cited in Arthur 2009).

Under Heidegger´s and Ellul´s points of view, technology simultaneously drives and serves our lives, and both points of view are simultaneously valid. That is, we are at the same time dazzled and disappointed by technology.

However, I wish to clarify that technology enriches and adds depth to our lives. As Arthur said, technology is a big part of what makes us human. Technology is part of us, at a deep level (Arthur 2009). As the development of technology requires certain human characteristics, humans throughout history have also developed and deepened their knowledge through technology.

To Norman, technology is essential for the growth of human knowledge and mental abilities, and each new discovery changes society in some way. Currently, the background knowledge requires more and more learning, and therefore more specialization. Cultural groups that have had more technological development have enjoyed some advantages over groups that have had less technological development. Each technology adds power to the human ability to produce yet more technology, and each new technology require more abilities, more knowledge, and more specialization (Norman 1993).

According to Arthur, more than anything else, technology makes our world. It creates our wealth, our economy, and our way of being (Arthur 2009).

As technology changes and develops, so does the economy, and so do historical periods. But this is a symbiotic development: to Arthur, an era creates technology, but also, technology creates an era. And so, the history of technology is not only a chronicle of individual discoveries like the printing press, the steam engine, and the computer, but it also works as a chronicle of the times — of all the social, historical and economic factors that happened thanks to the technology — and at the same time, that shaped the technology itself (Arthur 2009).

All this can be summarized by saying that technology not only defines an era, but also defines the possibilities of the time and the spirit of the age, or Zeitgeist.

Finally, and in order to link the relationships established between people and technology with the glass issue, I will use a wine glass as an example.

In the first relationship, the intentional one, the user experiences the wine glass “in the flesh”, making use of the body senses: he or she touches the glass, feeling its weight, its temperature; through vision, he or she can see the shape of the glass, and so on.

In the second relationship, the embodied one, the wine glass becomes a mean to an end: the user´s attention is focused in the wine, not in the glass. The user ceases to be aware of the glass, as long as it works well.

The third relationship, the hermeneutical one, is not applicable to a wine glass, so let me talk about a glass thermometer: it “feels” the temperature and then it translates this data into readable information to the human being.

In the fourth relationship, the background one, the object is not being used, and it becomes invisible, it becomes part of the background, and the user is not aware of it. The object stays in the background until it is needed again. For example, a mirror: this object is usually part of the background, and only comes to the foreground when it is needed, or when it is broken.

One can still use the wine glass to exemplify the different attitudes towards technology, such as reliability, where the user is not being aware of the wine glass if it works well. At the moment it is not working well, there is an interruption of the flow, and the user is again aware of the wine glass.

If a person buys a new set of wine glasses, just for a whim, no matter if he or she has a perfect set of glasses of wine at home, a dazzled point of view is being established. And if the user buys this new set of glasses without thinking about all the hidden cost behind them such as transport, manufacture, etc; an enframed point of view is established.

Chapter Six: **A Hidden Cost of Technology: Environmental Pollution**

"Depth is hidden. Where? On the surface " (Calvino 1988).

In the previous chapters a definition of technology was given, some features of the human-technology relationship were discussed, and three attitudes towards technology were presented: reliability and enframed point of view, dazzled point of view, and seeing nature as a standing reserve.

These attitudes toward technology carry several consequences, and in this thesis I would like to mention two of them: the environmental hidden cost of technology, and the semiotic pollution.

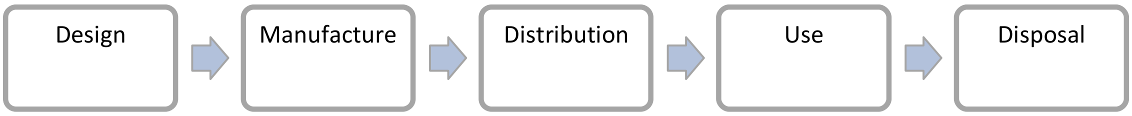
6.1 Environment and the lifecycle of products

An important consequence of the use and development of technology is modification of the environment. According to Ihde, even without technology, animals and ourselves as human animals, modify our local environments. There have always been natural issues such as deforestation, irreversible erosion, and regional climate changes, and these changes have happened without the active participation of human beings. But when technology is used, these changes are accelerated; even simple technology has led to major changes in the environment, and these changes may occur more rapidly in contexts where technology is more advanced (Ihde

1979). For example, the industrial revolution brought pollution and environmental degradation to London on a larger scale than what previously occurred.

Currently, technological advances allow us to manufacture large volumes of products at low cost and in a short time, which creates an overcrowding of objects. But, how does this saturation affect the environment? To answer this question it is necessary to say that technological products have a life cycle, and that each stage carries environmental consequences.

Every product has a life: objects are designed, manufactured, distributed, used, and then discarded. In this section I will mention some of the "hidden costs" behind every phase of the life-cycle of an object. This exercise is useful in order to eliminate a biased point of view, as well as to be aware of all the hidden costs that an object carries.



6.1.1 Design

Design is the first stage in the life cycle of an object. Industrial designers are usually responsible for this stage, where several factors such as ergonomics, aesthetics, and function are considered[2].

This stage is so important that some authors, such as Thackara, consider that 80% of the environmental impact of a product, service, or system is determined at the moment of designing it, because design decisions will shape the processes behind the products we use, the materials and energy required to make them, the way we use it, and what happens to them when they are no longer used (Thackara 2005).

McDonough and Braungart stated that designers should always question themselves before beginning their work: why is this product here? Is it really necessary? What happens when it is discarded? What is the entire system (cultural, commercial and ecological) in which the product will be? McDonough and Braungart called all these questions a "design filter"(McDonough and Braungart 2002). This filter can be useful in order to avoid the overcrowding of objects.

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[2] Industrial design, according to the Industrial Design Society of America, is the professional service of creating and developing concepts and specifications that optimize the function, value and appearance of products and systems for the mutual benefit of both user and manufacturer (Cuffaro 2006). According to McDonough and Braungart, industrial design must also meet certain human needs within a specific cultural and technical context.

6.1.2 Production

After designing an object, the next step is making it. The selection of a manufacturing process directly relates to the needs of the user, the resources of the producer, and the time available to bring the product to market (Cuffaro 2006).

It is important to point out that manufacturing even the simplest product entails a number of hidden costs; for example, in addition to manufacturing processes, other factors must be considered, such as the extraction of materials and the manufacturing of packaging, as well as the energy used and the waste generated at every stage of the manufacturing process.

An example of a hidden cost behind the manufacturing stage is that, according to McDonough and Braungart, more than 90% of materials extracted to make durable goods in the U.S. become waste almost immediately (McDonough & Braungart 2002).

6.1.3 Distribution

After being produced, the object has to be distributed to the place of sale, as usually production sites of and retail locations are different.

One must take into account that distribution does not only mean moving a product from point A to point B, but also involves many other factors, such as traffic, pollution, noise, and hidden infrastructure costs.

Also it is important to mention that the distribution of an object is rarely direct; instead, it has multiple stages: it goes from the manufacturing site to a wholesaler, then it is distributed to a retailer, and finally purchased and transported to the final destination, and every one of these stages has hidden costs.

6.1.4 Use

After an object is designed, produced, and distributed, it finally comes into contact with the final user.

This stage entails a number of hidden costs, which vary according to the complexity of the object used. For example, the hidden costs behind the use of a hammer are different from the hidden costs behind the use of an electronic device.

A significant hidden cost at this stage that must be mentioned is the length of life of a product; for example, besides being a major consumer of resources, information technology artifacts have notoriously short lives. In theory, electronic products have a life of 30 years, but because innovation cycles are getting shorter, many devices are discarded after a few years or months (Thackara 2005).

Finally, I should mention that even objects that are not used have a hidden cost. For example, the average domestic power tool, say a drill, is only used for 10 minutes in its entire life, but it takes a lot more time to make that object (Thackara 2005).

According to Thackara, despite all the resources involved in their manufacture, only 1% of the material in the U.S. economy is being used after 6 months of being sold, with some of the objects never being used and many going straight into the trash (Thackara 2005).

6.1.5 Disposal

An object may be used only once, or repeatedly. It may be used for only a few seconds and then discarded for safety reasons, as is the case of needles and surgical instruments, or it may be used for years and years. However, there comes a time when the object goes to the next phase of its life cycle: disposal, where it can be discarded or recycled.

When the object is not retained, it is discarded. When it is not recycled, this waste commonly goes to landfills or is incinerated, and there is a certain risk of environmental pollution when disposal is not carefully managed. In order to avoid it, there are regulations for waste management; however, these regulations are not always enforced. But even when all regulations are strictly enforced, landfills have a waste absorption limit, and this limit is being challenged by the current overcrowding of objects.

Image 12: *A saturated landfill*

Finally, I want to emphasize that so far I have mentioned the lifecycle stages of an object in order to detect some hidden costs behind it, but if the reader is interested in the subject, there is a great variety of literature on the topic which analyzes each of these stages in depth.

6.2 Chapter conclusions

In Chapter 5, I mentioned some attitudes towards technology, such as: having an enframed and biased point of view, being dazzled by technology, and taking technology for granted. In this chapter I have established that these attitudes, coupled with technological development, have triggered an overcrowding of objects which commonly goes unnoticed because, as I mentioned in Chapter 5, if an object works well, it goes into the background and one stops being aware of it. This reliability has triggered an increasing consumption of objects, and thus an increasing manufacture of objects which, in turn and in a vicious circle, produces more saturation.

This saturation of objects involves a number of hidden costs such as environmental pollution.

Now, what could be a solution to tackle the problem of saturation? It can be argued that a decline in production and consumption is not a 100% workable solution, as it would affect other areas, including economic growth and job creation; but what is feasible is to know the stories behind these objects: be aware that each object has consequences on the anthroposphere, and that each object has a life-cycle and that each stage of it entails consequences in the biosphere.

We must also be aware that an object is never alone; it is always part of a system that involves manufacture, transport, and use and disposal, among other things, so when one think of the objects as part of a system, it becomes clear that each object is more than the sum of its parts.

Every product that comes into our lives has a “hidden history”, an undocumented inventory of lost or discarded materials and energy used in their production, transportation, use, and disposal. Industry moves, extracts, mines, burns, discards, pumps, and dumps millions of kilograms of material in order to distribute the products that we take for granted (Thackara 2005). We also need to be aware that almost every product needs roads, buildings and infrastructure, and that each of these has an environmental impact too.

In summary, it is necessary to know the "hidden stories" behind every phase of the life cycle of the object. Realizing the hidden problems surrounding the manufacture, production, use and disposal of an object, we are eliminating our biased point of view towards technology.

Finally, I want to mention that industrial designers can minimize the negative consequences of this overcrowding of objects; on one hand, industrial designers should be aware of all the possible hidden costs behind objects, and on the other hand, before starting any work, industrial designers must ask themselves whether it is necessary to bring even more objects to the world, whether this new object is absolutely necessary, and if it is better than any of the existing objects. In other words, industrial designers should try to avoid creating banal objects.

In the next chapter I will mention some strategies that can be used by industrial designers in order to alleviate the negative consequences on the environment, caused by the attitudes toward technology mentioned so far.

Chapter Seven: **Some Strategies**

In this chapter I will introduce some strategies which can be used to alleviate the environmental consequences caused by technology. However, these strategies are just recommendations that designers can use, and I do not pretend to give recipes or solutions to this problem, due to the environmental impact of technology not being only caused by the practice of industrial designer, but by a multitude of factors.

7.1 Technosphere behaves as biosphere

One interesting theory proposed by McDonough and Braungart is that there are two types of metabolisms on the planet: the first is the biological metabolism, also called the biosphere, and refers to the cycles of nature, and the second is the technical metabolism, or the technosphere, referring to the cycles of industry.

Products can be made up of two types of raw materials: technical or "biological". McDonough and Braungart defined biological raw materials as materials that degrade and become food for biological cycles (i.e., biological nutrients) and they defined technical raw materials as technical nutrients that remain in technical closed-loop cycles in which they continuously recirculate as valuable nutrients for the industry (McDonough & Braungart 2002). For example, in Kalundborg, Denmark, some industrial plants were linked by using waste from one facility as nutrients for other facilities (Thorpe 2007).

So, it can be said that a biological nutrient is a material or product that is designed to return to biological cycles, and is consumed by microorganisms and other animals, and a technical nutrient is a material or product that is designed to return to a technical cycle, the industrial metabolism where it came from.

A strategy to lessen the technological impact on the biosphere is to carefully avoid contaminating one metabolism with the food of the other in order for these two metabolisms to remain healthy, valuable, and successful. I must point out that materials are called "unmarketables" when they do not fit either in the technical metabolism or in the biological metabolism because they contain dangerous substances for both metabolisms (McDonough & Braungart 2002).

7.2 Eco-efficiency/ eco-effectiveness

This strategy is focused on the problems that manufacturing brings.

There are different strategies to alleviate the environmental problems generated by manufacture; one of them is called eco-efficiency. Eco-efficiency’s goal is to transform industry, from a system that makes and wastes to a system that integrates economic, environmental, and ethical concerns. Another tenet of eco-efficiency is to reduce the amount of used raw materials, or to reduce the product, which is known in business circles as dematerialization or "reduction" (McDonough & Braungart 2002).

Another strategy is called eco-effectiveness. The eco-effectiveness concept of McDonough and Braungart means to work on the right things (products, services, and systems), instead of making the “wrong” things less bad. The key is not making industries and systems smaller, but to make them grow in a way that replenishes, restores, and nourishes the rest of the world (McDonough and Braungart 2002).

7.3 Locality

The previous strategies can been applied mostly at the manufacturing stage, but locality is a strategy that is useful at the distribution stage, because transportation of products is an important part of the environmental impact of technology.

According to Frank Barkow, location is an important aspect that influences our work as designers. There is much talk about globalization, but economy, skills, available materials, and techniques differ greatly from place to place (as cited in Kolarevic 2003).

To use this strategy, locality, one must be aware that it is difficult to apply universal solutions to local problems. For example, manufacturers who try to use universal design solutions usually design for the "worst-case scenario", which means that a product is designed to operate effectively in the worst possible circumstance (McDonough & Braungart 2002), but these design solutions may be too aggressive for all scenarios.

An example of the use of "locality" as a design strategy can be seen in decentralization of production; for example, Coca-cola exports the recipe, and sometimes the machinery, but it uses local raw materials and is locally distributed; then, distribution costs are lessened and product freshness is guaranteed.

7.4 Waste management

So far I have mentioned strategies that can be performed at the time of manufacturing and distribution, but which strategies can be used when the object is disposed of? I have grouped a number of strategies under the common name of waste management.

An interesting strategy, developed by McDonough and Braungart is to eliminate the concept of waste at the moment of design. To eliminate the concept of waste means to design things (either products, packaging, or systems) thinking that the concept of garbage does not exist, so a designer must think on waste as technical nutrients, not just garbage, and thus these technical nutrients are not causing any active harm, but are nurturing a system (McDonough & Braungart 2002).

Another strategy would be to lengthen the life of a product, but this is not always a good strategy. A group of Dutch designers called "Eternally Yours" discovered that designing a product that lasts longer does more harm than good, if the product is energetically inefficient (Thackara 2005).

McDonough and Braungart also proposed that instead of assuming products will be purchased, owned, and subsequently discarded by consumers, products can be rented for a while (McDonough & Braungart 2002).

7.5 Diversity

A challenge for the designer is to enable situations that can withstand a variety of fast and slow movements; that is, to make design resilient (Thackara 2005). Diversity is a strategy to make the design more resilient. Diversity makes an organism more resilient and able to respond successfully to change.

According to Thorpe, in design, resilience occurs when the fastest layers of art / fashion and commerce are those that innovate, while slower layers of culture and nature are those that maintain stability and provide support for the long-term structure (Thorpe 2007).

To respect diversity in design means not only taking into consideration how a product is made, but how it is used, and by whom. It is also important to note that a single object can have many uses and many users. An object can be designed to suit different uses, instead of designing it for a specific purpose and discarding the object when the purpose is accomplished (McDonough & Braungart 2002).

According to McDonough and Braungart, people prefer diversity over "one-size-fits-all" designs. So, instead of promoting "one-size-fits-all", industries can design while having in mind processes such as mass customization, allowing the product to suit local tastes and traditions, without compromising product integrity, and respecting the different ecological, economic, and cultural variables (McDonough & Braungart 2002).

7.6 Chapter conclusions

Technosphere behaves like a biosphere: glass can stay in the technosphere, and it can be continuously recycled, but if some glass enters into the biosphere, glass doesn´t pollute it, because it is an inert material.

Eco efficiency/ eco-effectiveness: In this strategy, I would recommend the use of recycled glass to fabricate new glass instead of using pure substances as raw materials, in order to lessen some energetic costs at the moment of manufacturing.

Locality: glass is made mainly by silica, which is one of the most common substances on Earth, so glass can be made almost anywhere. I want also to point out that some glass manufacturing techniques do not need a large infrastructure or very specialized machinery. Glass can be manufactured at small scale just by one person and a kiln.

Waste management: currently there are some governmental programs to gather glass to be recycled. But there are also some places where there is not any regulation and glass goes directly to landfills. In these cases, glass doesn´t pollute the biosphere, because, as it was stated before, glass is inert.

Diversity: glass can achieve a different variety of characteristics and features in order to accomplish specific user´s needs. For example, glass can be used to fabricate prosthesis, insulators, tableware, telescope lenses, and so on.

Some other punctual recommendations can be found in Appendix I, but at this point I would like to introduce two more concepts: visibility and translation. These key concepts summarize all the strategies I have mentioned so far.

Visibility

This strategy consists of making hidden costs visible. Lucretius stated that emptiness is just as concrete as solid bodies. This could be translated to design language that which is: unseen also has weight (Calvino 1988). So, before applying any strategy, industrial designers must be aware of all possible hidden cost behind objects; i.e., they must broad their scopes to avoid enlarge any enframed point of view.

Calvino stated that one has to be fully aware of things, and aware of infinite variety (Calvino 1988). One must also be aware of everything that is present in the objects, even if not present at first sight. This strategy, visibility, is closely linked to Heidegger´s idea of eliminating any biased point of view.

In summary, a designer's duty is to make the invisible visible, so, the main strategy is not just recycling, or reducing, but to consider technology broadly: to consider its social, cultural, and environmental consequences, and to be aware of all the possible consequences of any design exercise.

Translation

The second key concept that I want to introduce is translation. A feature of technology is its iterative and mutable character. Designers should act as negotiators between always changing science / technology and the final user of an object. According to Leonardo da Vinci, inventors were the translators between nature and man: "inventor e interpreti tra la natura e li homni" (Calvino 1988). We can think of designers as translators between people and technology.

Throughout Chapters 4 to 7 I have talked about the characteristics and the essence of technology, mentioned some of the relationships that are established between people and technology, pointed out some attitudes towards technology and the consequences that they entail, and finally I listed some strategies that industrial designers can use in order to mitigate those consequences on the environment.

Let us remember that in order to understand the impact of technology, it is necessary to understand it in its broadest sense. The problem concerning technology comes when we are not aware of its scope. It is necessary to be aware of its consequences and its hidden costs.

Technology´s impacts on the biosphere and anthroposphere comes as a result of, firstly, a biased and enframed point of view, secondly, considering nature as a limitless standing reserve, and thirdly, a dazzled attitude towards technology.

So far I mentioned some strategies to minimize the negative impact of technology on the environment, but I would like to emphasize that these strategies are not a magic recipe, but just some guidelines for design practice. Industrial designers should propose the design solution which carries the least possible negative consequences, but before doing so, designers should eliminate their biased point of view, and should also understand technology in its broadest sense. Having done that, designers can be aware of any hidden cost behind an object, and therefore, they can be aware of any possible negative consequence.

In the following chapters I will explore the other hidden cost of technology; the semiotic pollution, and I will present a strategy that can be used to minimize the consequences of it. But before that, I wish to bring back Heidegger's idea that the essence of technology is not technological. It is a way to see nature, to let nature reveal itself as a potential resource to be used by humans, and, as Arthur stated, the question is not whether the technology is neutral, but rather whether the technology enslaves our nature or improves it. Arthur stated that we, as human beings, need challenge, meaning, and purpose, and that we need to commune with nature. For Arthur, when technology denies this, it kills us a little, but when technology encourages it, it affirms our existence and reaffirms our humanity (Arthur 2009). We cannot stop technological development, and there is no reason why we should stop it, as it is useful and enriching; we just have to be aware of the hidden costs of it.

Chapter Eight: **Signs, Signs, Signs. Semiotic Pollution.**

"Advertisements cry out: 'Buy me!'. The board announces: 'A25'!. The pulse throbs: 'Your heart has something to tell you'. The clock warns: 'You are late!'. The signs laugh: 'Over here, over there!'"(Uebele, 2009)

When I started to write this thesis, my aim was to analyze the latest technological advances in the field of glass, as well as their applications in the industrial design field. However, once I started to analyze these technologies, I realized that it was impossible to do a review of all of them because new technology is being developed in the field every day.

I was suddenly at a dead end, and I realized that it is not important to make a list of all new technologies in the glass field because that list would become obsolete almost instantly; instead, at one point I realized that if glass is a man-made material, then it is a product of technology, and in order to understand glass it is necessary to analyze what technology is in its broadest sense.

Through this analysis I identified some attitudes towards technology, such as dazzled point of view, EPV, and reliability, and the consequences that these attitudes entail, especially two consequences: semiotic pollution and environmental pollution, which affect the two areas where human beings develop: biosphere and anthroposphere. Environmental pollution affects the biosphere, while semiotic pollution affects the anthroposphere[3].

In Chapters 6 and 7 I talked about environmental pollution as a consequence of technology, and I listed some strategies that industrial designers can use to alleviate it. At this point I would like to talk about semiotic pollution and analyze how it can be palliated.

First of all, one must remember that, as was said in Chapter 6, changes in manufacturing processes allow the production of large numbers of products in a short time, which entails an overloading of objects.

An example can be seen in the following image: the cost reduction of manufacturing processes, together with other circumstances such as more competition between manufacturers, allows the purchaser to have a large selection of products at hand.

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[3] Semiotic pollution occurs in the anthroposphere, environmental pollution occurs in the biosphere, and both are related. For the purposes of this thesis, I will call the anthroposphere the intangible cultural environment of human beings, and I will call the biosphere the sphere where living beings interact in a "biological" sense.

Image 13: *A large number of products are available to consumers*

This superpopulation of objects entails an increasing amount of information: every one of these objects demands, in some way, the attention of human beings. I must point out that all objects, even the most insignificant ones, transmit a certain degree of information; for example, the two pencils shown in Image 14 have the same function, but the signals and messages transmitted by them are different. And the amount of information increases when the objects are more complex: for example, a smartphone.

Image 14: *Two objects with the same function but different messages*

Thackara gave this example: “during the first part of the industrial era, progress and development meant the continued production of more products and more technology. At first, the benefits of technology seemed to be obvious: better, faster, smarter and usually cheaper products. But at the end of the day, the penetration of technology goes further: the differences between the gadgets are minimal; technology has become a commodity, sometimes an infringement of personal space, a form of pollution” (Thackara 2005).

However, the amount of objects is not the only cause of this pollution; it also has to do with the nature of these objects. Thanks to digital developments, the nature of many objects has changed, and the technology has become, in a way, intrusive.

An example of how the development of digital technologies has allowed many objects to become invasive is the use of smartphones: they are constantly demanding attention, even in social situations where their use is reprehensible, such as weddings and funerals.

One can say that currently, technology forces people to respond to multiple stimuli simultaneously, and more devices, objects, and gadgets mean more and more information and more and more visual saturation. Enzio Manzini called *semiotic pollution* to this saturation of information and images (as cited inThackara 2005).

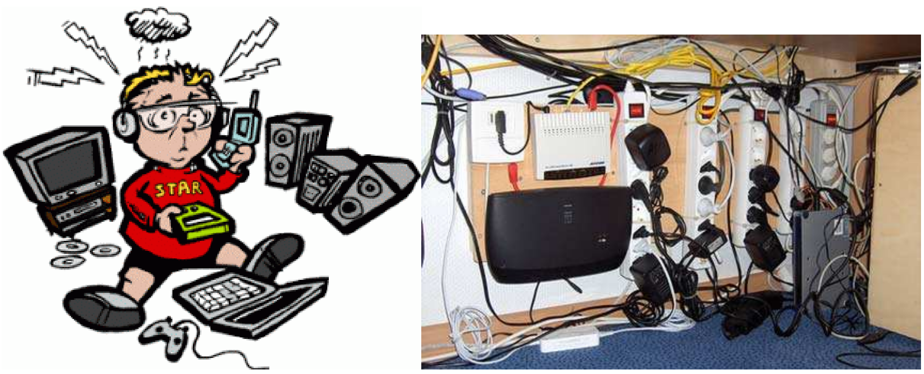

Image 15: *Technology forces people to respond to multiple stimuli at the same time. More objects mean more saturation*

Indeed, technological development seems to entail an increasing number of objects, and all these objects are constantly asking for attention, causing semiotic pollution, or *visuality*[4] .

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[4] "Visuality" is a term used by Thorpe to address the domain of visual imagery in our lives, and the unidirectional flow of these images (Thorpe 2007).

A major current problem regarding new technologies is: to what extent do we allow them to invade our environment? For some objects, such as smartphones, users can turn them off or ignore them, but what happens when doing this is not possible? What happens when these invasive objects are always present, sending messages? Why do designers of these invasive objects, these information transmitters, believe that human beings need or want them?

I should clarify that some information must be out there in a permanent basis, such as service signaling. The problem arises when, to this necessary information, a lot of trivial information is added. The result is an increasingly semiotically polluted environment, because every one of these objects is demanding human attention. Also, it is important to point out that, as Meyer stated, human brain cannot multitask; instead, it parcels attention to selected tasks over time. A person may seem able to handle several tasks at once, but he or she is really only moving from one to another, usually giving less attention to each (Meyer, as cited in Haugen 2007). The problem comes when a human being is seen as an empty entity with unlimited capacity for absorption, because human beings do have a limited capacity for information processing and they also have a limited capacity to filter stimuli. So, what happens when this capacity reaches its limit? Human beings arrive, as Calvino says, at a situation of "alienation and discomfort" (Calvino 1988).

For example, in 28 years (1980 to 2008), the consumption of information has increased 350 percent (Short, Bohn, & Baru 2011). Meanwhile, down-time, which is crucial to synthesize, digest and shape new ideas and experiences, continues to decline[5] .

It can be said that semiotic pollution changes the way human beings behave or changes the way human beings face technology because the relationship between objects and people has changed in some way; objects that usually stayed in the background are now constantly going from background to foreground to background again, demanding attention but without the necessary strength to catch the care of the user for a long time. And this can be considered an enframed point of view: to think of the user as an empty vessel to be filled with information and stimuli. While the user consumes these stimuli passively, he or she still has to process and filter them. Such information and stimuli will not leave an imprint, but can leave a sensation of discomfort, because the stimuli introduce a cacophony of visual background noise that users must contend with.

Industrial designers can help to alleviate this enframed point of view using two strategies: firstly, by not thinking of people as passive subjects, and by giving them some control, some authorship over those stimuli. Doing this, the user becomes an active subject, and the previous unidirectional flow of information becomes a dialog.

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[5] But this huge amount of information also involves a large amount of physical resources; for example, in addition to its impact on the economy, information technology uses a lot of resources: one of the hidden costs of the so-called "silicon era" is the flow of material and energy involved in the manufacture and use of microchips. It takes 1.7 kg of

Secondly, designers can lessen the amount of information and stimuli if they are designed in a non-permanent basis, so that users do not have to contend with chronic visual noise and stimuli.

In the next Chapter I will give an example of how semiotic pollution can offer an opportunity for a design intervention, and how these two strategies, authorship of the user and non-permanent stimuli; can be applied on a design intervention.

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material to make a 32-megabyte microchip; that is, 630 times more material than the material found in the final product (Thackara 2005). The amount of waste generated in manufacturing a laptop is close to 4000 times its weight.

Chapter Nine: **Lessening Semiotic Pollution. Design Brief.**

As stated in chapter 8, we are currently experiencing two problems: on the one hand, technological developments entail semiotic pollution and information overload, and on the other hand, human beings have to filter and process this large amount of information.

One strategy to palliate these problems is to reduce the number of signals and information issued in order to lessen the semiotic pollution. Another strategy is to give people some control over those signals. A third strategy is to work with those signals on a non-permanent basis.

In the next pages I will develop a practical example of these strategies; I intend to design a calming element within a very semiotically polluted environment: a meeting point (MP) placed in airports.

9.1 Brief

TITLE: Meeting Point (MP)

OBJECTIVES: To mitigate semiotic pollution, to give people authorship of signals, and to introduce communication media that is as much calming as communicating.

LOCATION: The MP can be placed in different indoors urban spaces such as museums, shopping malls, transportation terminals and other highly semiotically polluted environments.. In this case I will give the example of a meeting point placed in an airport, where the precise location of it will depend on the particular needs of every terminal.

BACKGROUND: Usually, there are many elements of stress at an airport: it is noisy and crowded; people are stressed out about the possibility of being late and missing their flight; and people arriving from a flight may be tired and disoriented. Strong semiotic pollution must be added to these stressors, because at an airport (or any crowded transport terminal) there usually are signs and stimuli everywhere; and those stimuli are continuously putting people in the position of unconsciously responding to them, or forcing people to filter them. So, the MP must act as a calming space within a crowded environment.

Image 16: *Mood board*

USE ENVIRONMENT: The design of the meeting point must take into consideration the existing infrastructure: information stands, waiting areas, stores, washrooms, airline desks, etc. The MP should be easily visible so that people can arrive there without difficulty. The MP must be as non intrusive as possible within existing infrastructures.

It is important to point out that transport terminals are usually very crowded environments, with lots of people, signals, noise, and stimuli. Moreover, in the periods of highest use, those stimuli multiply. So, in addition to being a calming space, the MP must also enable people to meet easily and comfortably.

Image 17: *Existing infrastructure board*

PRECEDENTS: The existing MP at airports work as meeting places, but they are not calming spaces because people are exposed to the crowded environment and to the semiotic pollution. In some of these meeting points there is no space where to sit, and in some meeting points signage is confusing. Some of them are easily visible, and some of them tend to merge with the environment.

The pictures on this board are examples of MPs that are currently installed in different airports. As one can see, despite fulfilling their purpose, they present many opportunities for improvement.

Image 18: *Precedent board*

END USE: The MP must act as a node where people can meet other people, before or after traveling. The MP must provide a calming space where people can relax for some time. The MP will adapt to the personal needs of every user: users will be able to sit or stand, and they will be able to write messages and leave signals for others. The meeting point must be comfortable enough to spend time there, and offer a space to relax, in a stress-free zone to rest, or to forget about a tiring journey. The MP must have a friendly interface and be easy to use.

USERS: The MP should take into consideration all possible users: the MP will be used by persons who arrive after a tiring journey or that are just about to travel. The people can be of any age, from babies to elderly people; they may use lots of medical equipment or wheelchairs; they may be carrying lots of baggage or just one small bag; they may travel alone or with family and pets; they may have a smart phone or no phone. They do not want to wait in a crowded space, but they still want to be able to see other people.

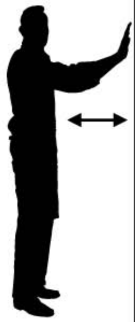
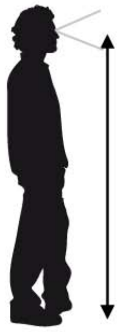
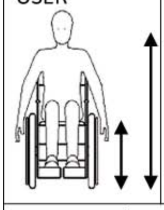
Image 19: *User board*

Characteristics of users

USER	Smartphone/ tablet owner	Travel in groups	Travel with family	Travel with pets (owner)	Travel alone	Travel in a couple	Travel for business	Use a wheelchair
Baby	NO	NO	YES	NO	NO	NO	NO	NO
Toddler	NO	NO	YES	NO	NO	NO	NO	NO
Child	NO	MAYBE	YES	NO	NO	NO	NO	MAYBE
Teenager	MAYBE	MAYBE	YES	NO	NO	NO	NO	MAYBE
Adult	MAYBE	MAYBE	MAYBE	MAYBE	MAYBE	MAYBE	MAYBE	MAYBE
Elderly	MAYBE	MAYBE	MAYBE	MAYBE	MAYBE	MAYBE	NO	MAYBE

USERS CONSTRAINTS: MP users will have different constraints, depending on their age, characteristics, etc. An anthropometric table is useful to address these constraints.

Anthropometric table

USER	HEIGHT	SITTING HEIGHT	MAXIMUM FRONTAL REACH	HEIGHT OF VISION
				
ADULT MAN*	97.5 p: 190 50 p: 177.8 2.5p: 164.8	According to Dreyfuss (1967), comfortable seating height for adults is 44-48 cm	97.5 p: 78.2 50 p: 72.6 2.5 p: 67.3	97.5 p: 178.8 50 p: 166.6 2.5 p: 154.7
ADULT WOMAN	97.5 p: 177.8 50 p: 164.8 2.5 p: 153.2		97.5 p: 72.6 50 p: 67.3 2.5 p: 62.7	97.5 p: 166.6 50 p:154.7 2.5 p:143
TEEN** 16 years	169.9	40.6	69.9	159.5
TEEN** 11 years	147.6	36.1	61.2	137.4
CHILD** 6 years	140.7	34	58.4	130.6
CHILD*** 6 years	116.6	27.2	47.2	106.7
WHEELCHAIR USER 	A combination of the height of the user and the height of the wheelchair seat	Seat height may vary between 45.7 and 55.9	Side reach may vary between 50.8 and 61	Eye level height may vary between 109 and 129.5

P: percentile
Measurements are in centimeters
Measurements are based on USA population
*Elderly population fits in with adult man/woman measurements
**Children and teenager measurements shown in this table belong to the 50th percentile
***Babies and toddlers are under adult supervision at all times, and they are not a representative user of the meeting point because they usually are in strollers or held in arms.
Data taken from Pheasant (Pheasant 2006) and Dreyfuss (Dreyfuss 1981).

TECHNICAL CONSTRAINTS:

The MP must:

- take into consideration existing manufacturing technology and available materials
- integrate the energy supply into the design
- be easy to install
- take into consideration the existing infrastructure
- integrate with the existing environment
- withstand the weight of people walking and sitting down
- take into account the large number of people daily using an airport or transport terminal
- be easy to clean with normal cleaning products
- be effectively identifiable as a meeting place
- be easy to use.

Chapter Ten: **An Oasis. Design Intervention**

As discussed in chapter 8, it can be argued that that there is an excess of information and stimuli in many indoor and outdoor environments, semiotic pollution as a result of technological development. A strategy to mitigate this pollution is to reduce the amount of stimuli.

In this chapter I will present the design of an MP that acts as a calming element within a polluted (semiotically speaking) environment: an airport. This MP lessens, in some way, the amount of stimuli received by the users.

Two of the characteristics of the signals received at an airport are: first, they are fixed signals (i.e., they are always there), and second, human beings cannot turn them off. Therefore, this calming element, in addition to fulfilling the requirements asked in the design brief, must also be flexible (i.e., the signals and information at the MP cannot be fixed), and act on an ephemeral basis.

In addition, any signal or information provided by the MP must act as a response to the environment, and the user will go from being only a receptor to being an active element capable of generating information (on a temporary basis).

Thanks to the special features of glass, it is possible to develop an MP with the desired characteristics.

10.1 Design

10.1.1 Preliminary steps

Mental map

Before starting with the brainstorming process and in order to in order to identify and assess the main concepts of this thesis as well as their relationships, a mental map was made. A large version of this mental map can be seen in Appendix J.

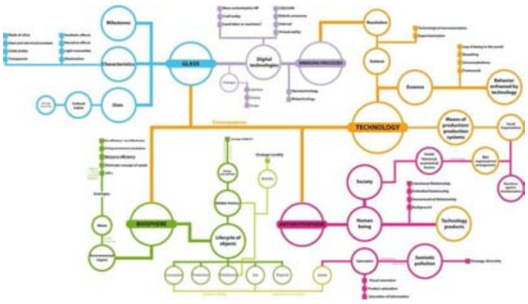


Image 20: *Mental map*

Public space precedents

Some examples of public spaces were analyzed, and some key points that could be observed are: space, shape, materials, and user experience. In image 21 some examples of public spaces can be observed. These spaces enhance the user´s experience in some way. Some of these spaces were made using the latest technologies available at the moment, while others were made of usual materials and production processes.

Image 21: *Public spaces*

Glass precedents

Some examples of glass usage in public spaces were analyzed. Some factors to take into consideration are: transparency, color, and light. In image 22 some examples of glass applications in public spaces, such as stained glass, translucent concrete, laminated glass y kilned glass, can be observed. In these examples one can see that glass clearly contributes to enhance the user´s experience by creating a colorful space that provides shelter to the user while offering enticing views to the surroundings, due to the transparency of the material.

Image 22: *Glass applications in public spaces*

Similar technologies

In the following image one can observe some examples of glass developments that can be used in the meeting point design. A key word to take into account is “interactivity”. In image 23 some examples of glass technology can be observed. Some of these examples allow an interaction between the glass object and the user; some others take advantage of the translucent state of glass, while others examples make use of composite materials to create a flexible glass.

Larger images and more precedents can be seen in Appendix K.

Image 23: *Some glass technology*

Sketches

The design process was an iterative one; I used tools like brainstorming, sketching, and 3D modeling. Please note that the totality of precedents and sketches can be seen in appendix K and L.

Image 24: *Previous ideas*

10.2 Meeting Point design.

After analyzing some precedents and through an iterative process, I developed a final design. The designed object is an MP where people can meet in a crowded space before or after traveling.

This MP is comfortable enough to spend 10 minutes there, either using the seating space or standing.

It offers a stress-free space where people can see each other easily.

This MP is effectively identifiable as a meeting place thanks to the use of graphics, color,and light.

This MP will be placed in airports and other transportation terminals.

It acts as a calming element in a crowded environment.

It integrates with the environment.

It takes into consideration the existing infrastructure.

The design of the MP considers all possible users´ dimensions and conditions.

It is easy to clean using normal cleaning products. Dimensions of the arc shapes are based in the Fibonacci series (Barrat 1989).

Image 25: *MP perspective*

Image 26: *MP wit steel frame*

Materials and processes

The MP is manufactured using thermoformed Corning Lotus ™ glass panels, as well as some panels of flat security glass. Corning Lotus™ Glass is an alkaline boro-aluminosilicate glass. It is also a high-performance display glass that can be used in organic light-emitting diode (OLED) displays and liquid crystal displays (LCD). The end result is a device that consumes less power while delivering superior picture quality

The intrinsic thermal consistency of Corning Lotus glass allows it to retain its shape and quality during high-temperature processing. Thanks to this feature, the shape of the MP can be achieved (www.corning.com).

This MP is a showcase of new technologies in several aspects: it is designed using CAD tools, it is manufactured using CAM tools and computer-controlled kilns, and the interaction with people makes use of digital touch-screens.

In order to install the MP in the desired place, preformed concrete squares will be used. Glass panels will be anchored to the preformed concrete squares using specialized attachments. Those attachments will also provide electric energy to the MP. Steel Titen™ anchors will be used to anchor the MP to the floor. It is important to point out that some shock absorbing elements must be placed between the anchors and the glass panels. An antibacterial coating can be applied to the glass panels if desired.

The MP can be embedded on the concrete wall, or it can have a steel frame all around it.

Image 27: *Glass attachments*

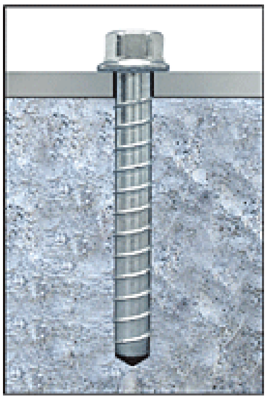


Image 28: *Titen anchors*

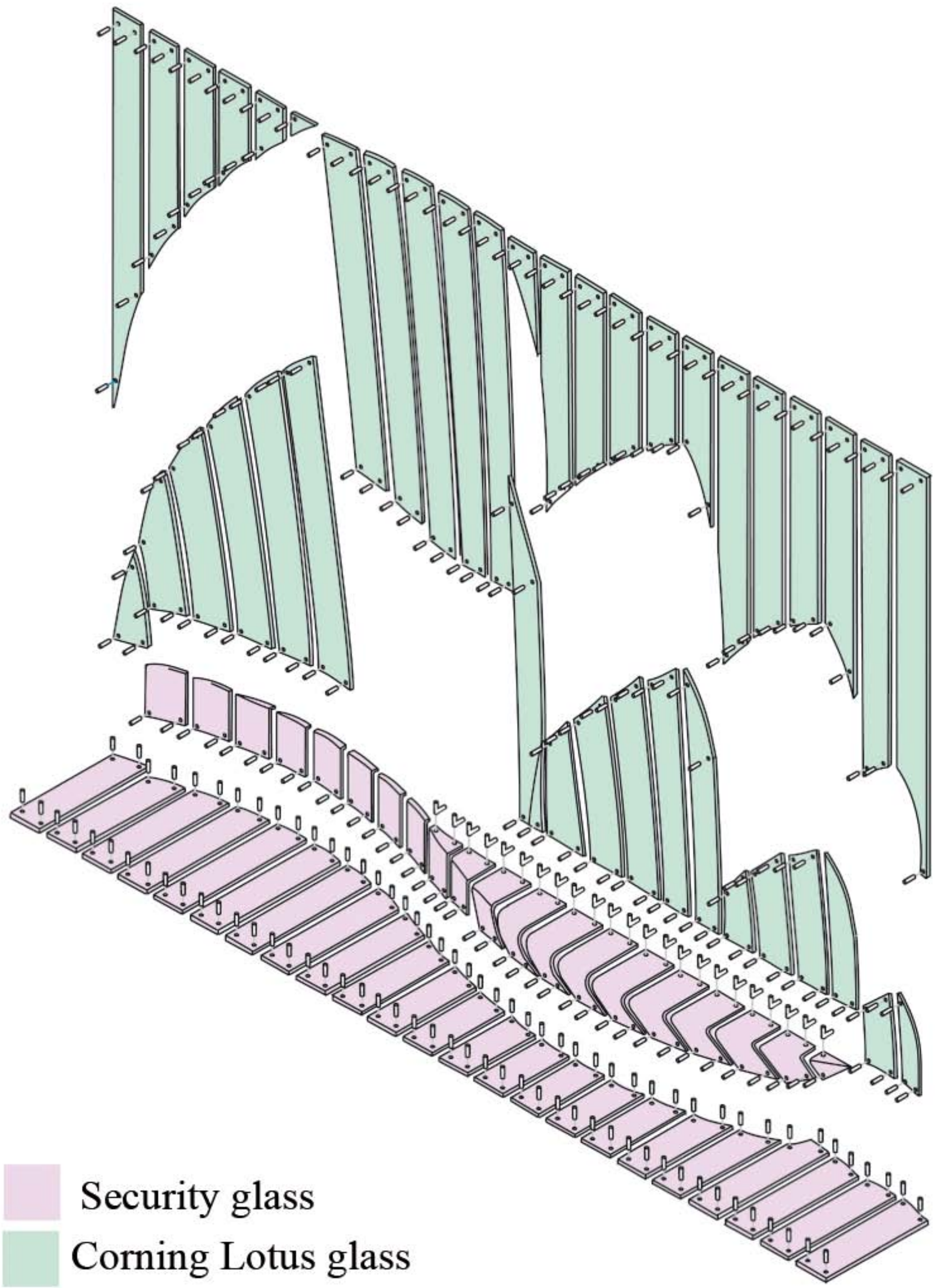


Image 29: *Exploded view*

A major milestone in glass technology is the use of digital tools in the design and manufacture of glass objects. This MP exemplifies how the shape of an object is a reflection of technological advances. Thanks to digital based technologies, we can obtain non-traditional glass shapes. Also, technological changes can affect not only the shape of glass objects, but also their chemical composition and therefore their characteristics and properties. This MP is an example of the application of both new glass types and new processes. The manufacture of this object would not have been possible 10 years ago.

Flexibility

This MP uses light and color as follows: the glass used to manufacture it is transparent, but it has a series of lights which change the color of the MP. These lights are controlled by a central computer, but also, when people stand or walk in the MP, they activate sensors and the lights will turn on.

In addition, the use of graphics and images are also controlled by computer. It can be said that glass is in this case used as a message transmitter through a message board and a drawing board. Moreover, the user is an active element who can change the appearance of the surface. In some random moments, an MP in one location can connect with an MP placed in another location, and users can see drawings made by other people in distant airports. However, all of these pieces of information are a temporary. Thanks to its flexible character (which responds to the environment and the user´s requirements), the MP tends to come back to its default calming state.

User interaction

As we can see in Image 30, The MP has sensors that detect people, and if a person stands in the MP for about 10 seconds, the sensor will activate a light below him or her.

Image 30: *Use of light*

The MP can be used as a message board, as a drawing board, and as a name board, i.e., the name of a person can be displayed. In order to avoid vandalism, software that recognizes rude words in several languages will be used.

Image 31: *Displaying messages on a temporary basis*

Real-time image of a place: this may be the city where the airport is, or some other place. For example, either the cities of Amsterdam or Beijing may be displayed in real-time at the Amsterdam airport MP.

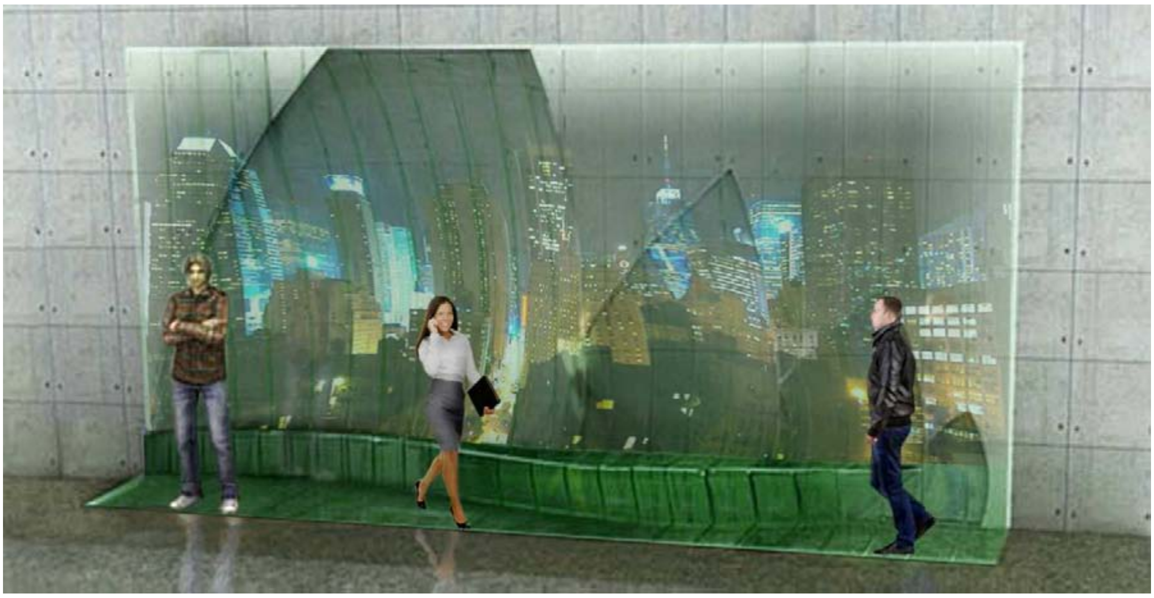


Image 32: *The MP connects airports using the internet*

Users can draw using their fingers on the surface of the MP. These drawings would disappear in around 10 minutes.

Image 33: *MP as a drawing board*

Users can write a message on the MP´s surface using their smart phones or a pop-up keyboard.

These messages would disappear in around 10 minutes.

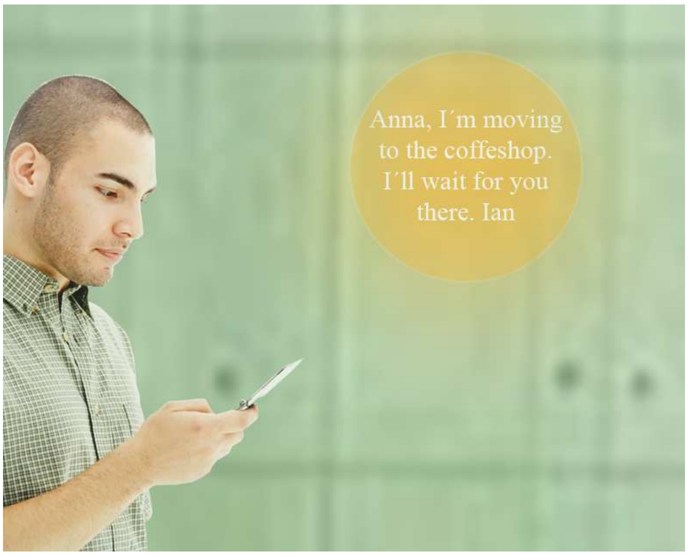


Image 34: *MP as a message board*

Image 35: *People using the MP*

The MP has a friendly interface; it has a message board that people can use through their phones (using a phone application). Users can “leave their mark” by drawing on the surface using their fingers. The name of the person waiting can be placed on some panels.

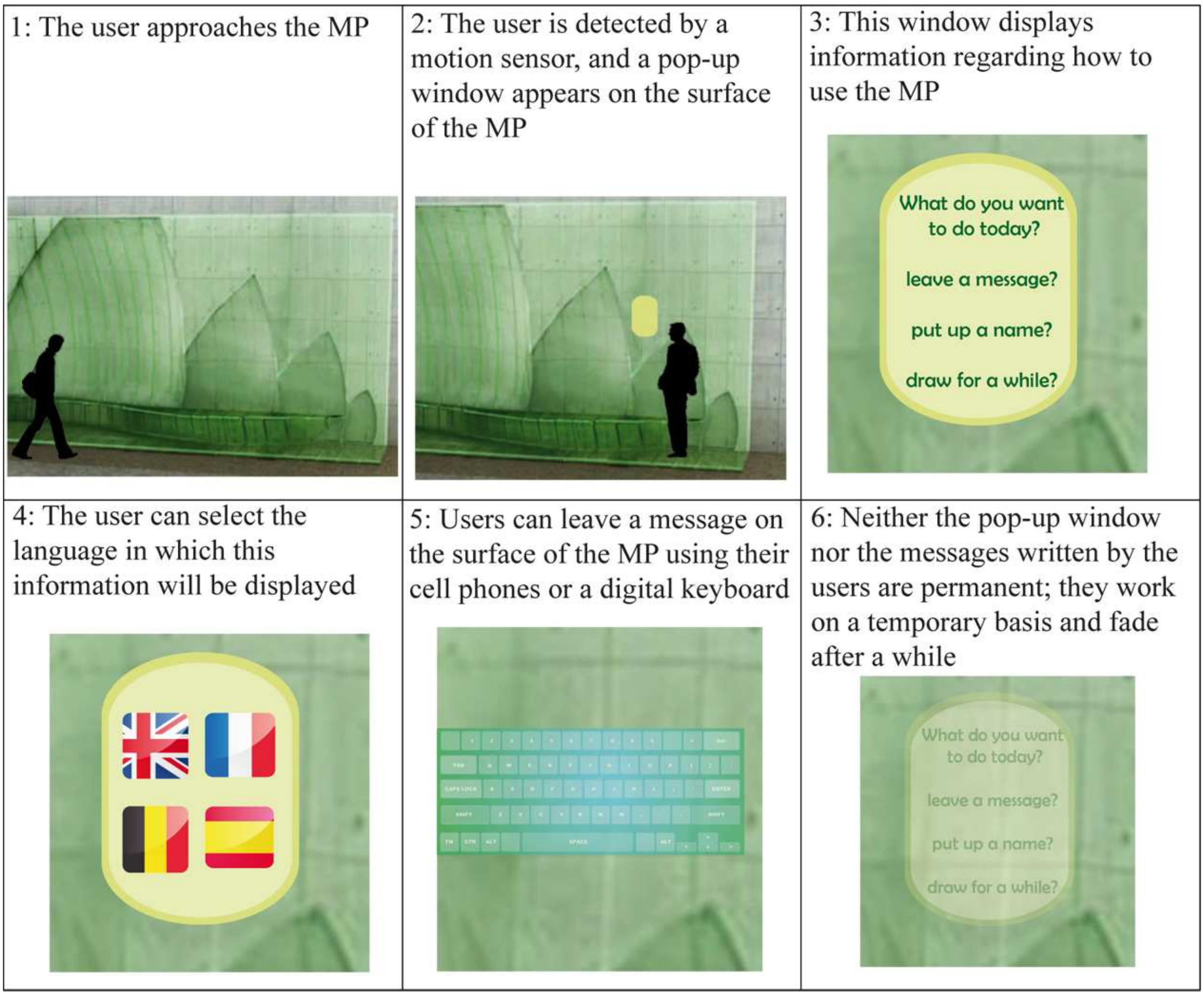


image 36: *Story board showing the interface of the MP*

In the design of this MP I used glass to enhance the user experience, taking advantage of its features and characteristics. However, it is necessary to clarify that glass is not the end, but the medium: what I wanted is to create an experience (an atmosphere) using color, light, and interactivity.

Image 37: *MP surrounding environment*

10.2.1 Views

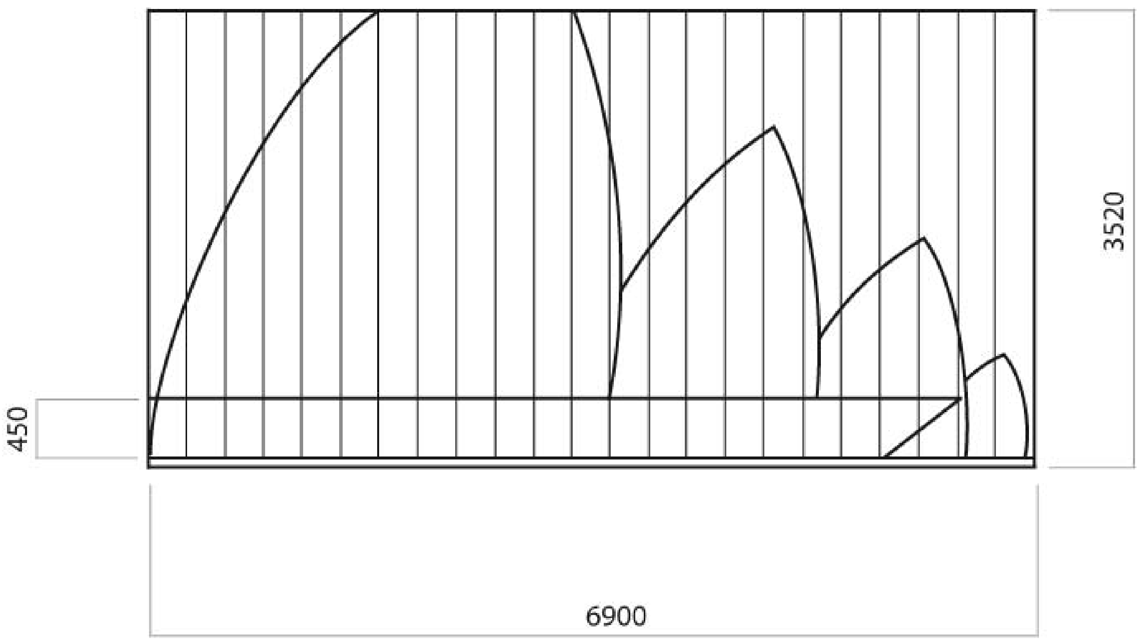


Image 38: *Front view*

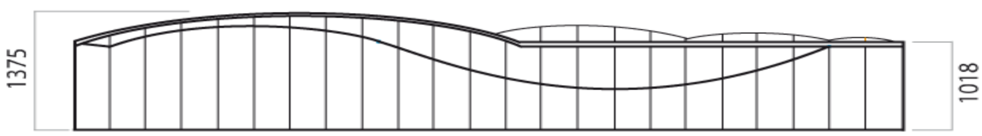


Image 39: *Top view*

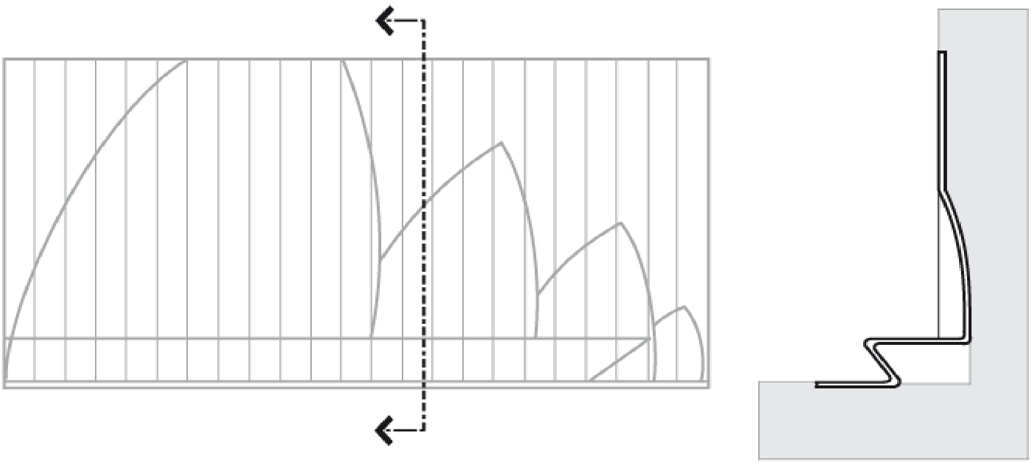


Image 40: *Sectional view*

Chapter Eleven: **Thesis Conclusions**

As I stated in Chapter 8, we are currently living with an overcrowding of objects, and each of those objects emits signals and demands attention. Human beings have three options to face these stimuli: to respond to them, to filter them, and to turn them off.

Let us look at the first case: to respond to signals. Many times we respond to an object's stimulus without thinking about it, even in embarrassing social situations such as answering a cell phone at a wedding. One can think of Heidegger´s concept of an enframed point of view (explained in Chapter 4). The enframed point of view forces us to respond to technology without thinking about it. In a certain way, manufacturers of objects are also affected by the enframed point of view regarding technology: it is an enframed point of view to suppose that human beings are just there to pay attention to stimuli, that they are interested in them, and that they want them.

The second case refers to filtering those stimuli, but the human filtration capacity has a limit. As stated by Meyer, the human brain does not multitask, instead, it parcels its attention to various tasks overtime. A person may seem to be able to handle several tasks at once, but he or she is really only moving from one to another, usually given less full attention to each (Meyer, as cited in Haugen & Musser, 2007).

The third case refers to turning signals off. Sometimes people can do it, but usually they cannot. So, the mandatory question is: how can people have more control over those stimuli? One strategy to do that is by giving human beings the authorship of the emitted signals and messages.

In this way, people move from being an element that receives all the messages in a passive way, to become an active element. This strategy could reduce the semiotic pollution caused by the overcrowding of objects, because people would only produce necessary signals.

In Chapter 10 I developed a practical example of this strategy through the design of a calming element located in a crowded and semiotically polluted environment. In this MP, the user becomes an active element, and thanks to this MP, visuality (unidirectional flow of images) can be reduced because the user changes from being a passive receptor to an active subject. Moreover, the information displayed by the MP is only there when it is needed, unlike common signage that is constantly present, contributing to semiotic pollution.

In this MP one can observe the different relationships between people and technology: the first approach of the user to the meeting point involves an intentional relationship; when the user starts to interact with the object, an embodied relationship is established. When the user stops being aware of the MP and focus his attention on the surrounding environment, a background relationship is established. And finally, when the MP provides some kind of information to the user, such as the weather forecast, a hermeneutical relationship is established.

This MP also exemplifies how technology has changed the relationships between people, allowing distant persons to interact thanks to information technologies. It also exemplifies how the relationship between people and objects has changed, since the approach to objects (interface) is different than in previous meeting points.

I must point out that, despite the possibility of other materials being used, glass is the best option to manufacture this MP thanks to its unique characteristics and features. For example, glass is a material that can support multiple interfaces and act as a message board, and at the same time, be transparent and visually light.

At this point I wish to emphasize one historical usage of glass: that of glass as a message transmitter, from Gothic cathedrals´ stained glass windows, to intelligent screens in public spaces. In this MP, glass acts as a message transmitter, no longer using stained glass, but digital technologies. However, unlike its predecessors, the messages sent by the MP are only there when they are needed.

Art and the meeting point

According to the Oxford companion to philosophy, art is closely related to the aesthetic attitude, and this is supposedly a particular way of experiencing or attending to objects. It is said to be an attitude independent of any motivation to do with utility, economic value, moral judgment, or peculiarly personal emotion, and concerned with experiencing the object “for its own sake” (Honderich, 1995).

Having stated this concept, it is possible to say that the MP is both a design response to a concrete problem, as well as an art response, where the user can experience an aesthetic attitude towards the MP, by enjoying the smooth curved shapes of its surface, the subtle use of color, and the sheltering space that the MP provides.

And I also want to mention that artistic interventions made of glass and created by internationally renowned artists can be seen through different airports, such as the Venice airport, the San Jose airport and the Changi airport.

Some possible further steps

The MP design has some weaknesses that can be seen as opportunities to explore.

Since Corning Lotus™ Glass was developed for use in smaller applications such as cell phones and displays; it is not the optimal material for the MP. There is an opportunity for material engineers or glass manufacturing companies to develop a better glass for large-scale applications.

Current manufacturing processes used to thermoform large pieces of glass can be improved, which represents an opportunity for mechanical engineers or glass manufacturing companies to develop a new process to manufacture large pieces of interactive glass for architectural applications.

There are some opportunities for designers as well.

The MP has been designed for users to spend around 10 minutes there. A designer could explore ways to develop a pleasant place to spend more time.

The inner characteristics of the MP require that it can only be installed indoors. It would be interesting to explore the possibility of an outdoor version.

Another further exploration of the MP is to develop the same kind of interactive spaces, but place them in different public urban spaces such as shopping malls, museums, art galleries, etc.

There is also an opportunity regarding the MP´s interface; for example a multimedia designer could improve it and make it accessible to blind people.

And, finally, semiotic pollution and the responsibility of designer in this problem are two issues mentioned through this thesis document; both are complex issues that could be developed in depth as PhD research by a graduate student. This thesis has sought to establish a framework and raise a number of questions.

I want to conclude by saying that technology (not only in the glass field, but in all fields) is developing all the time, and therefore designers should act as translators between the ever-changing technology and the final user of an object. Designers need to understand technology in its broadest sense, understand that it is a way of seeing the world and being in the world, and that technology enriches and adds depth to our lives. It is useful and enriching, but we just have to be aware of the hidden costs of it.

In summary, one can say that technological changes involve not only changes in objects´ shapes or in production processes. The consequences of a new technology go beyond these, and modify the relationships established between people and people, people and objects, and people and technology to the point that one can say that technology defines, in a way, the zeitgeist of a historical period. Moreover, technology also shapes the way people face the future.

REFERENCES

Arancibia, J., P. Alfonso, J. Cortez, M. Garcia-Valles, D. Parcerisa, and Martinez. S. 2012. Obtencion de vidrio a partir de escombreras de la mineria del Sn en Bolivia. Universidad Tecnica de Oruro, Bolivia

Arthur, W. Brian. 2009. *The nature of technology: what it is and how it evolves.* New York: Free Press.

Ashby, M. F., and K. Johnson. 2002. *Materials and design: the art and science of material selection in product design*. Amsterdam; Boston: Butterworth-Heinemann.

Bahaj, AbuBakr S., Patrick A. B. James, and Mark F. Jentsch. 2008. "Potential of emerging glazing technologies for highly glazed buildings in hot arid climates." *Energy and Buildings* no. 40 (5):720-731. doi: http://dx.doi.org/10.1016/j.enbuild.2007.05.006.

Barratt, Krome. 1989. *Logic and design: in art, science & mathematics*. London: Herbert Press.

Calvino, Italo. 1988. *Six memos for the next millennium*. *(Charles Eliot Norton lectures; 1985-86).* Cambridge, Mass.: Harvard University Press.

Bunnin, Nicholas. Yu, Jiyuan.2004. *The Blackwell dictionary of Western philosophy*. Malden, MA.: Blackwell, 2004.

Cheng, K. 2005. *E-manufacturing: fundamentals and applications.* Southampton, U.K.: Boston: WIT Press.

Craig, Blanche. 2008. *Contemporary glass.* London: Black Dog Pub.

Cuffaro, Dan. 2006. *Process, materials, and measurements: all the details industrial designers need to know but can never find*. Gloucester, Mass.: Rockport Publishers.

Debord, Guy. 1994. *The society of the spectacle*. 3rd ed. New York: Zone Books.

Diamond, Freda. 1953. *The Story of glass*. New York: Harcourt Brace.

Dreyfuss, Henry. 1967. *The measure of man; human factors in design*. 2nd ed. New York: Whitney Library of Design.

Diffrient, N., Tilley, A., Harman D. 1981 *Humanscale 7-8-9.* Cambridge,Mass.: MIT Press.

Fox, Howard N. 2006. *Glass: material matters.* Los Angeles: Los Angeles County Museum of Art.

Frank, Susan. 1982. *Glass and archaeology.* London; Toronto: Academic Press.

Goldstein, E. Bruce. 2010. *Sensation and perception.* 8th ed. ed. Belmont, Calif: Wadsworth Cengage Learning.

Guerrero, E., M. Mur, R. sans, J. Velazco, I. Francisco, V. Lennikov, L. Estepa, and G. De la Fuente. Descripción del horno Laserfiring. Instalacion y puesta en marcha.: Centro Tecnológico de Toledo.

Haugen D., Musser s. 2007. *Technology and society.* Detroit : Greenhaven Press.

Headrick, Daniel R. 2009. *Technology: a world history.* The new Oxford world history. Oxford; New York: Oxford University Press.

Heidegger, Martin. 1977. *The question concerning technology and other essays*. New York: Harper Colophon Books.

Hench, Larry L. 2009. "Genetic design of bioactive glass." *Journal of the European Ceramic Society* no. 29 (7):1257-1265. doi: http://dx.doi.org/10.1016/j.jeurceramsoc.2008.08.002.

Honderich, Ted. 1995. *The Oxford companion to philosophy.* Oxford: Oxford University Press.

Ihde, Don. 1979. *Technics and praxis*. Edited by (Synthese library and v. 130), *(Boston studies in the philosophy of science ; v. 24).* Dordrecht, the Netherlands: Reidel.

Ihde, Don. 1993. *Philosophy of technology: an introduction.* 1st ed. *(Paragon issues in philosophy).* New York: Paragon House.

Ihde, Don. 2010. *Heidegger's technologies : postphenomenological perspectives*. 1st ed, (*Perspectives in Continental philosophy*). New York: Fordham University Press.

Kolarevic, Branko. 2003. *Architecture in the digital age: design and manufacturing*. New York: Spon Press.

Kolarevic, Branko. 2008. *Manufacturing material effects: rethinking design and making in architecture*. New York: Routledge.

Krar, Stephen, and Arthur Gill. 2003. *Exploring advanced manufacturing technologies*. New York: Industrial Press.

Krishna, Aradhna. 2010. *Sensory marketing : research on the sensuality of products*. New York: Routledge.

Lefteri, Chris. 2002. *Glass : materials for inspirational design*. Mies, Switzerland; Hove, East Sussex, UK: RotoVision SA.

Lesko, Jim. 2008. *Industrial design : materials and manufacturing guide*. John Wiley & Sons.

Lidenmller, J. 2012a. El mosaico: Pasado, presente y futuro.: Gustav Van Treeck, GmbH, Germany.

Lidenmller, J. 2012b. La conservación, la restauración o la reconstrucción de las vidrieras históricas. Gustav Van Treeck GmbH, Germany.

Macfarlane, Alan. 2002. *Glass: a world history.* Chicago: University of Chicago Press.

Manzini, Ezio. 1986. *The Material of invention.* Milan: Arcadia Edizioni.

McClellan, James E. 2006. *Science and technology in world history: an introduction.* Edited by

Harold Dorn. Baltimore: Johns Hopkins University Press.

McDonough, William, and Michael Braungart. 2002. *Cradle to cradle: remaking the way we make things*. New York: North Point Press.

Menendez, E., C. Argiz, A. Alvaro, J. Parra, and A. Moragues. 2012. Caracterizacion de cenizas de cenicero procedentes de centrales termicas de carbon para determinar su viabilidad de uso.: Instituto de Ciencias de la Construccion

Moronta, R., R. Lopez, P. Poza, F. Orgaz, and J. Rodriguez. Ceramicas transparentes. Procesamiento y transmisión óptica.: Instituto de Cerámica y Vidrio, Madrid.

Norman, Donald A. 1993. *Things that make us smart: defending human attributes in the age of the machine.* Reading, Mass.: Addison-Wesley.

Norman, Donald A. 2011. *Living with complexity.* Cambridge, Mass.: MIT Press.

Nye, David E. 2006. *Technology matters: questions to live with.* Cambridge, Mass.: MIT Press.

Quinn, Bradley. 2011. *Design futures*. London ; New York: Merrell.

Pheasant, Stephen. 2006. *Bodyspace : anthropometry, ergonomics, and the design of work.* 3rd ed. Boca Raton, FL.: Taylor & Francis.

Petrie, Kevin. 2011. "Creative glass research case studies from art and design." *Glass Technology - European Journal of Glass Science and Technology Part A* no. 52 (1):1-10.

Pfeifer, Michael. 2009. *Materials enabled designs: the materials engineering perspective to product design and manufacturing*. Burlington, MA: Butterworth-Heinemann .

Quinn, Bradley. 2011. *Design futures*. London ; New York: Merrell.

Rodriguez, O., I. Garcia-Diaz, A. Urien, F. Alguacil, M. Sanchez de Rojas, M. Frias, and F. Lopez. 2012. *Refuerzos de matrices cementantes mediante la incorporacion de fibra de vidrio reciclada procedente de la pirolisis de materiales compuestos*.: Centro Nacional de

Investigaciones Metalurgicas, Madrid.

Schodek, Daniel L. 2005. *Digital design and manufacturing : CAD/CAM applications in architecture and design*. Hoboken, NJ: Wiley.

Short, James E., Roger E. Bohn, and Chaitanya Baru. 2011. *How much information? 2010 Report on enterprise Server Information*. San Diego: Global Information Industry Center.

Smith, Cyril Stanley. 1981. *A Search for structure: selected essays on science, art, and history.* Cambridge, Mass: MIT Press.

Standage, Tom. 2005. *A history of the world in 6 glasses*. New York: Walker & Co. : Distributed to the trade by Holtzbrinck Publishers.

Sullivan, Louis H. 1922. *The tall office building artistically considered*. Minneapolis.

Thackara, John. 2005. *In the bubble : designing in a complex world.* Cambridge, Mass.: MIT Press.

Thorpe, Ann. 2007. *The designer's atlas of sustainability.* Washington, DC: Island Press.

Tilley, Alvin R. 2002. *The measure of man and woman : human factors in design.* New York: Wiley.

Uebele, Andreas. 2007. *Signage systems & information graphics : a professional sourcebook.* London : Thames & Hudson.

Vallet-Regi, M. 2012. Desde los biomateriales a las nanoparticulas mesoporosas de silice destinadas a aplicaciones medicas. Universidad Complutense de Madrid.

West, Margaret. 2010. "Practical guide for the assessment of glass making sands: Part 1- procedures for sampling and physical testing." *Glass Technology* no. 51 (2):81-85.

www.britglass.org.uk. [cited 20/09/2011 2011].

www.corning.com/displaytechnologies/en/products/lotus/index.aspx [cited 09/07/2013 2013].

Yan, Jiwang, Takashi Oowada, Tianfeng Zhou, and Tsunemoto Kuriyagawa. 2009. "Precision machining of microstructures on electroless-plated NiP surface for molding glass components." *Journal of Materials Processing Technology* no. 209 (10):4802-4808. doi: http://dx.doi.org/10.1016/j.jmatprotec.2008.12.008.

Yan, Yang, Kang Boseon, Huang Shiguo, and Chen Xing. 2007. "Glass Polishing Technology Using MR Fluids." *Journal of Rare Earths* no. 25, Supplement 2 (0):367-369. doi: http://dx.doi.org/10.1016/S1002-0721(07)60507-9.

IMAGE REFERENCES

Image 1 http://cn1.kaboodle.com/hi/img/b/0/0/1a/b/AAAAC54PXeEAAAAAABq89w.jpg?v=1229412294052

Image 2 http://1.bp.blogspot.com/-8m0gWuGbzTs/TbzvaRw1tAI/AAAAAAAAAxc/4VKSrnIZ22I/s1600/Fiber-Optics.jpg

Image 3 http://graphics8.nytimes.com/images/2007/05/25/arts/design/26vision.600span.jpg

Image 4 http://4.bp.blogspot.com/-pEUKwsdNlo0/TVnvooA27tI/AAAAAAAAAlw/NMZ-CEa-_cE/s400/transparent%2Bglass%2Bphysical.jpg

Image 5 http://www.shapeways.com/blog/uploads/3D_printing_glass_Shapeways1.jpg

Image 6 http://img.archiexpo.com/images_ae/photo-g/laser-engraved-patterned-float-glass-panel-for-tables-counter top-67333-2865311.jpg

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Image 10 http://2.bp.blogspot.com/_tvjcLbI2DMY/TLXMkeaTY9I/AAAAAAAAAhE/WvzWW5BAC90/s 1600/shoe-maker.jpg

Image 11 http://www.scoot-utc.com/images/ControlRoom.jpg

Image 12 http://www.darcynorman.net/wp-content/uploads/2011/09/251646154_55e331da36.jpg

Image 13 http://3.bp.blogspot.com/BEzgJj4yz4/T7SHbcMxl2I/AAAAAAAASig/ezPTjm5zJrw/s1600/costco.jpg

Image 14 http://kawaii.kawaii.at/img/pink-glitter-pencil-kawaii-hearts-cute-27045-1.jpg

http://www.ryman.co.uk/Catalogue/Ryman/large/global/images/main/09/0960735170.jpg

Image 15 Cartoon: http://hrtoolchest.com/blog/wp-content/uploads/2013/09/gadget_overload.gif

Cables: http://media.treehugger.com/assets/images/2011/10/power-cord-overload.jpg

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http://www.smh.com.au/ffximage/2006/03/31/airport_wideweb__470x306,0.jpg

http://i.dailymail.co.uk/i/pix/2008/07/25/article-1038442-01E4036E00000578-78_468x286.jpg

http://www.colourbox.com/preview/1910800-492117-tired-young-girl-sitting-in-the-airport-waiting-room.jpg

http://guest-travel-writers.com/wp-content/uploads/2011/01/heathrow-crowded.jpg

Image 17 http://image.shutterstock.com/display_pic_with_logo/136654/136654,1251905426,6/stock-photo-interior-f-airport-terminal-building-pudong-shanghai-china-36392224.jpg

http://www.dreamstime.com/airport-interior-thumb19543663.jpg

http://image.shutterstock.com/display_pic_with_logo/572056/572056,1318697877,1/stock-photo-newark-nj-oct-newark-airport-interior-on-october-in-newark-new-jersey-newark-86686342.jpg

http://www.asce.org/uploadedImages/About_Civil_Engineering/Featured_Images/Oslo-Gardermoen-Airport-interior.jpg

http://www.eurocare.org/var/eurocare/storage/images/library/updates/carlsberg_airport_marketing2/76479-16-eng-GB/carlsberg_s_marketing_campaign_at_airport_or_the_flaws_of_self_regulation_large.jpg

http://www.manlyexpress.com.au/images/img_meeting-points01.jpg

Image 18 http://upload.wikimedia.org/wikipedia/commons/thumb/0/01/Airport_Oslo_Gardermoen_-_Meeting_point.jpg/240px-Airport_Oslo_Gardermoen_-_Meeting_point.jpg

http://www.uow.edu.au/content/groups/public/@web/@accomm/documents/mm/uow122706.jpg

http://us.123rf.com/400wm/400/400/offscreen/offscreen0910/offscreen091000013/5737817-meeting-point-for-passengers-at-the-airport.jpg

http://www.travelsignposts.com/Portugal/files/2010/02/IMG_0895.jpg

http://www.italycab.com/page/img/MeetP.jpg

http://www.aia.gr/UserFiles/Image/airport/140128_Meeting_Point.jpg

http://taxirent.nl/wp-content/uploads/2011/08/MeetingPoint_taxisu_211.gif

http://greecefsp2009.files.wordpress.com/2009/03/meeting_point1.jpg?w=510

http://blogs.mcclatchydc.com/.a/6a00d83451c64169e201761749415b970c-pi

Image 19 http://i.telegraph.co.uk/multimedia/archive/01290/airport_1290976c.jpg

http://images.sodahead.com/polls/001682439/5131468825_people20mourning20at20the20airport_answer_2_xlarge.jpeg

http://www.featurepics.com/FI/Thumb300/20080128/People-Traveling-Airport-595825.jpg

http://1.bp.blogspot.com/-C1jpnV_d8PU/Ta1t3hJDVGI/AAAAAAAACOA/BmDKhYjp11Y/s1600/old+couple.jpg

http://i.dailymail.co.uk/i/pix/2011/03/28/article-1370672-0B5EA99F00000578-750_468x286.jpg

http://www.escapeartistes.com/wp-content/uploads/2013/01/5076797788_7d7a3b4eed_b.jpg

http://3.bp.blogspot.com/-TK68lbyxuyw/UHys3LdJ6FI/AAAAAAAAATk/VjHQ7lTlPqo/s1600/IMG_3167.jpg

http://assets.nydailynews.com/polopoly_fs/1.1206212.1353558862!/img/httpImage/image.jpg_gen/derivatives/landscape_635/laguardia-airport.jpg

http://thechive.files.wordpress.com/2012/03/power-outlets-airport-1-e1333037603488.jpg?w=500&h=373

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http://www.heatheronhertravels.com/wp-content/uploads/2009/04/holocaust-memorial-berlin-6jpg.jpg

http://williamsonchong.com/wp/wp-content/uploads/2009-06-09_Digital-Fabrications-Architectural-and-Material-Techniques-Cover.jpg

http://3.bp.blogspot.com/_FMqmvLLwSVk/SBL9roDgSsI/AAAAAAAAAOo/0lpNURRog4M/s400/Origami,+by+FOA.jpg

http://3.bp.blogspot.com/-I34MpDAC-1M/ToSxNx4N3LI/AAAAAAAACeE/OIT9ELdfbtw/s1600/-5.jpg

http://dudye.com/wp-content/uploads/2009/12/SHA-POROSITY-Installation-Detail.jpg

http://static.dezeen.com/uploads/2009/12/dzn_The-Sectionimal-by-gt_2P-03.jpg

http://www.evolo.us/wp-content/uploads/2012/08/Slipstream-1.jpg

http://www.digitalcrafting.dk/wp-content/uploads/2010/08/IMG_4523_b1_2.jpg

Image 22 http://www.lutzhaufschild.com/cw3/assets/product_full/IMG_1050_w.jpg

http://www.lutzhaufschild.com/cw3%2Fassets%2Fproduct_full%2FIMG_0090_R4_Tree_of_Life_detail_Oct.07.jpg

http://www.litracon.hu/images/content/highres/EinHausfuersLeben01_HR.jpg

http://www.trendir.com/archives/litracon-light-transmitting-concrete.jpg http://0.tqn.com/d/govegas/1/0/t/Q/1/chihulybell9.jpg

http://www.chihulygardenandglass.com/sites/default/files/glasshouse-BG3.jpg

http://www.lamberts.de/uploads/pics/wuppert_petruskh_verbeek_02.jpg

http://1-background.com/images/stained-glass-panels/stained-glass-panel-repeating-tile-4.jpg

http://www.purldeco.com/content/themes/default/category_images/cache/stained-glass-film_1_2_1335794897_300x300.jpg

http://www.striking-glass.com/im/08ab.jpg

Image 23 http://assets.curbly.com/photos/0000/0008/6622/pingpongplus.jpg

http://www.fastcodesign.com/multisite_files/codesign/imagecache/960/article_feature/corning-glass.jpeg

http://www.techmonkeymag.com/wp-content/uploads/2012/02/COH_COM_ADMOG_2_EN_dino.jpg

http://blogs.estadao.com.br/a-educacao-no-seculo-21/files/2012/12/Corning_Day_made_of_Glass-2.jpg

http://cdn.androidcommunity.com/wp-content/uploads/2011/03/Screen-shot-2011-03-18-at-1.06.49-PM.png

http://images.businessweek.com/ss/08/01/0128_material/image/led_embedded_film.jpghttp://cdn.inventables.com/technology_application_images/6700/wan_table_1.jpg

http://www.sae.org/dlymagazineimages/6174_6000_ART.jpg

http://www.wired.com/geekdad/wp-content/uploads/2012/11/CrayolaDigitalLightDesigner.jpg

http://mail.free-knowledge.org/tv/jZkHpNnXLB0.jpg

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http://static5.depositphotos.com/1007995/499/i/450/depositphotos_4997111-Business-man--texting.jpg

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Image 41 http://www.syahdiar.org/images/2010/11/essence-uno-luca-nichetto-medium.jpg

Image 42 http://ny-image2.etsy.com/il_430xN.83307802.jpg

Image 43 http://retroartglass.com/store/image/2vl4y/View_All_Glass_Spinning_Glass_Sculpture_Set_Uses _Centrifugal_Force.jpg

Image 44 http://mikegigi.com/fs-bowl.jpg

Image 45 https://encrypted-tbn0.gstatic.com/images?q=tbn:ANd9GcQ_kn4tNgzTGfV u-pXFtqrExhRNeZHCCzn1YlAToFOjVZ-zraEd

Image 46 http://image.made-in-china.com/4f0j00BCtQuGPzRVpk/Curved-Tempering-Glass.jpg

Image 47 http://www.krepcio.com/vitreosity/archives/roeun-grisailleDET_400.jpg

Image48 http://www.cgs.org.uk/sites/default/files/styles/medium_scale/public/events/Steve%20Robinson%20 Grasses%20Panel%20photo%20artist.jpg

Image 49 http://www.lamberts.de/typo3temp/pics/echt_antikglas_03_85774b9533.jpg

Image 50 www.bullseyeglass.com

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http://aerolineasmexicanas.mx/wp-content/uploads/2011/09/mapa-aicm-terminal-1.png

http://aerolineasmexicanas.mx/wp-content/uploads/2011/09/terminal-2-planta-baja2.gif

http://www.constructionphotography.com/ImageThumbs/A148-00616/3/A148-00616_Interior_design_on_walls_of_new_airport_express_railway_station_in_central_Beijing_2009.jpg

http://upload.wikimedia.org/wikipedia/commons/thumb/0/01/Airport_Oslo_Gardermoen_-_Meeting_point.jpg/240px-Airport_Oslo_Gardermoen_-_Meeting_point.jpg

http://www.uow.edu.au/content/groups/public/@web/@accomm/documents/mm/uow122706.jpg

http://us.123rf.com/400wm/400/400/offscreen/offscreen0910/offscreen091000013/5737817-meeting-point-for-passengers-at-the-airport.jpg

http://www.travelsignposts.com/Portugal/files/2010/02/IMG_0895.jpg

http://www.italycab.com/page/img/MeetP.jpg

http://www.aia.gr/UserFiles/Image/airport/140128_Meeting_Point.jpg

http://taxirent.nl/wp-content/uploads/2011/08/MeetingPoint_taxisu_211.gif

http://greecefsp2009.files.wordpress.com/2009/03/meeting_point1.jpg?w=510

http://www.tripadvisor.com/LocationPhotos-g188590-Amsterdam_North_Holland_Province.html#26801313

http://2.bp.blogspot.com/-XpnYwVNhnwA/URDyif2P5LI/AAAAAAAAXcM/a24LsRYFk04/s400/Museum+of+Liverpool+by+3XN09.jpg

http://blogs.mcclatchydc.com/.a/6a00d83451c64169e201761749415b970c-pi

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Appendix A: Characteristics of glass

Materials and their particular properties make design multi-sensory; we not only see the material surfaces, but we also use all the senses. As Kolarevic stated, "material effects are not only visual effects; they are experiential effects" (Kolarevic, 2008).

Vision

Normally, our first appreciation of glass objects comes through vision, which allows us to appreciate different characteristics such as size, color, and shape. The shape of glass depends directly on its manufacturing process.

A full description of glass processes can be found on Appendix G. This is only a brief overview of some of the most common manufacturing processes in the glass field as well as the shapes that result from those processes.

The blowing process: this is used to make hollow, thin-walled glass items such as bottles and flasks, and is similar to blow molding of thermoplastics. The main step involved in the production of an ordinary glass bottle by the blowing process is: blown air expands a hollow gob of heated glass against the walls of the mold. These molds are usually coated with a parting agent such as oil or an emulsion to prevent the part from sticking to the mold. The surface finish of the products made by the blowing process is acceptable for most applications. Although is difficult to control the wall thickness of the products, the process is used for high rates of production (www.britglass.org.uk, 2011).

Using this process, rounded shapes and thin walls can be obtained, as can be seen in Image 39.

Image 41: *The blowing process*

Pressing: this process is used to form fairly simple open shapes with good dimensional accuracy. A plunger forces a gob of molten glass into a one-piece or split mold. The process cannot be used on thin-walled parts or closed shapes from which the plunger cannot be retracted. Textures can easily be obtained using this process, as can be seen in Image 40.

Image 42: *The pressing technique*

Centrifugal casting or spinning: this process is used to make symmetrical products. The process is similar to centrifugal casting for metals, and the centrifugal force pushes the molten glass against the mold wall. Symmetrical forms can be obtained using this process, as can be seen in Image A3.

Image 43: *Centrifugal manufacture*

Sagging: this is a process that shapes lightly embossed glass parts such as dishes, lighting diffusers, and sunglass lenses in a shallow mold. The heated glass sheet sags from its own weight and takes on the shape of the mold as it cools. Shallow shapes with little detail can be obtained.

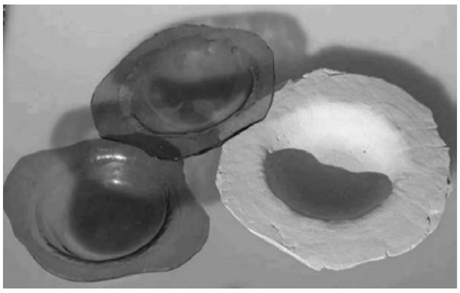


Image 44: *Sagging*

Thermal tempering is a process that chills surfaces, causing tensile stresses to develop on its surfaces. As the rest of the glass sheet cools, it contracts, developing residual compressive surface stresses and interior tensile stresses. The process improves the strength of a glass sheet, and the energy stored from the residual stresses causes tempered glass to shatter into many small pieces when broken. The resulting sheets can be flat or curved, as can be seen in Image 43.

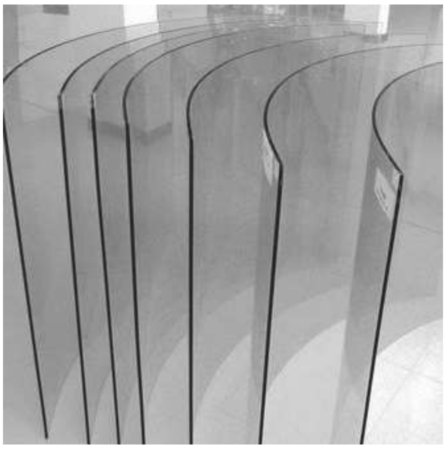


Image 45: *Thermal tempering*

Laminating is another way to strengthen glass, and is commonly used for automotive windows. A tough plastic is sandwiched between two pieces of flat glass. The plastic holds the pieces if the glass is broken (Lesko 2008). Usually the result is a flat, transparent sheet, but a decorative layer can be added, as can be seen in Image 44.

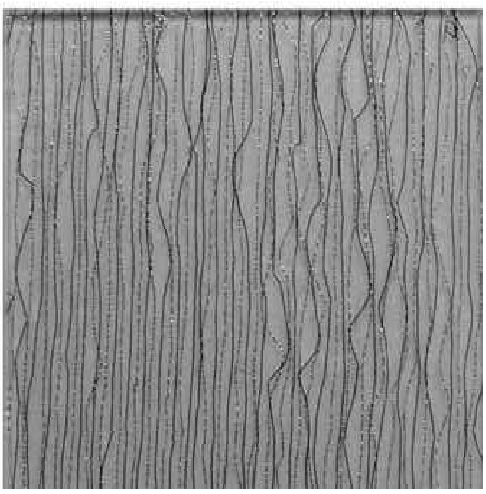


Image 46: *Laminating process*

Besides these “traditional” processes, it is important to point out the current application of CAD/CAM processes for glass manufacturing.

Digitally-based technologies have changed the formal capacities in architecture and design, and as Kolarevic said, “We should understand the digital as a tangible and sensual reality. The beauty and power of digital technologies lies in its universality and its generic quality. Binary data is an abstract entity that can contain anything we want. We consider it a new raw material in our hands that we can creatively manipulate in an infinity variety of ways with a degree of complexity we would not dare attempt by hand” (Kolarevic, 2008).

We can appreciate the formal characteristics of glass through vision, but what happens with the other 4 senses? In order to fully appreciate a material, simply using the sense of sight is usually insufficient. For example, some plastics can have the same optical characteristic of glass, but handling it will quickly give away its real identity, as the user will find a significant difference in terms of weight, temperature to the touch, and the sound produced by tapping (Ashby and Johnson 2002).

Haptics

The importance of the sense of touch has been recognized for centuries. Aristotle believed that touch mediated all sense perception, even vision.

The sense of touch is often called the near sense or the proximal sense. Touch can be extended beyond its normal body bounds with special tools, such as a cane. However, for the most part, if somethigis to be perceived by touch, it must come into contact with the skin (Krishna 2010).

According to Krishna, touching goes beyond mere contact, and tactual perception is inextricably linked to action; what we feel depends on how we explore. An initial division can be made between two subsenses of touch, called cutaneous and kinesthetic. The cutaneous system responds to stimulation of the skin and conveys information about the surface being contacted. The kinesthetic system responds to signals from muscles, tendons, and joints; it conveys a sense of the positions that the limbs take in space (Krishna 2010). There are a lot of everyday glass objects, like tableware, that require a kinesthetic exploration to use.

The haptic system is particularly adept at encoding an object's properties corresponding to texture, hardness, temperature, and weight information (Krishna 2010).

For example, due to its physical and chemical characteristics, glass is normally colder than human skin, we can note its density and we can obtain different textures according to the manufacturing process used. The user can perceive all these characteristics thanks to the haptic sense.

Glass is a curious material full of contradictions in perception; for example, it can be seen as heavy but brittle at the same time, as fancy despite its humble raw material, as cold despite its hot fabrication. In fact, even before touching it, glass is imagined as cold.

Scent

Scent has long influenced human behavior, indicating objects that should either be approached (e.g., food, flowers, potential mates) or avoided (e.g., predators, poisons, gas leaks).

The application of ambient scenting has been reported by a variety of retailers, such as Boomingdales, Sony, Samsung, and others. In a marketing context, approach behaviors could manifest as more positive consumer evaluations, more time spent within the stores, intentions to revisit the stores, the spending of more money in the store, and so on (Krishna 2010).

Glass itself has no perceptible odor, and this is a desirable characteristic, especially in tableware and packaging design because it does not alter the scent of food, beverages or perfume.

Sound

We expect that the sound an object emits will reveal something about the properties of that object. For example, in animals it is expected that volume and pitch correlate to animal size. According to Rochesso, this natural correlation between sound and size is behind much of the work on sound symbolism, where the sounds of the world connote the objects it represents. But humans have also been able to notice patterns occurring in man-made objects and in inanimate objects in the natural world. When hearing unknown sounds, people are able to recognize features of the source, such as shape, material, and hollowness (Krishna 2010).

It also depends of the context and the scale. For example, the sound of a glass breaking is perceived as dangerous, but the clink of a cup is perceived as attractive. The sound of objects made of glass depends on their thickness and the raw materials used.

Taste

According to Krishna, taste is closely linked to the rest of the senses:

Taste and smell: Smell is considered to be one of the most important drivers of taste perception. The combination of smell and taste generates the concept of flavor. Smell has such an important role in taste largely because of the nose`s close proximity to the mouth. We smell the food when it is outside our mouth (orthonasal) and once again when we are actively chewing on the food (Krishna 2010).

Taste and color: Much of the research on the interaction of vision and taste has looked at the impact of product color. DuBose, Cardello, and Maller showed that participants blind to the color of a fruit-flavored drink could accurately identify only 20% of the flavors, compared to 100% when they could see the color of the drink (Krishna 2010).

Taste and sound: Krishna gave us an example, “Visualize yourself biting into a bright green, refreshingly cold stalk of celery. What if one important element was missing, the audible crunch? Undoubtedly this would affect your perceptions of the celery, both in perceived freshness and in actual perceived taste” (Krishna 2010).

Taste and haptics: Krishna and Morris explored the effect of an extrinsic cue, product haptics, on taste perception. In a series of experiments, they showed that the haptic quality of glasses from which water and other drinks are consumed can affect taste perception, for example, water from a firm disposable glass tastes better than water from a flimsy disposable glass (Krishna 2010).

Glass does not react chemically with the beverage or food contained, so it does not alter the taste. This is a highly desirable characteristic in food packaging and tableware.

In order to illustrate the previous concepts, I would like now to use a wine glass as an example. This is an object in which each of the five senses play a practically equal, important role. At first, the approach to the object takes place through sight, and in this phase the user can appreciate the formal characteristics of the wine glass (shape, symmetry, ornamentation, etc.) One of the characteristics of glass, transparency, plays here a primordial role, as it allows the user to see the color of the wine. In a second instance, there is a haptic approach to the object: the user takes the wine glass and can feel the coldness of the glass against their skin. Upon returning the wine glass to the table, the characteristic ring of the material can be heard. Lifting the wine glass again and bringing it near the nose, the user can smell the wine without any interference, as one of the characteristics of glass is that it is inert and does not react with the contained substance (with scarce exceptions, such as some acids). As the wine glass is taken to the mouth, there is again a haptic approximation to the object, and at last the sense of taste enables the user to fully appreciate the flavor of the wine, as glass is also inert with regard to taste.

This series of approaches could not be possible with any other material: metal and ceramics are not transparent and therefore do not allow viewing of the contents, wood is not inert and would affect the odor and taste of wine, and plastic does not provide the same sound as a wine glass.

Perceived characteristics of glass

Besides their physical and chemical characteristics, materials and surfaces have languages of their own. For example, stone speaks of its distant geological origins, its durability, and its inherent symbolism of permanence, bronze evokes the extreme heat of its manufacture, and wood speaks of its previous life as a tree (Juhani Pallasmaa, as cited in Kolarevic, 2008).So, what can glass tell us?

Silvia Levenson said that “Glass is not a neutral material, but a very powerful medium of communication. I see it as a metaphor for transparency, for feeling and revealing emotions. It is a wonderful material that is both beautiful and treacherous” (Craig 2008). On the other hand, Kiki Smith said, “I use glass as a narrative medium. Glass is strong and fragile, hot and cold” (Craig 2008).

Material effects are also physical and perceptual: how the material looks matters as much as how the material performs structurally, thermally, acoustically, etc. Materials can be manufactured mechanically through several processes, but, in the end, they are used to affect the perceptions and experience of the forms, surfaces, and spaces; they can embody meanings and evoke feelings (Kolarevic, 2008).

As Toshiko Mori noted, “By understanding materials’ basic properties, pushing their limits for greater performance and at the same time being aware of their aesthetic values and psychological effects, an essential design role can be regained and expanded” (As cited in Kolarevic, 2008).

Appendix B: Color in Glass

First of all, it is important to point out that the apparent color of glass is the sum of the color of the glass itself plus the color of incident light (natural or artificial), plus the color of objects seen through the glass objects (curtains, blinds, etc), plus the color of reflected objects (sky, clouds, or other buildings). Having said that, I will now describe how the color of the glass itself is obtained.

The color of the glass may be a body color, or it may have been applied to the glass surface as an enamel or stain. Particularly intense colors, such as the deep red produced by copper in glass, are often applied as “flashing”, a thin coating layer on a thicker, relatively colorless glass base (Frank 1982).

Some glass is a deep green color; usually this is not intentional but arises as a result of iron as an unavoidable impurity in the raw materials. Sand, even the sand we call “white sand”, is usually not white at all, but a brownish color. Most of this brown is due to iron oxides which end up in the glass, coloring it with a greenish tint.

Because of lack of chemical knowledge, the old glass-makers could not identify coloring agents uniquely. Recipes and processes were closely guarded secrets at least up to the 19th century, and were handed down from generation to generation. As the glass itself could not be analyzed at that time in history, these recipes were a commercial advantage and a trade secret.

The colors obtained by the medieval glass-makers were determined by many factors, such as the purity of their raw materials, the times and temperatures of melting, and reducing or oxidizing furnace atmospheres, over which they had little control, and therefore they must often have selected from available colors rather than being able to determine the colors in advance. Glass makers were advised that if they were able to manufacture a special color, they should make as big a production run as possible in order to keep it in stock.

The difference between soda and potash was finally made clear in the late 18th century, when methods of chemical analysis were developed, and when new elements such as uranium were discovered which could be used for the coloring of glass; the new chemical knowledge was quickly applied to glass making processes (Frank 1982).

Currently, various metal oxides are added to glass during the manufacturing process to get different colors.

Blue: It is obtained using cobalt oxide (CoO), and cobalt carbonate (CoCO3) can also be used.

Brown: This color is achieved with nickel oxide (NiO).

Green: It is achieved using chromium oxide (CrO) or potassium bicarbonate (K2CrO4).

Purple: this color is obtained using manganese oxide (MnO2) or potassium permanganate (KMnO8).

Red: This is achieved using chloroauric acid (HAuCl).

Yellow: This is obtained from iron oxide (FeO). The “yellow silver” requires nitrate (Ag NO) and chloride (Ag CI) of gold. Certain shades of yellow are achieved with sulfur, but carbonate also offers shades of that color.

Another way of applying color in the glass is through the use of enamels, grisaille, or inclusions.

Inclusions

This technique consists of putting a material between two flat glass sheets. Different materials can be used as inclusions, such as copper, silver, gold, iron, tin, or organic materials. Organic materials do not remain after glass goes to kiln, but leave a translucent trail.

Grisaille

This technique has been used since ancient times in the development of stained glass, and although it has been refined through the years its basic procedures are the same. This technique consists of paint on a glass sheet using pigments derived from metal oxides such as those from iron and cobalt.

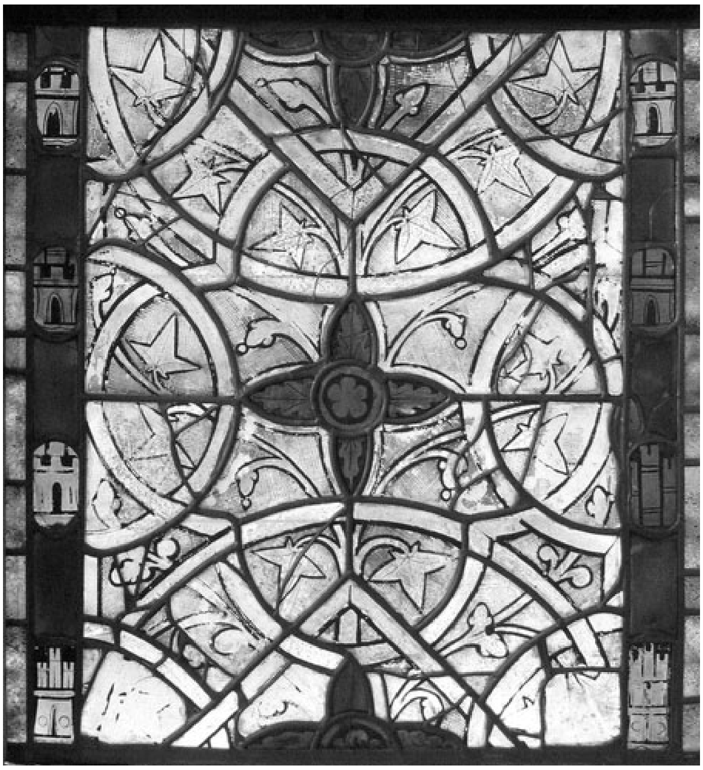


Image 47: *An example of the use of grisailles.*

Enamels

This technique consists of paint on a glass sheet using lead glass powder finely ground and agglomerated with water, oil, or ethylene glycol. Ethylene glycol provides a drying capacity as fast as acrylic, and the use of water achieves a watercolor paint effect. Finally, the oil gives a very thick consistency without losing transparency.

Image 48: *An example of the use of enamels on glass*

Finally In addition to color, texture is another characteristic of glass that must be mentioned.

Glass may be homogeneous or contain seed (small bubbles), striae (streaks with a different refractive index from the rest of the glass), cord (thicker streaks) or stones (opaque inclusions).

Image 49: *Seed glass*

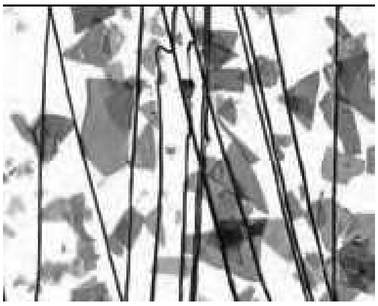


Image 50: *Glass with opaque inclusions*

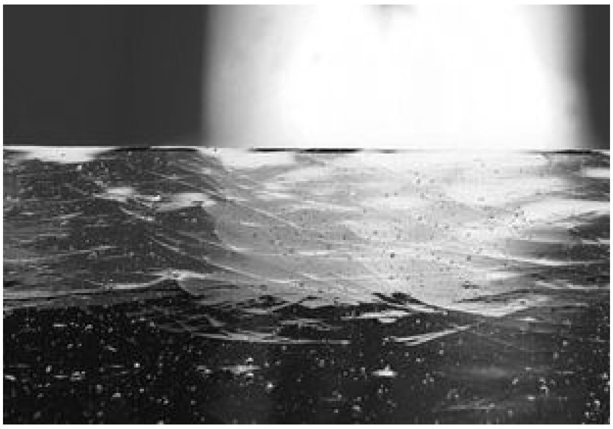


Image 51: *Striae glass*

The seed imprisoned in rigid glass is the result of chemical reactions occurring during its original melting. The process of removal is known as refining. Nowadays, with better control of temperature and advanced melting techniques, it is possible to obtain bubble-free glass, but old glass often contains many bubbles. (Lefteri 2002).

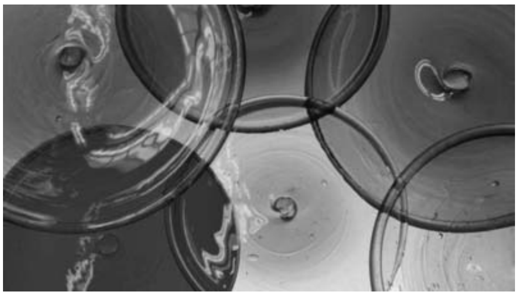


Image 52: *Crown glass, also known as bullseye glass.*

Stones in the glass can be unmelted batch materials, bits of the melting crucible which have been broken away, accidental inclusions or devitrification products, indicating that the glass was held in a critical temperature range for too long during melting (Lefteri 2002).

Appendix C: Brief history of glass

So far I have talked about the physical and chemical characteristics of glass, but at this point I want to explore the historical relationship between human beings and glass.

The history of glass is extensive, and different authors have explored this subject in depth. This thesis offers just an overview of the most significant developments, and its objective is to identify the milestones in glass-making and their main consequences.

Ancient precedents

Natural glass

According to Diamond, if one consider obsidian (a material of volcanic origin also known as hyalopsite or Iceland agate) and quartz as natural glass, then it has to be mentioned that cutting tools or spearheads made of obsidian and tektites (naturally-formed glasses of other origin), are believed to have been used by stone-age man.

Some Meso-American cultures developed highly specialized tools like arrow points and knives out of obsidian, and they also they also developed artistic sculptures using quartz (Diamond 1953).

No one is certain where, when, or how synthetic glass originated, but references to it by Pliny the Elder can be found. According to him, glass was first discovered by the Phoenicians, by accident, when they were cooking at the beach.However, some researchers have shown that glass is considerably older than the Phoenicians, and contemporary scientists are convinced that no open fire can create the degree of heat necessary to produce glass.

Pre-Roman glass

Some researchers such as Frank have found evidence of glazed steatite and faience objects that were made in northern Mesopotamia in the 5th millennium BC and exported to other parts of the ancient East, including Egypt, where the art of glazing objects may have been introduced towards the end of the 4th millennium BC. A few glass beads have been found in 6th Dynasty Egyptian tombs, but glass vessels, formed on a removable core, appeared suddenly around 1500 BC in northern Mesopotamia. Molded objects were also made and exported from here to Asia Minor, Syria, Palestine, Cyprus, Egypt, and the Mycenaean sites in mainland Greece (Frank 1982).

According to Macfarlane the earliest forms of glass were not transparent. There are a number of recovered glass objects which were made approximately about 1500 BC. At this time the "core-formed" technique was developed: a stick was covered with clay, then dipped into a crucible of heated glass. After cooling, the stick was pulled out and the clay scraped away. At that point glass making extended along much of the eastern part of the Mediterranean, and, through Phoenician merchants, was spread through the Greek islands and North Africa. In this period glass was used to glaze pottery, to make jewelry and to make small containers. Somewhere between 1500 BC and 0 AD, glass making techniques spread to East Asia (Macfarlane 2002).

Frank said that early Egyptian vessel manufacturing passed through a long formative stage, and it was only in the last decade of the 15th century BC that the industry began to grow. In the 14th century BC mature industries were in existence in both Egypt and Mesopotamia and glass making flourished, but by about 1200 BC people from Libya and Asia started to threaten the Egyptian state; internal conditions were also unsettled, and the industry there declined. Glass making was kept alive by the Syrians, and Syria and Mesopotamia became the two main centers of glass manufacturing when the revival began during the 9th century BC. Phoenicians traded overseas, spreading the products of the glass makers, among other things, throughout the ancient world. Glass making centers grew up in Cyprus, Rhodes, and the Italian peninsula; in the 5th century BC either this industry or its products spread to the region around modern Venice and up into present-day Austria (Frank 1982).

To Macfarlane glass making in Mesopotamia declined at the end of the 4th century BC following the conquest of Alexander the Great, but the Syrian industry flourished, a specialty being plain, molded monochrome bowls produced in a range of colors. In 332 BC Alexander founded the city of Alexandria, and here the Egyptian glass industry again prospered for the first time since the 11th century BC. Alexandrians may have introduced their new techniques into the Italian peninsula in the 1st century BC, and the Syrians established glass making workshops in northern Italy around the beginning of the Christian Era (Macfarlane 2002).

In this stage of glass history, blown glass techniques were developed. One can think of the invention of glassblowing as the first great revolution in glass making.

Roman glass

With its conquests, trade relations, road-building, and effective political and economical administration, the Roman Empire created the conditions for the flourishing of glassworks across Western Europe and the Mediterranean. In Rome, glass was cheap, and every part of the Empire could be supplied with it. Rubbish heaps suggest that glass utensils where thrown away when only slightly damaged, as it was easier to buy a new one than repair the old (Macfarlane 2002).

According to Macfarlane, In Rome, window glass was apparently made by casting. Probably the slow development of window glass in Italy was due to the warm climate and the use of mica, alabaster, and shell as cheaper alternatives. It was in northern Europe that window technology developed and flourished after the fall of Rome (Macfarlane 2002). Other authors have noted that Romans began to use glass for architectural purposes with the discovery of clear glass (through the introduction of manganese oxide) in Alexandria around 100 AD (www.britglass.org.uk, 2011). Cast-glass windows, albeit with poor optical qualities, thus began to appear in the most important buildings in Rome and the most luxurious villas of Herculaneum and Pompeii (www.britglass.org.uk, 2011).

Archeological investigations have uncovered that the Romans knew how to make glass mirrors, yet metal mirrors were preferred.

Many different methods of decoration were employed: the walls of a mold were often carved so that glass blown into it bore the carved design in relief. The Romans also knew how to paint their glassware with gilt and enamel, how to add studs or raised lumps of glass to a glass surface and how to encase a decorated surface in a gleaming protective coat of nearly transparent glass. A deeper description of ancient manufacturing techniques can be found in Appendix F.

To Frank, the Romans produced a relatively stable soda glass, while medieval glass (where the alkali was usually potash) was more susceptible to corrosive attack, and this is the reason why medieval glass is harder to find than Roman glass (Frank 1982).

The secret of glass making came to Britain with the Romans. However, the skills and technology required to make glass were closely guarded by the Romans, and it was not until the Roman Empire disintegrated that skills for glass making spread throughout Europe. (www.britglass.org.uk, 2011).

Medieval glass

According to Frank, the existence of widely dispersed centers of glass making helped the glass industry to survive when the Roman Empire started to decline. Glass making continued in the valleys of the Rhine and the Rhone, although many workers went to Italy. Although the industry as a whole survived, some techniques went into a decline. The new Teutonic patrons probably demanded simpler, plainer shapes, and the knowledge of many complex Roman techniques was lost. On the other hand, in the East, the industry continued to flourish after the Islamic conquest, and the arts of painting, enameling, and gilding glass developed (Frank 1982).

Macfarlane argued that there is no substantial evidence of glass objects in the medieval era due to several reasons: firstly, the development of Christianity meant that very few objects, including glass ones, were now placed in graves, the major source of Roman glass artifacts. Secondly, it is known that broken glass was collected for recycling, and thirdly, much of the glass in Europe after the 9th or 10th century was made using potash, which was made made from the ashes of woodland plants such as bracken and beechwood, rather than from marine plants. The glass resulting from this mixture was not as stable as the Roman glass, and therefore when buried in especially acidic soil, it tended to decompose (Macfarlane 2002).

Frank said that the ingredients used by the medieval Western glass-makers were almost the same as those employed by the Romans: sand containing shell provided silica and lime while the soda (sodium carbonate), which was used as a flux to lower the viscosity of the resultant glass, would be present in the ash of sea plants obtained from the Mediterranean coasts. However, around the end of the 10th century AD there was a fairly rapid switch in the north-western area of the former Roman Empire to using potash (potassium carbonate) as a flux, obtained from bracken and other woodland sources such as beech wood. The glass makers could easily obtain these materials on their travels, as the woodlands were far more extensive then than they are today, and glass making centers were established throughout such wooded regions as Germany and Bohemia. After the tenth century this potash glass became characteristic of central Europe, whilst soda glass continued to be made in the coastal regions (Frank 1982).

According to Frank, the church was an important factor in the development of the glass in the Middle-Ages. With its monopoly of production and collection of manuscripts, the church acted as a recorder and preserver of the methods of glass manufacture. It was also a rich patron, needing glass for the windows of its buildings in great quantities. By 1000 AD, painted glass is mentioned quite frequently in church records; for example, the 1st Benedictine Monastery at Monte Casino in 1066.

By the end of the 10th century AD conditions in Europe were becoming more settled, and church building began to flourish. In the early 12th century AD, the introduction of the Gothic style with its pointed arch and, later, flying buttresses, took much of the stress off the walls, enabling the builder to construct larger windows which they filled with panes of glass in vivid colors. These windows not only added to the beauty of the churches, they also fulfilled theological and didactic purposes, reflecting the idea of God as the source of perfect light and explaining the Bible stories in simple and dramatic pictures to people who could not read (Frank 1982).We can see here an example of glass as a message transmitter, or form of media.

Venetian glass

To Diamond, the Venice Period is known as the second Golden Age of Glass. Venice had almost everything for successful glass industry: the Venetian islands were composed of silica-rich sand, forests on the hills provided the fuel, it was a center of Renaissance art, it was equipped to send ships to different markets, and craftsmen from Syria arrived at that time (Diamond 1953).

Venice became a dominant influence in European glass making for the next 200 years. Glass was made in Venice from the 10th century, but in 1291 the glass-makers had to move to the island of Murano, because of the fire risk in Venice itself. This isolation and concentration favored the development of a powerful guild of glass makers, which had both good and bad effects: the glass makers enjoyed many privileges and could experiment with new designs and compositions, but they were not allowed to take their secrets from the island. Those who did so were often hunted down and killed (Frank 1982). By the end of the 16th century, 3,000 of the island's 7,000 inhabitants were involved in some way in the glass making industry (www.britglass.org.uk, 2011).

Diamond said that in the middle of the 15th century, Venice seemed impregnable, but by the end of that same century its strength was weakening. Turkey threatened its sea traffic, while France beset it by land. By the beginning of the 17thcentury Venice was losing its position as glass maker leader. but its influence remained predominant until the end of the 17th century (Diamond 1953).

Venetian techniques

Venetians managed to develop a glass as clear as rock crystal which could be blown very thin; it was known as *crystallo*, a word first mentioned in 1409. It was thin, almost weightless, and free from flaws and color (Macfarlane 2002). They also discovered how to produce very good glass in a variety of colors and to decorate with gilding and enamels, techniques probably learnt from Eastern refugees (Frank 1982). Venetians also used millefiori as decoration, as well as spun glass, molded figures applied to the outside of a vase or goblet (Diamond 1953).

Antonio Neri wrote *L'arte Vetraria* in 1612. He was a glass maker who published the first systematic account of the preparation and treatment of raw materials for glass-making, together with directions for melting a wide variety of glasses. During the next 200 years this influential work ran through many editions, being annotated and translated into several languages(Frank 1982).

European glass after Venice

Glass in Britain

Frank stated that although extensive finds of both Roman and Anglo-Saxon glass have been made in England, it is uncertain how much of it was produced there, and how much was brought from abroad. However, glass was made in England in medieval times. The medieval English glass industry was probably started by glassmakers from France. The industry was rather backward in comparison with its French counterpart. The industry survived in a quiet way: wood for fuel and other raw materials were plentiful, and the manufacture, requiring little in the way of capital equipment, could often be fitted into the farming year as a source of extra income (Frank 1982).

Diamond said that in 1615, glass-houses were prohibited from using any wood as fuel, because England´s Navy, largest in the world at that time, needed great quantities of wood. As a result, a new furnace that could use coal instead of wood was developed, and glass making became an urban industry (Diamond 1953).

To Frank, the opportunity for fresh advances in the English glass industry coincided with the decline in popularity of the elaborate Venetian styles which had dominated European tastes for so long. Starting in the second half of the17th century various types of glass were developed in England, culminating in heavy lead crystal glass (Frank 1982).

Although lead had been used since ancient times in glass, crystal glass containing lead was developed by George Ravenscroft, who started his experiments in London in 1673. He patented a remarkable lead glass in the late 17th Century made from potash, lead oxide, and calcined flints; these ingredients produced a brilliant glass with a high refractive index which was very well suited for deep cutting and engraving (Frank 1982).This new glass could be mass produced.

To Macfarlane these developments brought a major milestone in glass making development, with multiple consequences. One important consequence of this new glass was the development of the microscope. Lead glass had different light-bending properties than Venetian glass, but when used in combination, it enabled the development of powerful microscopes in the 18th century which were able to reveal details of bacteria (Macfarlane 2002).

Another consequence of this development was that the British glass industry achieved a leading position in the 18th century which it held for the next 100 years. However, it is necessary to point out that although Britain was a leading manufacturer, every country in Europe was making more glass, and it even passed between countries before completion, such as goblets sent from England to Holland for engraving prior to re-importation and sale (Frank 1982).

German and Bohemian glass

Elaborate carving on rock crystal had long been a specialty of the Bohemians, and towards the end of the 17th century they developed a heavy, clear, potash-lime glass, similar in appearance to natural rock crystal, which could be blown into substantial vessels and then decorated in a similar manner. According to Frank, the glass, the skill of the cutters, and the artistic climate of the time combined to produce fine pieces which were sold by well-organized marketing groups throughout Europe (Frank 1982).

Colored glass was also developed to a high degree by the Germans. As Frank said, a notable experimenter of the time was Johann Kunckel, the director of the glassmaking house of the elector of Brandenburg in the 1670s, who was the first to develop and describe a reliable formula for the preparation of rich, ruby-red glass, using gold chloride as the coloring agent. He also produced an opaque white “porcelain glass” made by adding burnt bone or horn, which contained phosphates, as the opacifier. This became very popular during the 18th century, when objects made in imitation of true porcelain became fashionable (Frank 1982).

Glass in France

As Diamond stated, in 1688 in France, a new process was developed for the production of plate glass, principally for use in mirrors, whose optical qualities had until then left much to be desired. The molten glass was poured onto a special table and rolled out flat. After cooling, the plate glass was ground on large round tables by means of rotating cast iron discs and increasingly fine abrasive sands, and then polished using felt disks. The result of this "plate pouring" process was flat glass with good optical transmission qualities. When coated on one side with a reflective, low-melt-point metal, high-quality mirrors could be produced.

France also took steps to promote its own glass industry and to attract glass experts from Venice; the government placed heavy duties on glass imports, and offered Venetian glass makers a number of incentives: for example, a total exemption from taxes.

The wine industry of France also encouraged the glass makers, who early on turned to specialization in bottles of many shapes and colors (Diamond 1953).

So far I have mainly talked about glass development in Europe, but what was happening in other parts of the world? Now I will briefly mention glass development in Asia and America.

Glass in the East

According to Macfarlane , after the collapse of the Roman Empire, the centre of glass making shifted back to the eastern Mediterranean: Syria, Egypt, Iran, and Iraq. Techniques included blowing, casting and pressing wheel-cutting, and stamped and applied decoration (Macfarlane 2002).

In the 7th century, as part of the spread of Islamic civilization, the Arabs destroyed the Sassanian Empire, but the glass industry was not extinguished. Hence, since Islam had also absorbed two other great areas of glass making, the Syro-Palestinian and the Egyptian, the new civilization was heir to many of the most advanced techniques of glass making (Macfarlane 2002).

To Macfarlane , it appears that there was only a very limited development of window glass, which was hardly used in the traditional houses of the Middle East where it was important that air circulated in the hot season (Macfarlane 2002).

As Macfarlane stated, the Mongol invasions destroyed the flourishing glass industry in Kievan Russia in the early 12th century, and the flourishing Persian industry was nearly all destroyed by Genghis Khan in the early 13th century. The next wave of destruction occurred in the 14th century. The destruction of glassmaking houses and the deportation of the glass makers from Damascus by Timur in 1400 more or less put an end to the golden period of Islamic glass making, but the decline in quality and quantity had in fact, started about 50 years before Timur. Little glass of any quality was produced in Syria or the neighboring regions after 1400. The glass industry had simply died out, and it was Venice that began to fulfill the need for luxury glass (Macfarlane 2002).

Arabic world

According to Macfarlane , by the 9th century, Arabic thinkers had available reflecting devices, mirrors, and refracting tools which were primarily glass bubbles with a liquid such as water in them. The Romans had used these water-filled glasses, and both Pliny and Seneca referred to them. Glass instruments were vital in the period when Islamic experimentation was at its peak, between the 9th and 12th centuries. In about 984 Ibn sahel wrote a treatise on burning-glasses and other kinds of mirror (Macfarlane 2002).

Mosque lamps (actually lanterns) for use in schools and mosques were particularly important, with the nearest equivalent in their symbolism and widespread use to being growth of stained glass in western European churches. They illustrated the words of the Koran, “Allah is the Light of the heavens and the earth. The likeness of His light is as a niche, in which is a lamp. The lamp is in a glass, the glass as if it were a shining star” (Macfarlane 2002). One can note here again the use of glass as a symbol, as well as a means to express a message.

India

According to Macfarlane, in the several thousand years before the birth of Christ there appears to have been a widespread knowledge of glass, but its use was mainly for decoration. Early Indian craftsmen made glass beads, bangles, seals, and discs. From the golden period of Guptas, from about 450 AD, the glass industry in India declined to a point where it hardly existed a thousand years later. In the Bahmani period (1435-1518) there was a small revival (Macfarlane 2002).

Beads and bowls and bangles were produced, but there was an absence of windows, mirrors, lenses, spectacles, and in widespread use of glass for drinking vessels. In the Mughal period, Persian craftsmen were brought to court and glass was manufactured. Clear glass was uncommon; usually it was of a deep copper blue and ornamented with flowers and other decorations. Hukkah bowls ("hubble bubble") were decorated with glass, and some bowls and spittoons of glass were made. It is interesting to note that while glass began to be used for mirrors, it was used on the back of a metal mirror for decoration and was usually green or light brown in imitation of jade (Macfarlane 2002).

As Macfarlane stated, in the 19th century there was quite a large local glass industry, although it seems that the main products were bangles and vessels and little evidence is to be found of the making of mirrors, window panes, spectacles, lenses, etc. The quality of Indian glass was a problem during this period, as it was full of impurities. This had various consequences: the lack of transparency led to demand for superior foreign glass, and particularly from the later 17th century for English lead glass, so that the local industry was almost crushed. While Indians had a full knowledge of all the techniques of glass making, they hardly developed an industry, but as

Macfarlane stated, India did not need glass for several reasons: firstly, it had an ancient and very widespread pottery tradition, and cheap pots and drinking vessels dealt with the storage and drinking needs better than costly glass vessels. Secondly, its climate did not make glass windows a high priority, so flat glass was not developed. Thirdly, it had plenty of good brass and other metals for mirror-making. Another thing that may have influenced the poor development of glass in India is that glass-makers had a low position(Macfarlane 2002).

China

To Macfarlane China is a civilization that has produced some of the most skilled craftsmen in several fields, like pottery, metal working, print-making, and weaving, but these craftsmen contributed almost nothing to the field of glass making.

The art of glass-casting was mastered in the Han period (206 BC-AD 220), when ritual objects and jewelry were made. The next major turning point was the introduction of glass-blowing techniques. At first blown-glass objects were imported, but from the 5th century, native glass-blowing was being undertaken. During the next thousand years there was a mixture of some native manufacturing and a good deal of importation of first Roman, and later Islamic and European glass. According to Macfarlane, in China glass was seen very largely as an inferior substitute for precious and scarce substances, not as a valuable material in its own right. It was mainly used to imitate precious stones(Macfarlane 2002).

Macfarlane stated that the poor development of glass in China was probably because the status of glass and of glass-makers was a low one. Another factor was that southern China has a warm climate, so glass windows can be substituted with oiled paper. On the other hand, one of the principal uses of glass was the fabrication of containers and vessels of various kinds, and the Chinese had a big porcelain industry(Macfarlane 2002).

As Macfarlane argued, Chinese pottery has grown to its predominant position because of the fortuitous presence of two different materials in China. There were large deposits of kaolin and petuntse near to each other. The kaolin provides the body of the object, and the petuntse acts as a flux which will cause over-glaze colors to vitrify. It was hence possible to make an excellent hard, dense, beautiful and translucent ceramic. Meanwhile, in Western Europe, these substances were not available, either in the same high quality or quantity. Instead there were other clays out of which a less sophisticated pottery tradition emerged (Macfarlane 2002).We can see that the cultural context has a big impact in technological development.

In China, glass technologies such as the making of colored and plain glass, glass blowing, and the use of lead and barium, were all known before 800 AD, yet there was little interest in glass from then on until the brief burst of enthusiasm under the impetus of the Jesuits between about 1670 and 1760, which again faded away for a century or so. Thus, over much of the period between about 800 and 1650, which was the precise time of the rush of glass technology first in Islam and then in western Europe, glass technology hardly developed in China (Macfarlane 2002).

Japan

According to Macfarlane, the Japanese knew how to manufacture glass, and could make both colored and colorless varieties. According to Dorothy Blair, glass beads and discs were found, and possibly made, in Japan in the Yayoi period (c.300BC to AD 300). Glass was used for beads, decorations, and religious artifacts, but there is no mention of windows, drinking vessels, or mirrors (Macfarlane 2002). In the Heian period (794-1185) glass making declined, yet there were still some examples of beads and inlaid glass (Macfarlane 2002).

To Macfarlane, while glass beads were still desired, local glass making had decreased greatly by the Kamakura period (1185-1333). There was still some work being done, but glass vessels were probably imported from China. The decline accelerated through the Muromachi period (1333-1568) to a point where glass making was almost nonexistent. Between about the 10th and 16th centuries, glass making practically disappeared in Japan. By the early 19th century, fine glass objects were being made. Various feudal lords, in particular Satsuma, were experimenting with glass manufacture. There was a disruption in glass development caused by the arrival of American and other foreign powers (Macfarlane 2002). After the Meiji restoration (1868), there was a flood of new technologies and uses. The multiple uses of glass for windows, lamps, and many other purposes were well known. Foreign experts were brought in and industrial glass production soon developed. The result was that Japan is today one of the world largest producers of glass, probably ranking second after the United States, producing, among other things, a vast amount of plate glass of very high quality; however, it is important to point out that the Japanese had all the knowledge to make high-quality glass from at least the 8th century and probably before (Macfarlane 2002).

Glass in America

Before the Europeans arrived, there was no glass industry on America (except for work using natural glass like obsidian, quartz, etc). Around 1535 the Spaniards began to make glass in Mexico (Diamond 1953), but the Mexican glass industry never became an important part of the nation´s economy until factories were established in the 20th century.

Frank stated that in the northern part of the continent, it was not until 1608 that the first glass factory was established at Jamestown, Virginia, but it did not prosper, and during the 17th century various others enterprises met with little success. The first to survive for a longer period was the one founded by a German, Caspar Wistar, in 1739 in Salem County, New Jersey, which he and his son operated until the outbreak of the American Revolution. The main purpose of this factory was to supply bottles for rum distillers, but they later began to produce all sorts of things.

There was good-quality sand in Salem County, and other glass making houses opened in the neighborhood, on a much smaller scale, making mostly bottles and window glass. The industry expanded sufficiently during the last two decades of the century to establish itself as a successful American manufacturing process. Skilled workers were brought over from Europe and the local men learned their skills, sources of raw material were located and tested, and thriving works were established along the eastern seaboard (Frank 1982).

According to Frank, by the end of the 18th century, expanding economies in Europe and America were increasing the demand for glass. The establishment of large, well-equipped and adequately financed factories was accompanied by the development of well-organized sales and distribution. However, the most important trigger was the industrial revolution, as well as several advances in the field of chemistry. Improvements also occurred in other batch materials; for example, sands were carefully selected for their purity, including freedom from iron, very small amounts of which give glass a strong green color. These trends have continued to the present day, when pure materials with accurately known compositions are essential to the modern, scientific production of glass(Frank 1982).

To Frank, the increased availability of better raw materials, improved organization of glass works, and more successful exploitation of markets would have been of little use without the development of machines for mass production. It was in North America, where workers were scarce and wages were much higher than in Europe, that means were urgently sought to increase productivity. By the middle of the 19th century acceptable, cheap, pressed glassware was produced there on a massive scale for general consumption as a substitute for the expensive cut-lead-crystal glass (Frank 1982).

According to Diamond, in 1817, Deming Jarves started a glass business on Cape Cod, setting up the Sandwich Manufacturing Company for the making of tableware, and the New England Glass Bottle Company for the manufacturing of ordinary green and black ware. The secret of his success was his large-scale production. His Sandwich glass was not blown but pressed, in a device that had been patented in New England: the hot glass was poured into a mold, pressed down with a plunger, and allowed to cool and harden for a moment. Then the mold was opened, and the glass removed and annealed. This large-scale production reduced the prices of glass tableware goods (Diamond 1953).

In contrast, the rest of the American glass industry was still basically a craft industry, probably because there was a shortage of labor with sufficient skills and technical knowledge, a lack of processes which could facilitate production on a large scale, and a reluctance to adopt new methods (Frank 1982).

Nevertheless, by the 1880s, glass making was approaching a technological revolution. The basic features of precision machinery had been developed. Tank furnaces developed by Friedrich Siemens, in which glass could be melted continuously on a large scale (Frank 1982).

In 1891, Michael J. Owens invented a machine that automatically opened and closed the molds for mold-blown glass. He also invented an automatic bottle-blowing machine (Diamond 1953).

In 1903, J.H. Lubbers, who had been a window-glass flattener, invented a machine for blowing glass cylinders. This machine could make tubes 30” diameter and 40 feet long. The tubes still had to be flattened by hand, so they were wavy and distorted everything seen through them, but the result was cheaper flat glass, and so windows became bigger and more numerous as a result (Diamond 1953).

As Diamond stated, in Belgium (at about the time the First World War began) Emile Fourcault invented a machine where molten glass in a huge tank was forced upward, through a slot in a block of fire clay. It was cooled as soon as it emerged from the slot, and drawn further upward between asbestos-covered steel rollers. The cooling glass sheet always pulled more glass behind it so that a wide glass ribbon moved upward in a steady stream. When it reached the top of a tower rising 2 or 3 stories high above the furnace, it was cut off in big sheets. These sheets had no signs of distorting waves(Diamond 1953).

According to Diamond, almost at the same time, in the USA, a similar method was invented. Irving Coulburn tried to apply paper technology to the glass industry. There were differences between Coulburn´s method and Fourcault´s method: Coulburn started his ribbon of glass by lowering an iron bar into his metal tank and then drawing it slowly out. Viscous glass clung to it in a solid sheet that lengthened as the bar was drawn up. But Coulburn’s bar drew the glass vertically into the air for only a few feet. Then the rapidly cooled glass was reheated by jets of flame so that it could be bent over a polished steel roller and continue on its way horizontally. Steadily turning rollers bore it straight through the cooling apparatus and kept the sheet moving so that it formed an unbroken ribbon four feet wide from the furnace to the end of the annealing oven, or lear. When it emerged from the lear, at the rate of more than five feet per minute, it was ready to be cut and boxed for shipment (Diamond 1953).

The float process developed after the Second World War by Britain's Pilkington Brothers Ltd., introduced in 1959, combined the brilliant finish of sheet glass with the optical qualities of plate glass. Molten glass, when poured across the surface of a bath of molten tin, spreads and flattens before being drawn horizontally in a continuous ribbon into the annealing zone (Diamond 1953).

Appendix D: Raw materials through history

An interesting fact is that most of today´s glass is essentially the same glass of ancient times: both are made of silica fused or melted together with other ingredients such as soda and lime. Moreover, glass raw materials are so common in earth that glass can be made in almost any part of the world, at low cost, and using basic technologies.

First sources of silica

According to Frank, there are large deposits of soda in some parts of the world, and it was from deposits in Egypt that supplies for the eastern Mediterranean glass industry were obtained until around 700-800 AD. Supplies then became more difficult to obtain, and the ash of a sea marsh plant, barilla, which contained soda, was widely used.

Most Egyptian glass contained substantial amounts of iron, and some authors think that only impure sands such as the sands of the desert could have supplied this (Frank 1982).

Sources of alkali

An alkali is any of the soluble hydroxides of the alkali metals: i.e., lithium, sodium, potassium, rubidium, and cesium. The term “alkali” was originally applied to the ashes of burned sodium- or potassium-bearing plants from which the oxides of sodium and potassium could be leached.

As Frank stated, people have been using alkali for centuries, obtaining it first from the leaching (water solutions) of certain desert earths. In the late 18th century the leaching of wood or seaweed ashes became the chief source of alkali (Frank 1982).

In a few places in the world there are substantial deposits of the mineral form of soda ash, known as natural alkali. The mineral usually occurs as sodium sesquicarbonate, or trona ($Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O$). The United States of America produces much of the world's natural alkali from vast trona deposits in underground mines in Wyoming and from dry lake beds in California.

The manufacture of industrial alkali usually refers to the production of soda ash (Na_2CO_3, commonly known as sodium carbonate) and caustic soda ($NaOH$, known as sodium hydroxide). Other industrial alkalis are potassium hydroxide, potash, and lye. The production of a vast range of consumer goods depends on the use of alkali at some stage; for example, soda ash and caustic soda are essential to the production of glass, soap, rayon and cellophane, paper and pulp, cleansers and detergents, textiles, and water softeners (Encyclopaedia Britannica).

Alkalis for glass-making have been obtained from many different sources in the past, and the compositional complexities of the raw materials make it very difficult to define the places or substances of origin. Up until the medieval period, both in Western Europe and the East, the dominant alkali in ancient glass was soda (Frank 1982).

It is probably natron (a compound containing sodium bicarbonate) from Wadi Natrun, an ancient glass-making site to the north west of Cairo, that was used for glass making; it had been employed from very early times as a detergent, in medicine, and for embalming (Frank 1982).

The other major source of alkali was plant ash. This could produce a soda-or potash-type, depending on the plant composition. Frank said that the Assyrians in the 7th century BC were using this substance for glass making. Their recipes and processes are recorded on clay tablets from the Royal Library of Assur-bani-pal (Frank 1982).

Plant ash could provide sodium and potassium carbonates, calcium and magnesium carbonates, and phosphates; like other alkali sources, a raw material of complex and widely varying composition. This variation is not confined to that between different types of plant (for example, between a coastal plant relatively rich in soda and an inland plant relatively rich in potash). Plants draw their content from the soil, and if this becomes impoverished, or its composition changed, then the content of plants grown in that location will also change, and therefore the composition and features of glass made out of this mixture will change as well (Frank 1982).

R.G. Newton pointed out that the change to beechwood and other inland plant sources resulted in an exceedingly high lime-potash glass with such poor durability that much has vanished and the rest is now in great peril, but there was also a positive side: large and variable amounts of iron and manganese in beechwood ash made it possible to obtain glass in a wide range of colors by varying the melting conditions in the furnace (Frank 1982).

Another source of alkali at this time, and up until the early 19th century, was barilla. It was prepared from coastal plants near Alicante in Spain and was widely exported from the end of the 16th century. Neri expressed a preference for the use of polverine and rochetta (the plant ash from Syria and Egypt) over barilla, which seems to have been exceptionally rich in alkali.

Antonio Neri wrote in 1612 that there was also trades of alkali which presumably had been carried out since ancient times (Frank 1982).

In many inland areas, soda was more difficult to obtain so potash was substituted. Potash is contained in the burnt ash of many plants (bracken and beech wood are typical sources), and so forests that were near a source of clean sand became sites for glass production, the so-called "forest glass". A medieval description of glass making by Teophilus, a German monk writing around 1120 AD, describes glass-making using wood ash (Frank 1982).

Potash glass would typically contain 10-13%potash, and like soda glass, is often accidentally stabilized by the presence of lime and impurities in the raw materials. Even so, potash glass is more subject to disintegration or severe surface weathering due to water than soda glass. The proportions of the major constituents of glass (silica, soda, potash, and lime) are very variable, and different glass-making centers had different customs about the mixes that they used. However, it is often possible nowadays to make a fairly good guess about the place of origin of medieval glass from around Europe or the Middle East by a careful analysis of its constituents (Frank 1982).

A type of seaweed, known as kelp in Britain and varec in France, from the western shores of the British Isles and the coast of France was also burnt to produce an impure alkali for glass-making. This source became increasingly important, and by the end of the 18th century "kelping" was a major industry, only declining in importance as manufactured soda became widely available (Frank 1982).

In England in the 1670s a clear lead glass was developed (a typical composition was 51-60% silica, 28-38%lead oxide, and 9-14% potash) to compete with the Venetian glass that was being imported in large amounts. This new glass was highly successful, producing heavy, robust, but lustrous lenses that enabled substantial improvements in the quality of the images of first telescopes and then microscopes to be achieved (Frank 1982).

Finally, I must mention the glass from Venice. The source of silica for the famous Venetian cristallo glass was the white quartz pebbles from the bed of the river Ticino. These pebbles were roasted in a furnace and then pulverized before being mixed with the soda from barilla, which had itself been purified by dissolving in water and then re-crystallizing it. The choice of these pure raw materials produced a clear and readily-worked glass, but unfortunately the lime (calcium oxide) content was often too low, and the finished articles were rather prone to disintegration over time (Macfarlane 2002).

Appendix E: Commonly-used glass

Soda-lime glass

Soda-lime glass is the most common commercial glass. The chemical and physical properties of soda-lime glass make it ideal for use in windows.

Soda-lime glass containers are practically inert, and so cannot contaminate the contents inside or affect the taste. Their resistance to chemical attack from aqueous solutions is good enough to withstand repeated boiling without any significant changes in the glass surface.

One of the main disadvantages of soda-lime glass is its relatively high thermal expansion. Silica does not expand very much, when heated, but the addition of soda increases the expansion rate, and in general, the higher the soda content of a glass, the poorer will be its resistance to sudden changes of temperature (thermal shock) (Lefteri 2002).

Sodium calcium glass

This glass is mainly made of silica, sodium, and calcium. It melts easily and is one of the cheapest glass types on the market, but one of its drawbacks is its thermal expansion at high temperatures. It is used for the manufacture of incandescent lamps and Christmas ornaments.

The use of a potassium rather than a sodium compound as the alkali in lead glass is preferable for the production of high-quality blown glassware (Frank 1982).

Borosilicate glass

Borosilicate glass (Pyrex) is a hard, heat-resistant glass. It has good resistance to thermal shock; it can withstand high temperatures; it has good resistance to chemical corrosion; it presents a very low coefficient of expansion; and it has excellent resistance to physical shock.

Borosilicate glass is made mainly of silica (70-80%) and boric oxide (7-13%), with smaller amounts of the alkalis (sodium and potassium oxides) and aluminum oxide. This type of glass has a relatively low alkali content; hence its good chemical durability and thermal shock resistance.

Borosilicate glass was developed in the 1890s by Corning Glass Works, but it appeared on the market about 1915 as a general purpose, heat-resistant glass under the name of Pyrex. It is widely used in the chemical industry for laboratory apparatus, for ampoules and other pharmaceutical containers, for various high-intensity lighting applications, and as glass fibers for textile and plastic reinforcement (Lefteri 2002).

Lead glass

Lead glass, also known as lead crystal or lead alkali glass has a high percentage of lead oxide (at least 24%), which replaces the lime. This percentage of lead gives this type of glass a sparkling crystal brilliance that cannot be achieved with soda-lime. This brilliance makes it popular for glasses, decanters, and other decorative objects. Lead glass has a relatively soft surface so that it is easy to decorate by grinding, cutting, and engraving, which highlights its brilliance.

The traditional English full lead crystal contains at least 30% lead oxide (PbO), but any glass containing at least 24% PbO can be described as lead crystal. Glass containing less than 24%

PbO is known simply as crystal glass. The lead is locked into the chemical structure of the glass so that there is no risk to human health.

The properties of lead glass are: high refractive index, which means high clarity, more expensive than soda-lime, and excellent electrical insulating properties. It is typically used for tableware. Lead glass can be used in applications that require radiation shielding because of lead´s ability to absorb gamma rays and other forms of harmful radiation, but the glass must contain at least 65%lead oxide (Lefteri 2002).

Other types of glass by composition

Alkali-barium silicate glass

Glass containing barium is usually used for the screen of TVs.

Aluminosilicate glass

This glass contains 20% aluminum oxide (alumina-Al_2O_3), often including calcium oxide, magnesium oxide, and boric oxide in relatively small amounts, but with only very small amounts of soda or potash. It resists thermal shock and high temperatures. It is used for tungsten-halogen lights because it can withstand temperatures up to 750°C for prolonged periods (Lefteri 2002).

Bioglass

This is a material that that is engineered to work internally with the body in healing and generating new tissue and bone. The usual silica atoms in normal glass hold the atoms in this material together. Bioglass is only 45% silica, compared with 78% in normal glass. This is replaced by larger amounts of calcium, sodium, and phosphorus, which make it more compatible with the body´s immune system. Bioglass works like a fertilizer by assisting in an exchange of molecules when the material comes into contact with body fluids; this then produces a chemical that can physically bond with tissue and bone. Bioglass is important as a biomaterial (Lefteri 2002).

Borate glass

There is a range of glass containing little or no silica which can be used for soldering glass, metals, or ceramics at relatively low temperatures. When used to solder other glass, the solder glass needs to be fluid at temperatures (450-550°C) well below that at which the glass to be sealed will deform. Some types of solder glass do not crystallize or devitrify during the soldering process, and thus the mating surfaces can be reset or separated; this is usually lead borate glass containing 60-90% PbO with relatively small amounts of silica and alumina to improve the chemical durability. Another group consists of glass that is converted partly into crystalline materials when the soldering temperatures are reached, in which case the joints can be separated only by dissolving the layer of solder by chemical means. Such devitrifying solder glass is characterized by its containing up to about 25% zinc oxide. Glass of a slightly different composition (zinc-silicoborate glass) may also be used for protecting silicon semi-conductor components against chemical attack and mechanical damage. Such glass must contain no alkalis (which can influence the semi-conducting properties of the silicon) and should be compatible with silicon in terms of thermal expansion. These materials, known as passivation glass, have assumed considerable importance with the progress in microelectronics (Lefteri 2002).

Chalcogenide glass

This glass can be made without the presence of oxygen (non-oxide glass). Different types may be composed of one or more elements of the sulphur group in the periodic table combined with arsenic, antimony, germanium, and/or the halides (fluorine, chlorine, bromine, iodine). Some of them have the potential to be used as infra-red transmitting materials and as switching devices in computer memories because their conductivity changes abruptly when particular threshold voltage values are exceeded, but most have extremely low softening points and much poorer chemical durability than more conventional glass (Lefteri 2002).

Dichrolam ™

This is a unique material that is made up of hundreds of layers of polymer sheets sandwiched between two layers of glass. This stack of layers takes incoming white light and separates the colors by reflecting back certain color wavelengths so that a series of three dimensional textured patterns can be seen. It is cheaper than dichroic glass, and can be fabricated like any laminated glass sheet. Dichrolam´s typical uses are flooring, partition walls, furniture, lighting, wall tiles, and architectural glass panels (Lefteri 2002).

Foam glass

This is made by fusing a mixture of powered glass and powered carbon. When the mixture is pressed into a mold and heated, it rises to fill the mold in what is in effect a rigid honeycomb: each speck of carbon has become surrounded by a tiny glass bubble. Some 10,000,000 of these bubbles form a cubic foot of this foam, which can be sawed easily. It is a highly efficient thermal insulator and it can support up to 4000 times its own weight (Diamond 1953).

Glass ceramics

Strictly speaking, glass ceramics are neither glass nor ceramic. This material does not contain any crystal, but by controlling and stimulating growth of crystals it is possible to produce a material with the features of ceramic and glass.

It is formed from lithium-aluminum-silicate glass, magnesium-aluminum-silicate, and aluminium-silicate. Glass ceramics have a two-stage manufacturing process; during the first stage raw materials are melted, and the product can be then pressed, blown, rolled, or cast, and then annealed. Up to this point it is virtually the same as normal glass. During the second phase the molded products are subjected to a specific temperature and go through a process known as ceramification, which means that they reform into a polycrystalline material. Its properties are: high thermal shock resistance, high mechanical stability, low thermal conductivity, high temperature stability and durability, extreme heat resistance; excellent heat control, virtually no thermal expansion, and translucence for safety. It is used in space telescopes, missile nose cones, and furnace windows (Lefteri 2002).

Glass concrete

This is recycled glass embedded in a concrete mixture without using resin. It is used in architectural applications. One example is the so-called LiTraCon, created by Aron Losonczi, which is a combination of lightweight optical fibers and concrete. It is usually manufactured in block form, with networks of tiny optic fibers embedded in it. The fibers transmit light from one side of the block to the other while also intermeshing with the concrete´s aggregate materials to reinforce them. Although LiTraCon diffuses light, it still has the strength and durability of concrete. In particular, it has high compressive strength, meaning that it can be safely used for load-bearing structures. Walls made from LiTraCon can be up to 20 meters (66 feet) thick without any loss of light. Although LiTraCon has been dubbed “transparent concrete”, it is not possible to see through it; it is possible, however, to see shadows, movement and light fluctuations (Quinn 2011).

Dichroic glass

Dichroic glass reflects different colors depending on the angle of incidence of light on its surface. This type of glass is produced in a vacuum chamber, where the glass is coated with multiple layers of metallic oxides.

Intelligent glass

This material is made of vanadium dioxide. It allows visible light waves to come in, but reflects infrared light when temperatures are above 29°C. One disadvantage of this material is that it is only available in yellow and green.

Liquid crystal

Liquid crystal is a substance that acts both as a liquid and as a solid, depending on the temperature and pressure. This material is used to fabricate screens and computer monitors; these screens consist of two transparent conductive layers of flat glass, and between them the liquid crystal is set.

Phosphate glass

Most types of glass are good insulators at room temperature, although those with substantial alkali content may be good conductors in the molten state. Conductivity depends mainly on the ability of the alkali ions in the glass to migrate in an electric field. However, some types of glass that do not contain alkalis conduct electrons which jump from one ion to another. This is known as semi-conducting oxide glass and is used particularly in the construction of secondary electron multipliers. Typically they consist of mixtures of vanadium pentoxide (V2O5) and phosphorous pentoxide (P2O5) (Lefteri 2002).

Quartz glass

Fused silica can withstand temperatures of up 1200°C for short periods, and 900°C for a sustained period. This extreme ability makes it very difficult to work and very expensive. Also known as quartz glass or fused quartz, fused silica is one of the most highly heat-resistant materials and is used in the exterior of space shuttles; for example, space shuttle windows are a triple glazed sandwich: the external and middle panes of fused silica glass have aluminum-silicate internal glazing. The properties of quartz glass are: excellent resistance to high temperatures, good thermal resistance, and ultra-low expansion, and can be used for space shuttle windows, furnace sight glass, mirror blanks for astronomical telescopes, and high energy lasers (Lefteri 2002).

Sealing Glass

A wide variety of glass compositions are used to seal metals for electrical and electronic components. Here, the available glass types may be grouped according to their thermal expansion, which must be matched with the thermal expansions of the respective metals so that sealing is possible without excessive strain being induced. For sealing to tungsten in making incandescent and discharge lamps, borosilicate alkaline silicate glass is suitable. With glass designed to seal to Kovar alloy, relatively high contents of boric oxide (approximately 20%) are needed to keep the transformation temperature low, and usually the preferred alkali is potassium oxide so as to ensure high electrical insulation. Where the requirement for electrical insulation is paramount, as in many types of vacuum tube and for the encapsulation of diodes, a variety of lead glass (typically containing between 30% and 60% lead oxide) can be used (www.britglass.org.uk, 2011).

Self-cleaning glass

This glass has a coating of a thin layer of titanium (TiO2) which is activated by factors of weather such as rain, wind, or sun. This coating absorbs ultraviolet light to create a reaction on the surface that breaks down and loosens deposits. When it rains, these deposits are simply washed away. The coating is applied to the glass during the production of the sheets themselves, which means there is no secondary production process. Once windows have been installed, the process of self-cleaning takes several days to take effect, as the coating has to absorb enough UV light to begin to work.

This glass leaves no watermarks, it is cost-effective in larger buildings, it can be single- or double- glazed, it does not weaken with age, it can be used with toughened laminated or bent glass, it can only be used in exterior applications (it needs UV light), and it has a neutral appearance similar to flat glass (Lefteri 2002).

Soluble glass

This glass can be dissolved in water in order to form a viscous liquid. It is used as a flame retardant paint on certain objects.

Vitreous silica

Silica glass or vitreous silica is of considerable technical importance. However, the fact that temperatures above 1500°C are necessary in the melting makes the transparent variety (often known as fused quartz or quartz glass) expensive and difficult to produce. The less expensive alternative for many applications is fused silica, which is melted at somewhat lower temperatures; in this process small glass bubbles remain in the final product, which is therefore not transparent. (Lefteri 2002).

Some other types of glass products currently used in industry.

Animated visual effect

Visual Impact Technology produces a range of laminated glass with an animated visual effect: an "optical techno light visual show". This is made possible by a patented interlayer system sandwiched between two pieces of clear, tinted, annealed glass (Lefteri 2002).

Anti-reflective glass

Normal glass reflects 8% of light, and anti-reflective glass cuts this down to just 1% by applying a non-reflective interference coating which is vacuum-deposited. This process allows the same amount of light transmission but can reduce light reflection (Lefteri 2002).

Cellular glass

This is a material that consists of millions of glass cells tightly sealed and separated by small gaps of air. These two elements together form a thermal insulation barrier. This product is very brittle and susceptible to thermal shock at high temperatures. It is used in places with low temperatures and in installations with moisture problems.

Controlled glass vision

This is a laminated glass made of a plastic film between two panes of float glass. Depending on the angle of vision, the glass changes its appearance from transparent to translucent.

Glass block

These were first introduced in the 1930s and can be used in virtually the same way as ceramic bricks, while allowing for a high degree of transparency and light transmission. The blocks are made from two pieces of pressed glass fused together at a high temperature. The hermetically-sealed blocks are more secure than conventional glazing while maintaining good light transmission (Lefteri 2002).

Fiber-glass

Fiber-glass is the collective term for glass that has been processed into thin strands. It can be divided into three product areas: glass wool or insulating glass, textile fibers, and optical fibers. Glass wool is made from soda-lime glass by the centrifugal spinning of molten glass beads into short threads, and is generally used as building and loft insulation, either alone or combined with mortar or plaster. Fiberglass textiles are used in plastic reinforcement, both in injection moldings and hand lay-up work, and optic fibers are used within a range of industries to carry light. Because optical fibers can transmit light around corners, it can be applied in a diverse range of industries.

Glass fibers, unlike vegetable fibers, do not absorb anything: neither liquids nor odors. Only the surface of glass fibers can be wetted. For this reason, a fibrous glass product cannot swell with moisture, dries quickly, and retains its original dimensions. Since glass cannot rot, glass fibers will not be affected by fungus or other microbial action. The fibers cannot oxidize and are completely fireproof: under sufficient heat the fibers will melt but they will never burn, and they will never smolder and give off smoke or poisonous fumes.

Glass fiber has many uses,from roof insulation to medical equipment, and its composition varies depending on its application. For building insulation and glass wool, the type of glass used is normally soda lime. For textiles, an aluminum-borosilicate glass with very low sodium oxide content is preferred because of its good chemical durability and high softening point. This is also the type of glass fiber used to reinforce plastics to make composites such as protective helmets, boats, piping, car chassis, ropes, car exhausts, and many other items. In recent years, great progress has been made in making optical fibers which can guide light and thus transmit images round corners. These fibers are used in endoscopes for the examination of internal human organs, changeable traffic message signs, and communications technology, without which telephones and the internet as we know them would not be possible.

Optical fiber is a continuous strand of high-refractive glass within a casing of non-refractive glass. It is used to transmit light signals generated by LEDs (light-emitting diodes) and lasers. In 1970 Corning discovered that 2 types of glass were needed, which is now optical fiber has a glass core with a silica sleeve. The purity of the core allows for light to pass unobstructed through the length of the cable, while the sleeve, which has a lower refractive index, stops any light escaping. Optical fiber is flexible, it has good light-guiding properties, it is not affected by electromagnetic interference, it is chemically inert, it has excellent size-to-capacity ratio for carrying information, and it generates cold light for medical applications (Lefteri 2002).

Float glass

This technique was developed in 1952 and consists in the glass being heated and held at a temperature of about 1000°C before it is fed and floated into a long bath of molten tin. A ribbon (a continuous strip of glass) is formed which cools as it flows down the long bath, eventually reaching 600°C. The glass is then fed through a series of rollers until it exits at 200°C. From here the class is cut into sheets and packaged. It has a flat surface, it does not have any distortion, it can be toughened or laminated, it is suitable for acid etching, beveling, and screen printing, and it can be silvered for mirrors (Lefteri 2002). Further in this chapter, a larger description of this process is given.

Glass flakes

These were originally designed to be combined with other materials to reinforce and strengthen on a structural and microscopic level. One of the main industrial applications is as a barrier coating for pipes. The flat glass flakes bond to produce a layer which on a microscopic level acts as an impenetrable blanket. This layering potential is also used to increase the stiffness in plastic moldings. Because there is no set shape or direction to the flakes, they offer more support than strands or glass fibers, which tend to be long, thin, and unidirectional. However, when combined with glass fibers they can give even greater strength, toughness, and stiffness than could be obtained by using fibers or flakes alone. It is chemically inert, it increases chemical resistance, it improves wear and abrasion, it has decorative possibilities, it improves the fire retardant properties, it improves dimensional stability, and it can lower the cost of parts by reducing the amount of resin used. It is typically used as a reinforcement filler to add strength, stability, and durability and to increase fire-retardant properties in plastic moldings (Lefteri 2002).

Glass spheres and microspheres

These spheres are made from a number of different glass types, including soda-lime and aluminum silicate. These hard, perfectly round glass beads are used for road markings, as they add reflectivity as well as being hard-wearing. They improve mold shrinkage, reduce warping, and increase viscosity within plastic-molded parts. Microspheres are also are used as an additive for thermal insulation and to reduce weight.

Glass spheres can be found in sizes ranging from microscopic to 1mm in size, and microspheres are available in a range of densities, most of which look like a fine powder when seen together. Their production is as follows: the raw material starts off at the top of a tower. Droplets then fall past a series of flames, being heated and expanded in the process. This free-falling results in the formation of perfectly round beads. The computer-controlled process is 100% efficient. Every glass bubble is collected and packed at the base of the tower (Lefteri 2002).

Glass tubing

This is used as a starting point for the production of many products, from domestic tableware to fluorescent light tubes. Using mainly bench/lathe work or lampworking techniques as two of the processes to form products from them, the tubes themselves are produced by two main methods: the Danner process and the Vello process. As a semi-finished product, the glass tube is one of the main forms in which glass is bought before undergoing a secondary production process. It is available in round sections as well as an assortment of different shapes (Lefteri 2002).

Luminous glass

Luminous glass is a material developed by Gruppe RE. Gruppe RE was formed by two designers interested in finding new applications for existing materials and technology. Inspired by the phosphorescent ink found in plastic security and safety applications, they have produced a unique design for glass tiles. The tiles offer an alternative to the more common ceramic variety by allowing a greater depth of color possibilities. The screen-printing process they use involves three glass enamels: a first layer of illuminating ink, a second layer of red, and a third layer of turquoise. The three colored enamels are screen-printed onto clear glass tiles and then they go to the kiln at temperatures of 650°-720°C for two to 4 minutes to create a surface with a lasting resilience. This multi-layering creates depth so that in daylight the translucent ink allows the red and turquoise to come through, and in the dark only the phosphorescent element can be seen (Lefteri 2002).

Sandwich fillings

The primary function of double-glazing when it first appeared was to improve sound and thermal insulating properties. Okulux is a German company specializing in insulated glass. Okatech is the brand name for their product range of panels, which incorporate decorative metallic mesh designs sandwiched in the cavity of the glass panels. However, this sandwich filling is not just for decoration, it also reduces solar glare. Other products are Okasolar and Okaflex, two hermetically-sealed designs which incorporate reflective louver blades. In the Okasolar range, the blades are fixed at a pre-determined angle, but in Okaflex, the blades can be adjusted to vary the amount of light or to redirect it upwards on to the ceiling or into the room. Kapilux is a honeycomb glass structure of plastic tubes which diffuse light and insulate (Lefteri 2002).

Security blanket

This can remain in one piece when smashed. This product offers a cost-effective alternative to laminates. It is a sandwich of rolled glass with embedded wire (Lefteri 2002).

Security glazing

This is basically a glass sandwich of two pieces of plate glass joined together with a plastic layer. The plastic layer holds the pieces of glass together if the glass is broken. Together with chemical and thermal tempering, laminating is one of the ways of toughening large areas of sheet glass and making them safe when broken. Unlike toughened glass, drilling and cutting can further process laminated glass.

Bullet-resistant glass is produced by laminating several layers of glass of different thicknesses together with layers of PVB (polyvinyl butyral) plastic film. The first layer is designed to shatter, thereby absorbing the initial impact, with successive layers absorbing the shock waves.

Tempered glass

This is a single heavy sheet of glass heat-treated so that it is strong and resistant to impact and sudden temperature change. This glass must be cut into sheets before it is tempered.

Thin glass

One of the thinnest types of glass in the world at 0.03 mm thick, it is produced by Schott. It is flexible, chemically resistant, presents a good surface for coating, has a good thermal resistance and it is typically used in touch screen displays (Lefteri 2002).

Photosensitive glass

This material has gold or silver ions, which respond to light. Photosensitive glass is used in eyeglass lenses and electronics (Lefteri 2002).

Vision controlled glass.

This laminated glass is made up of two layers of clear or tinted glass. An interlayer of liquid crystal film is sandwiched between them. Passing an electrical current through the film excites the liquid crystals into a state where they align themselves and the glass becomes transparent. When the current is turned off, the crystals relax, diffusing light in all directions and making the glass opaque again. This kind of intelligent glazing could replace traditional windows, walls, and curtains. Properties are: instantaneous adjustable vision, excellent clarity in transparent state, low power consumption, can be laminated for security and soundproofing, can be curved, and can be used outdoors (Lefteri 2002).

Wearable glass

This refers to fabrics that are 54% glass, incorporating glass beads. It was developed by 3M as a safety material for outdoor garments needing a high degree of visibility, and with 30,000 glass beads in every square centimeter, this fabric reflects lights almost perfectly. This material has excellent safety advantages, it is unaffected by temperature variation, it can be dry cleaned, it can be hand cut, die-cut or guillotined, it is available as yarn or fabric, and it can be used for reflective clothes and fashion (Lefteri 2002).

__Overview of emerging glass__

So far I have given some examples of glass currently being used in industry, but now I would like to note some examples of emerging glass which are still in the experiment phase and which despite some attempts, are still not being used on a large scale.

Bioactive glass

Hench pointed out that only 42 years ago, the concept of a material that would not be rejected by living tissues seemed impossible, but since then, bioactive glass has transformed medical and dental technology (Hench 2009).

During the first decade of the 21st century, the concepts of bioactive materials and resorbable materials have converged; bioactive materials are being made resorbable, and resorbable polymers are being made bioactive. Third-generation bioactive glass and inorganic–organic hybrids are being developed to activate genes that stimulate the generation of living tissues (Hench 2009).

Localized therapies for cancer and autoimmune diseases

Most of the medical applications of ceramics and glass have been in the fields of hard tissue replacement or regeneration. An important exception is the pioneering use of radiotherapy glass developed by Professor D. Day et al. For the treatment of liver cancer, in which radioactive particles (microspheres) can be delivered to a target organ using either the blood supply to that organ or direct injection into the tumor (Hench 2009).

Soft tissues

Development of a blood supply, called vascularization, requires a process of proliferation of interconnected blood vessels. This process is termed angiogenesis. Studies have used third-generation, bioactive, resorbable glass composites to enhance vascularization of a regenerated soft tissue construct (Hench 2009).

Dental applications

The first of the advances in the field of dental restorative materials came with the development of advanced glass–ceramic dental restorations. The second example of prevention in health care by the use of glass or glass–ceramics is the use of very small, micrometer-sized particles of bioactive glass to remineralize teeth and to prevent dentinal hypersensitivity: for example, to prevent tooth pain. The commercial material is called NovaMin, and it is labeled as a calcium sodium phosphosilicate compound (Hench 2009).

Liquid crystal helixes.

When the pitch of helical liquid crystals is directed, the light they reflect can be channelled in a controlled wavelength. A consortium of researchers based at Philips Research, the Eindhoven University of Technology in the Netherlands, and the University of Alberta is pioneering techniques that make it possible to direct the liquid crystals in three dimensions. The liquid-crystal helixes can then be used to increase the brightness of powered displays without consuming more energy (Quinn 2011).

Innovative energy storage devices

The concept for a new generation of energy storage devices is based on the use of nanoporous amorphous silica matrices as a template to create electrically conducting carbon monolithic electrodes for assembly into a new generation of supercapacitors (Hench 2009).

Solar cells in films

At present, the majority of building-integrated photo-voltaic (BiPV) components consist of mono-crystalline (MC) silicon wafer solar cells connected in series to produce glass panels (modules) of the appropriate power rating. In the future it is hoped that thin-film (TF) solar cells (a series of active layers deposited onto glass or other appropriate substrates) will become a common facade element (Bahaj, James, and Jentsch 2008).

Other studies presented at the 52th annual conference of the Spanish Society of Ceramic and Glass which looked at using glass at an experimental level and that are particularly interesting for the purposes of this thesis are:

Assessment of coal power plants ashtray ash to determine their use viability (Menendez et al. 2012), and *Getting glass from mining tailings in Bolivia* (Arancibia et al. 2012). Both these studies were aimed at using a disposal material to fabricate glass.

Cementitious matrix reinforcement by incorporating recycled fibreglass from composite materials pyrolysis (Rodriguez et al. 2012). This project proposes to reuse the vast amount of disposed fiberglass objects as a part of a composite material.

Transparent ceramics. Processing and optic transmission (Moronta et al.). This is an interesting study about composite materials.

From biomaterials to mesoporous silica nanoparticles for health applications (Vallet-Regi 2012). This work studied composite materials for health applications.

I need to point out that despite the fact these studies were done at an experimental level, they allow us to forecast in some way the future of the glass industry.

Appendix F: How glass has been made. Traditional techniques

In this appendix I will look deeper into some of the most important traditional manufacturing processes in the glass field. It is important to go deeper because some of them are still being used today, although using machines instead of human labor.

Core- formed

Glass was used 6000 years ago as a glaze for beads. Besides its use as glazing, glass was used in many other forms: for example, vessels made with the core forming method. In this method, the core, probably made of mud bound with straw and fixed to a rod, was covered with glass either by dipping it into the molten glass or by wrapping molten threads of glass around it. The surface was then smoothed by continual re-heating and rolling on a flat slab. Surface decoration was added in the form of blobs or trails after which handles and foot stands were put on and the core finally chipped out (Lefteri 2002). The earliest pre-Roman vessels were frequently made using this technique. Often the inside of such a vessel will show signs of having been in contact with the core, and there may be small pieces still adhering to it (Frank 1982).

Millefiori

The millefiori (which means “thousand flowers”) process was used to make beakers, shallow dishes and cosmetics containers. A core was made in the shape of the inside of the required vessel, and sections of monochrome or polychrome glass rods, loosely held in position by adhesive, were laid on the surface of the core. A second mold was placed in position to keep the sections together whilst the glass was fused. The molds were then removed and the surfaces of the vessel ground smooth to produce a fine mosaic effect (Frank 1982).

Image 53 *Millefiori vessel*

Glass blowing

The invention of glassblowing was the first major breakthrough in glassmaking.

Egyptians used to make glass vessels by pressing soft glass into a mold,which was a laborious process, but once glass blowing was discovered, artisans were able to make large amounts of vessels in a short time (Macfarlane 2002).

Glass blowing was developed at some time between 27 BC and 14 AD. Syrian craftsmen from the Sidon-Babylon area invented a long, thin, metal tube to use in the blowing process, and this tube has changed very little since then. In the last century BC, the ancient Romans then began blowing glass inside molds, greatly increasing the variety of shapes possible for hollow glass items.

Glass became utilitarian and inexpensive, and could be purchased by a wide section of the population. According to Frank, this expansion brought problems: from 2000 BC the Roman government forced glassmakers to concentrate in the suburbs away from the city because the pollution caused by the numerous furnaces had become so troublesome (Frank 1982).

For nearly 2,000 years glass blowing by hand was the main method of forming glass articles. The last few years of the 19th century saw the beginnings of blowing glass by compressed air, and the 20th century brought in the revolution of mechanization, although glass blowing is still carried out by craftsmen today (www.britglass.org.uk, 2011).

Glass blowing tools have scarcely changed through history. They are:

* Blow pipe, made of iron
* Pontil, or punty, which was a rod smaller than the blow pipe and not hollow.
* The forming block, a heavy chunk of wood with a hollow carved into it, where the glass on the end of a blow pipe can be rotated until it forms a round ball with a slightly cooled surface
* Pallet, or wooden paddle, which was used for shaping surfaces and trimming edges
* The wood-jack, which was used for spreading open the mouth of a goblet or pinching a bubble of glass inward to form a narrow neck or the lip of a pitcher
* Handle-shear, a scissors-like tool with blades molded to form opposing right angles, and curved tips that can close gently around a pontil or a blow pipe to guide it into place

* Scissors, used for trimming off small amounts of viscous glass

* Pincers, used for guiding the pontil into place

* Forming tool: resembling a pair of tongs with wide flat ends, used for straightening stems and other delicate shaping work (Diamond 1953).

Flat glass

The Roman glassmakers did not only make glass vessels: window glass first came into widespread use during this period. It was probably cast as blocks, the hot glass being poured or pressed into flat, open, clay molds or even poured out upon flat stones (Frank 1982).

Glass-blowing also produced a kind of glass window, made by blowing a bubble of glass and then, while still hot, spinning it until the force produced a flat disc. This could be then cut into square panes. This process was known as crown glass or spun glass. It was slow work to produce it and therefore it was scarce (Lefteri 2002). The best pieces of glass from this disc, cut from its edges, were quite small because of limitations on the size of the disc, but they could be made very thin (a desirable characteristic, as the glass was often heavily colored by unavoidable impurities in the raw materials), and the glass surface, untouched during manufacture, had a bright fire-polish. The thicker “bull´s-eye” at the center of the disc was not wasted but sold more cheaply (Frank 1982).

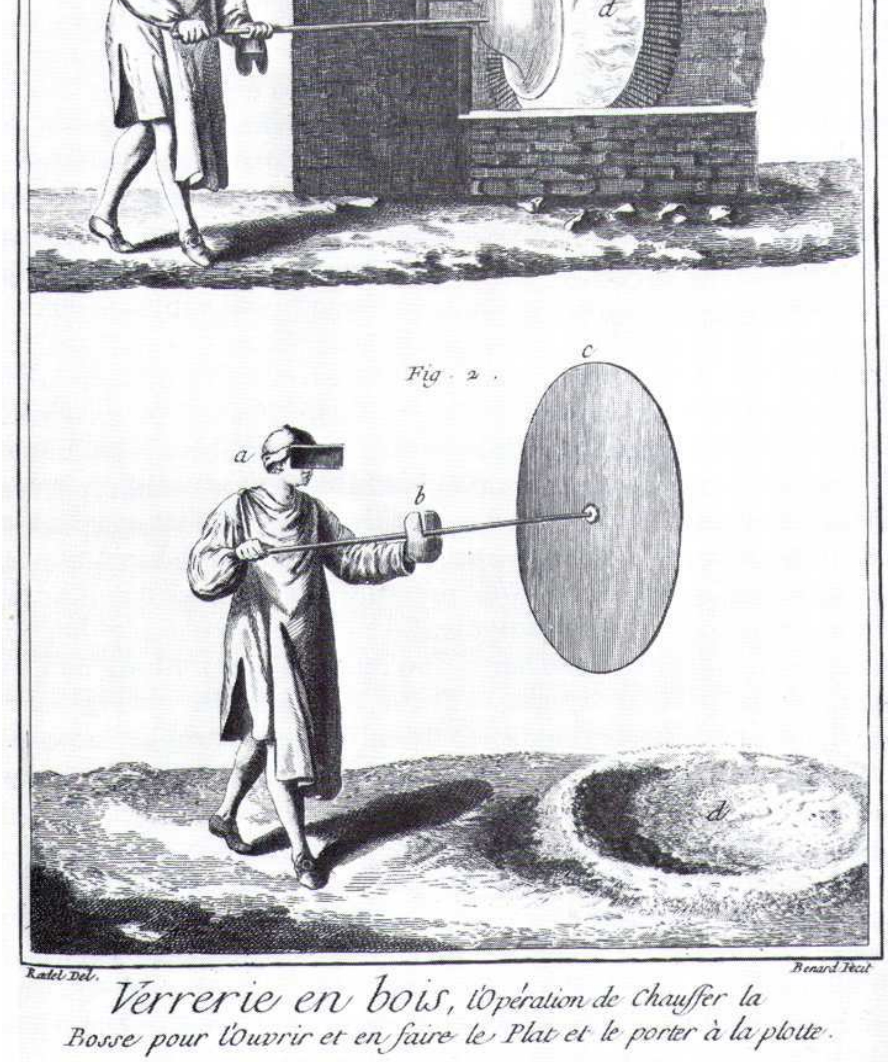


Image 54: *Making crown glass, an 18th century illustration*

Some authors such as Diamond have suggested that the slow development of window glass in Rome was likely due to the warm climate and the use of mica, alabaster, and shell as cheaper alternatives. It was in northern Europe that window technology developed and flourished after the fall of Rome (Diamond 1953).

In the 12th and 13th centuries, a new method (the cylinder method) was developed by French craftsmen: it began as blown glass, with a glass bubble, but instead of continuing to blow it, the artisan let it hang down from his pipe and swung it as he worked so that its own weight elongated the blown shape. From time to time he added more glass to increase the size of his long bubble, until finally he had a slender, almost perfect cylinder. Then he covered the mouthpiece of his blowpipe and thrust the end of the cylinder into the furnace. The air inside the glass expanded in the heat until the end of the cylinder blew out from the pressure, and then the cylinder was detached from the blowpipe. When the glass tube was cool it was slit from top to bottom with a hot iron, laid on a smooth slab, and reheated.

As it softened it opened and flattened out from its own weight, and a worker ironed it with a wooden hoe to make it as smooth as possible, but the outer surface of the cylinder was inevitably larger than the inner one, producing distortion in the finished glass due to wrinkling and puckering. This method to fabricate flat glass required great skill and was very costly (Diamond 1953).

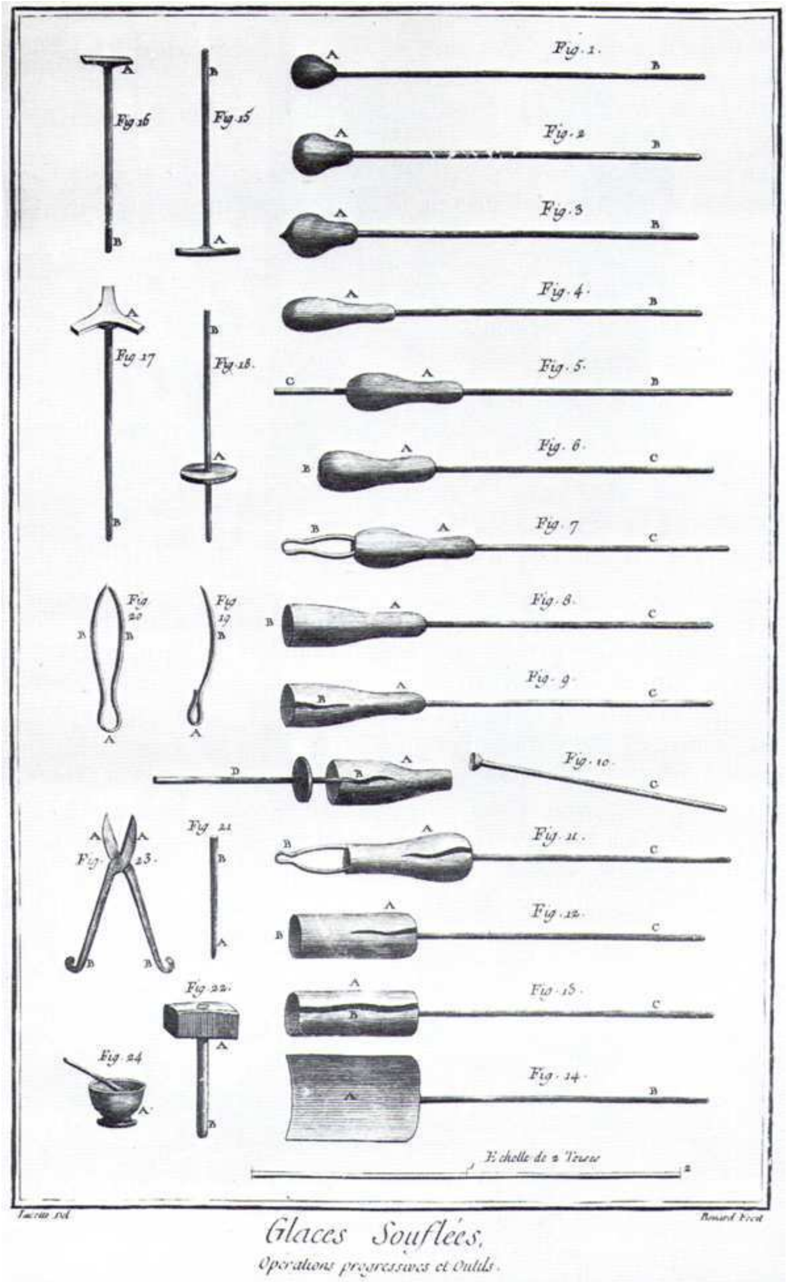


Image 55: *Making broad glass, an 18th century illustration. A bulb of glass is blown into an elongated shape, then opened out at each end, and finally slit along its length and flattened out to form a sheet.*

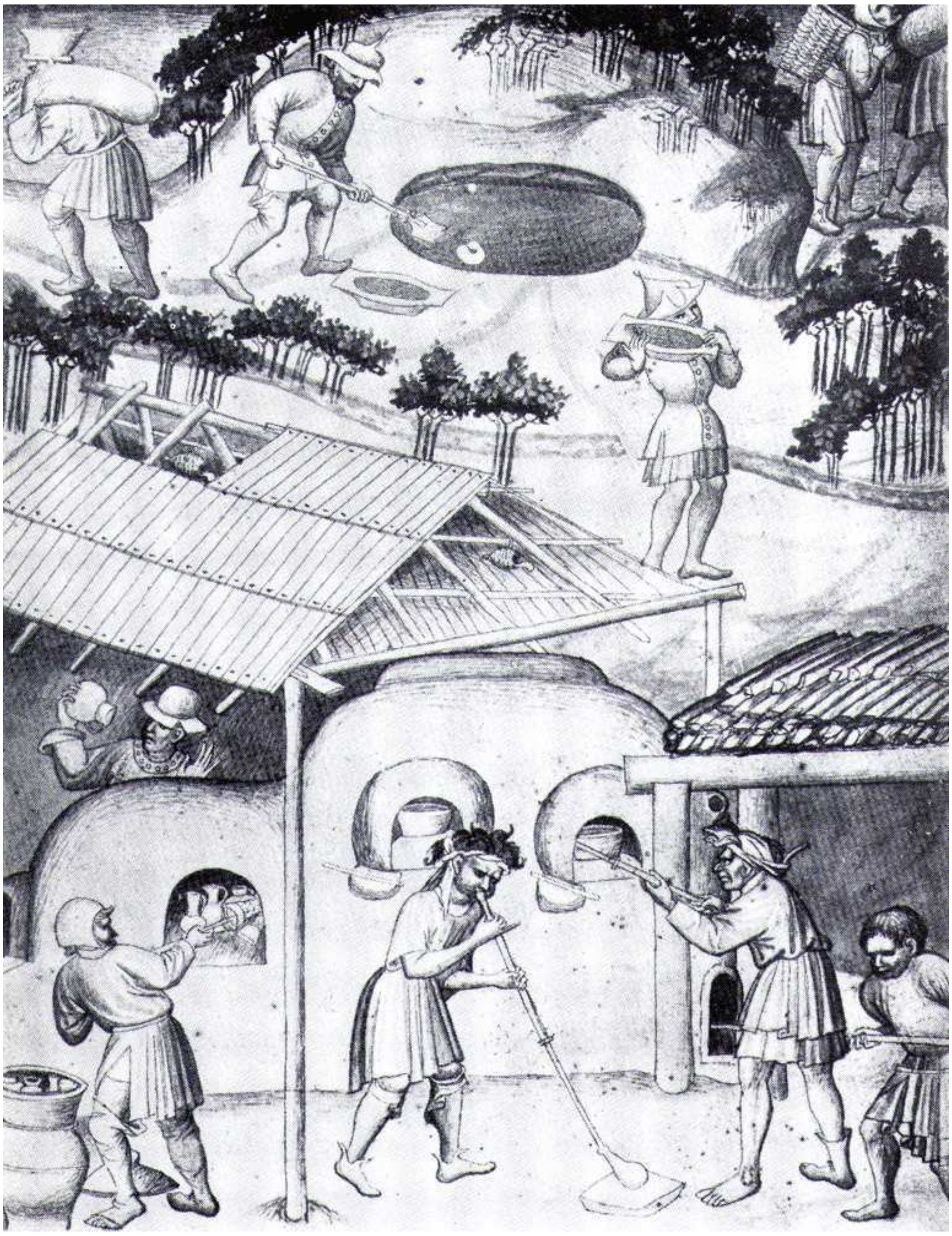


Image 56: *A Bohemian forest glass house of the 15th century. In the background a man digs sand from the hillside and fuel is carried in a basket. In front are the glassblowers gathering glass and blowing a vessel while a boy tends the furnace, and the worker on the left removes the vessels for annealing.*

Antique furnaces and fuels

All the earliest furnaces were direct-fired, although some improvements were made in direct-firing during the 18th century.

In1860 Frederick Siemens built his first tank furnace, and in 1867 he succeeded in converting the tank from intermittent operation (melting batch at night and working during the day) to continuous operation. The continuous tank consisted of three parts. Batch was charged into the melting chamber and was melted by gas flames sweeping across the surface. The molten glass then sank to the bottom of the chamber and passed through vertical channels into the top of the second chamber, where refining (removal of small gas bubbles) took place. After refining the glass, it moved into the third chamber, which was the working end of the tank (Frank 1982).

The introduction of the continuous tank furnace was a radical departure for glass making; it changed the old multistage, intermittent melting process that had remained essentially the same for many hundreds of years. With a continuous regenerative tank furnace regular operation was possible and the production capacity was about double that of the ordinary pot furnace. The continuously maintained melting temperature saved fuel because no heat was lost during a period of cooling, and there was also a reduction by about 60% of skilled workers (Frank 1982).

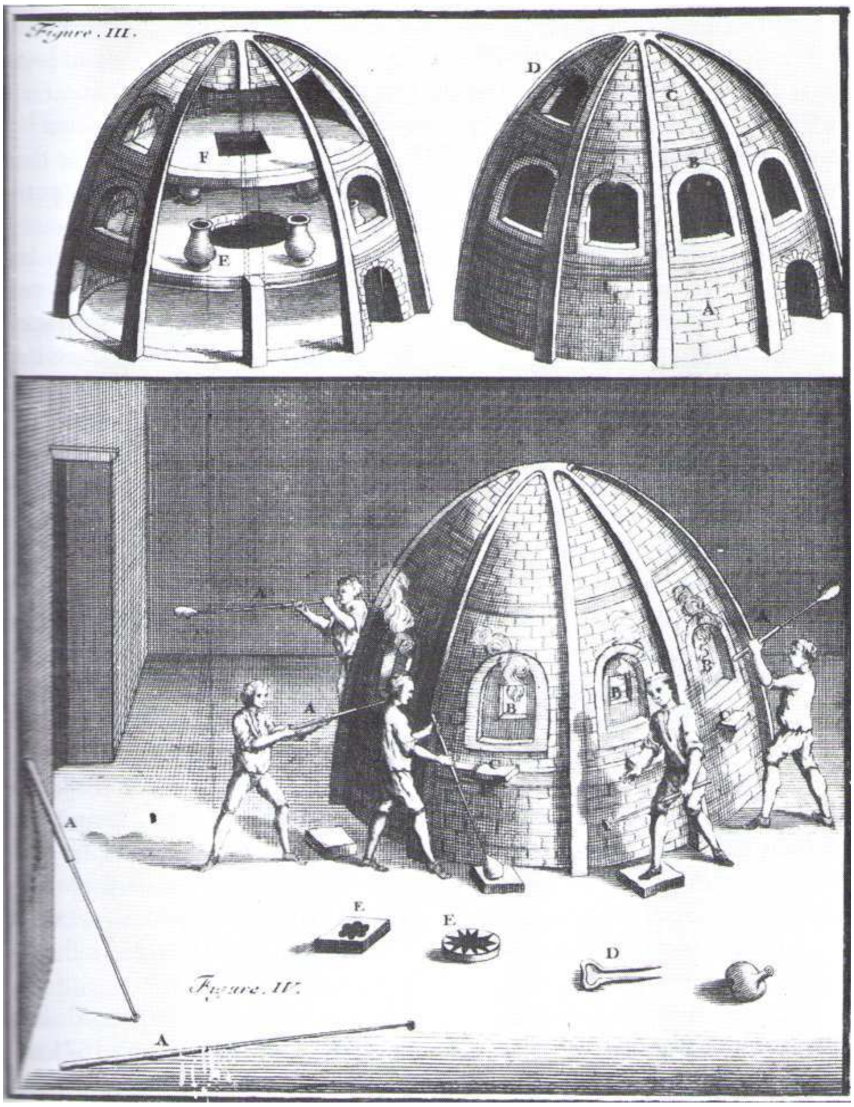


Image 57: *"Southern" type of glass furnace. It has three compartments: the lower one for the fire, the middle one for the pots containing the molten glass (worked through holes in the walls), and the upper one for annealing the finished articles.*

Appendix G: Most common manufacturing processes in the glass field

Deformation: molding and casting

These methods describe ways in which material can be cast directly into a mold as a liquid; pressed into a mold as a “plastic” material; deformed under pressure using dies, forming tools, or molds; or otherwise made into shapes different than that of the original material without directly removing or adding material (Schodek 2005).

Casting is a semi-automatic or manual process used for low or medium production. This process is not normally used in high production because it requires a long cooling time in order to avoid thermal shock. Furnaces for melting glass can use refractory or electric tanks.

The glass-melting process is carried out at temperatures from 1500 to 1600 ° C. The casting cycle for an industrial-grade load takes 24 to 48 hours.

Pressed-glass technique

The basic process involves a quantity of glass being squashed between an inner and outer mold. The thickness between these two parts controls the thickness of the final glass piece. The inner and other molds allow for control and definition to be achieved on both surfaces. Its main disadvantage over blown-glass products is that closed container shapes cannot be produced. The only requirement of any pressed shape is that the opening must have a greater width than the base. This process tends to produce robust, thick-walled products (Lefteri 2002).

Making glass containers by an automatic process

Until the second half of the 19th century, bottles were made by hand processes, mainly blowing glass. A semi-automatic method of bottle-making was developed after 1850, but this has since been replaced by the fully automatic process. All bottles and jars are now made automatically by one of two methods: “Press and Blow” or “Blow and Blow”.

The Press and Blow process is used typically for jars, while the Blow and Blow process is used to fabricate bottles with small necks. The blow and blow and press and blow processes use the same machines for production, but require different molds. Both processes usually use standard soda-lime glass, resulting in 70% of the final bottle being made of sand. However, produced bottles can contain up to 60% recycled glass. Apart from silica, the other main components of most mass-produced glass containers are sodium carbonate, which helps the vitrifying process, and calcium, which adds stability. The bottles and jars are formed at 1550° and then slowly cooled to room temperature, which eliminates any tension in the glass (Lefteri 2002).

The Blow and Blow method

Molten ‘gobs’ of glass are delivered into a mold known as a “blank” or parison mold. A puff of compressed air blows the glass down into the base of the mold to form the neck or ‘finish’ part of the bottle or jar. A second blast of compressed air is then applied through the already formed neck of the container to form the ‘parison’ of pre-form for the bottle against the walls of the parison mold cavity. The thick walled parison is then transferred to the final mold during which time the surface of the glass ‘reheats’ and softens again enough to allow the final container shape to be fully formed against the walls of the final mold cavity by the application of either compressed air or vacuum. The container is then removed and transferred to an annealing oven (the lehr) where it is reheated to remove the stresses produced during forming, and then cooled under carefully controlled conditions.

The Press and Blow method

Molten ‘gobs’ of glass are delivered into the parison mold, and a plunge is used to press the glass into the parison´s shape. The final mold stage of the process is the same as that described for the Blow and Blow Process (www.britglass.org.uk, 2011).

Making flat glass

The main flat glass products are for high-quality glazing in homes, offices, hotels, shops, vehicles, public buildings, wired glass for fire resistance, patterned glass for decoration, and a wide range of glass for environmental control and energy conservation.

Other uses for flat glass include toughened glass doors, suspended window assemblies, cladding for the exterior of buildings, mirrors, and low-reflection glass for pictures and instrument dials.

The current two main manufacturing processes for producing flat glass are the float glass and rolled glass processes (www.britglass.org.uk, 2011).

Float process

The float process, invented in 1952, makes flat glass. This process allows the manufacture of clear, tinted, and coated glass for buildings, and clear and tinted glass for vehicles.

A float line can be nearly half a kilometer long. Raw materials enter at one end, and from the other, plates of glass emerge and are cut precisely to specification, at rates as high as 6,000 tons a week.

In the first stage of this process, fine-grained ingredients, closely controlled for quality, are mixed to make a batch, which flows into the furnace which is heated to 1500°C. Several processes -– melting, refining, and homogenizing – take place simultaneously in the 2,000 tons of molten glass in the furnace. It adds up to a continuous melting process, lasting as long as 50 hours, which delivers glass which is free from inclusions and bubbles, smoothly and continuously to the float bath. Then, glass flows over a refractory spout on to the surface of molten tin, starting at 1100°C, and then leaves the float bath as a solid ribbon at 600°C. After this stage, a coating is deposited, the glass is annealed, and finally, diamond wheels cut the ribbon to the desired size. Computers translate customers' requirements into patterns for cutting (www.britglass.org.uk, 2011).

The rolled glass process

The rolling process is used for the manufacturing of patterned flat glass and wired glass. A continuous stream of molten glass is poured between water-cooled rollers. Patterned glass is made in a single pass process in which glass flows to the rollers at a temperature of about 1050ºC. The bottom cast-iron or stainless steel roller is engraved with the negative of the pattern, and the top roller is smooth. Thickness is controlled by adjustment of the gap between the rollers. The ribbon leaves the rollers at about 850 ºC and is supported over a series of water-cooled steel rollers to the annealing lehr. After annealing, the glass is cut to size. Wired glass is made in a double-pass process. The process uses two independently-driven pairs of water cooled forming rollers, each fed with a separate flow of molten glass from a common melting furnace. The first pair of rollers produces a continuous ribbon of glass, half the thickness of the end product. This is overlaid with a wire mesh. A second feed of glass, the same thickness as the first, is then added and, with the wire mesh "sandwiched", the ribbon passes through the second pair of rollers, which form the final ribbon of wired glass. After annealing, the ribbon is cut by special cutting and snapping arrangements (www.britglass.org.uk, 2011).

Glass fiber manufacture

Continuous glass fiber is a continuous strand made up of a large number of individual filaments of glass. Molten glass is fed from the furnace or "tank" through a channel or "forehearth" to a series of bushings which contain over 1,600 accurately dimensioned holes or "forming tips" in its base. A constant head of glass is maintained in the tank and forehearth, and the temperature of the glass in the bushings is controlled to very fine limits. Fine filaments of glass are drawn mechanically downwards from the bushing tips at a speed of several thousand meters per minute, giving a filament diameter, which may be as small as nine microns. From the bushing, the filaments run to a common collecting point where size is applied, and they are subsequently brought together as bundles, or "strands", on a high-speed winder.

Glass fiber is produced in a range of filament diameters and strand dimensions to tight tolerances for different end uses (www.britglass.org.uk, 2011).

Glass wool manufacture

Glass wool is made using the Crown process. From the fore hearth of the tank a thick stream of glass flows by gravity from the bushing into a rapidly rotating alloy steel dish (called a “crown”) which has several hundred fine holes round its periphery.

The molten glass is thrown out through the holes by centrifugal force to form filaments, which are further extended into fine fibers by a high velocity blast of hot gas, and then the fibers are drawn by suction onto a horizontally moving conveyor positioned below the rotating dish.

The mat of tangled fibers formed on the conveyor is carried through an oven which cures the bonding agent, then to trimmers and guillotines which cut the product to size (www.britglass.org.uk, 2011).

Optical fiber manufacture

Optical fibers consist of two distinct types of glass: a core made of highly refracting glass surrounded by a cover of glass with a lower refractive index. A typical system available commercially comprises a germanium-doped silica core and a borosilicate cladding. There are many manufacturing processes being used to produce optical fiber, and all the processes require ultra-pure raw materials (www.britglass.org.uk, 2011).

Chemical vapor deposition

High-silica glass fibers are prepared by chemical vapor deposition, in which layers of silica are deposited to make a preform, either on the outside of a mold or on the inside of a fused silica tube. The layers are doped during the deposition in order to control the refractive index. The surface is protected from damage by a plastic coating (www.britglass.org.uk, 2011).

The double crucible method

The double crucible uses purified glasses in separate crucibles in a controlled atmosphere furnace. Fiber drawn from the tip consists of a uniform core drawn from the central crucible and a cladding drawn from the outer crucible (www.britglass.org.uk, 2011).

Glass tubing

Glass tubing is used in many products including scientific instruments, fluorescent lights, and many other lighting applications. Glass tubes are made by the Danner process or the Vello process.

Danner process

The Danner process was developed for the continuous production of glass tubing and rod. This process can make tubing of 1.6mm to 66.5mm diameter and rods of 2.0mm to 20 mm diameter at drawing rates of up to 400m a minute for the smaller sizes.

Glass flows from a furnace forehearth in the form of a ribbon, which falls on to the upper end of an inclined refractory sleeve carried on a rotating hollow shaft or blowpipe. The ribbon is wrapped around the sleeve to form a smooth layer of glass, which flows down the sleeve and over the tip of the shaft. Tubing is formed by blowing air through a blowpipe with a hollow tip, and rods are made by using a solid tip on the shaft.

The tubing is then drawn over a line of support rollers by a drawing machine situated up to 120m away. The dimensions of the tubing are determined as the glass cools through its setting point at the unsupported section between the blowpipe and the first line roller. A given range of size is based on the diameter of the refractory sleeve, and variations within the range are obtained by adjusting the temperature of the glass, the rate of flow, the pressure of the blowing air and the speed of the drawing machine (www.britglass.org.uk, 2011).

Vello Process

The Vello process was a later development with a production capacity greater than that of the Danner process, but based on a different principle. Glass flows from a furnace forehearth into a bowl in which a hollow vertical mandrel is mounted, or a bell surrounded by an orifice ring. The glass flows through the space between the bell and the ring and travels over a line of rollers to a drawing machine up to 120m away. Tubing is made by blowing air through a bell with a hollow tip, and rod is produced by using a bell with a solid tip. The dimensions of the tubing are controlled by the glass temperature, the rate of draw, the pressure of the blowing air, and the relative dimensions of the bell and ring (www.britglass.org.uk, 2011).

Making drinking glasses and light bulbs: automatic domestic glassware production

Tumblers, wine glasses, and pint pots are usually made using the Westlake machine, which was originally developed for blowing bulbs for domestic lamps and radio valves. It has since been adapted for making drinking glasses at a rate of up to 55,000 a day. In this process, glass is gathered from the furnace, forming a parison and this parison is blown in a cast iron mold to form an article. Twelve pairs of spindles or blowpipes, together with their blowing air valves and past molds, travel around a central column. The gathering equipment is carried on top of the column, and sets of cams are fitted around the column to control the sequence of operations.

Glass is gathered by vacuum into a pair of blank molds, and the pairs of blanks are transferred in turn to each pair of spindles. The spindles are rotated and swung down, and air is introduced to form each blank into a parison, controlling the profile and distribution of the glass before blowing the required shape in the wetted mold. The mold opens, and the spindle jaws release the article that is then transferred to the stemming machine.

Here, the neck formed in the mold is reheated and stretched to the required length. The article then passes to the burn-off machine where oxygen-gas flames remove the "moil" or waste glass which was originally formed at the gathering position, and the finished piece is sent to the tunnel for annealing (www.britglass.org.uk, 2011).

Electric light bulb envelope production

The ribbon machine was developed for the high-speed manufacture of bulbs for domestic lamps, auto lamps, vacuum flasks, etc. Its main feature is that glass travels through it in a straight line rather than on a rotary path as with the Westlake machines (www.britglass.org.uk, 2011).

From the furnace forehearth, molten glass flows down between two rotating water-cooled rollers and on to the ribbon machine. On leaving the rollers, the ribbon of glass is carried through the machine on a series of orifice plates forming a continuous belt pierced with holes.

As the ribbon moves forward, a continuous chain of blowheads blows the glass through a hole, and the "blister" forms into a bulb inside a rotating mold, which meets and closes around it. Still moving forward on the ribbon, the shaped bulb is released from its mold, cooled by air jets, and then tapped off the ribbon to fall onto the scoops of a rotary turntable which tips it on to a conveyor belt (www.britglass.org.uk, 2011).

Secondary glass processing

As part of the production process, some types of glass are subjected to secondary processing such as annealing, toughening, coating, and decorating. Formed and annealed glass may be further processed. This may be done by taking away from or adding to the surface of the glass. It may also be heated, manipulated, and reshaped. If it is reshaped, it would need to be re-annealed and be toughened again (www.britglass.org.uk, 2011).

Annealing

Glass contracts when cooling, like most other materials, and the surfaces, which cool more rapidly, shrink more quickly than the centre. This produces uncontrolled strain in the glass object. If the internal surface of an unannealed container is scratched, the container will disintegrate. Badly annealed glass articles cannot withstand thermal shock and are liable to break in use.

The excessive strain can be avoided by slow cooling at a controlled rate, called annealing. Annealing is done in an oven called a lehr. As the object enters the lehr, the temperature is at first increased to about 560°C, at which the glass just begins to flow, and is then gradually reduced to a temperature at which no further strain can be induced, and then cooled to room temperature. The time required for this process depends on the size of the article and the wall thickness, but is normally completed in less than an hour (www.britglass.org.uk, 2011).

Toughening

Glass has an extremely high compressive strength, and when it breaks it does so due to induced tension on the surface. Glass can be thermally strengthened by inducing invisible thin layers in compression on the outer surfaces. In order to break such toughened or tempered glass, the compression has to be neutralized and additional tension applied. Toughening is obtained by re-heating the glass article uniformly to a temperature just above that at which deformation could take place and then rapidly cooling the surfaces by jets of air (www.britglass.org.uk, 2011).

The air jets rapidly cool and freeze solid the outer layers, while the inner layers continue to contract. While it is contracting, it exerts compression on the outer layers while putting itself under tension. This method can be applied to flat glass or simple shapes like curved car windscreens or even tumblers. Glass thickness must be uniform, and the shape of the article must be such that all surfaces can be uniformly cooled at the same time. Bottles do not satisfy these conditions and cannot be toughened in this way. However, it is possible to toughen bottles chemically by immersing hot bottles in a molten potassium salt. Potassium ions replace sodium ions on the surface and, being larger, create a very thin layer of compression (www.britglass.org.uk, 2011).

Toughened glass cannot be further processed since any damage to the surface will expose the centre layer, which is in tension, and the glass will break down.

Coating

The coating of glass surfaces has been practiced for centuries; mirrors are an example. Lightweight glass containers can be coated with organic compounds, or with tin or plastic materials. All of them increase the strength of the glass object and enable glass manufacturers to make a lighter and better product (www.britglass.org.uk, 2011).

Decoration

Glass surfaces can be decorated with enamels and grisailles, as I explained in the previous chapter, but there are other forms of decorations, such as etching with hydrofluoric acid and sandblasting.

Metal compounds can also be applied, but in this case the article is then reheated after application of the enamel or metal coating so that it fuses permanently to the surface of the glass. Also metal films can be applied by spraying, or by chemical or vapor deposition (www.britglass.org.uk, 2011).

Waterjet and abrasive waterjet cutting

Waterjet and abrasive waterjet cutting was introduced in the early 70s as an alternative cold-cutting process to the traditional machining methods. Waterjet cutting is the process of producing a highly pressurized stream of water which is used as the cutting tool. The controlled jet stream is capable of cutting virtually any material, hard or soft, thick or thin. The jet stream may have an abrasive cutting material added to it, which then produces an extremely aggressive cutting action. Waterjets and abrasive waterjets are being used in many industries such as aerospace, industrial machining/cutting and maintenance, construction, automotive, mining, environmental, and chemical and food processes. The jet stream passes through a nozzle or orifice with an opening of .030 to .160 in. (0.76 to 4.06 mm) at a pressure of up to 60,000 pounds per square inch (psi) creating a controllable fine stream of water (Krar and Gill 2003).

Abrasive waterjet cutting is when the same pressurized jet stream of water has a cutting abrasive added to the stream. This abrasive is usually garnet, a hard brittle mineral that produces a cutting action. When the jet stream is controlled by Computer Numerical Control (CNC), the designs, patterns, and shapes that can be produced are limited only by the imagination, and the materials that can be cut are virtually limitless (Krar and Gill 2003).

The waterjet machine is designed for commercial cold cutting of glass and other sheet materials, and avoids unwanted heat effects (Petrie 2011).

Adhesives

Glass is commonly held in place by mechanical devices along the edges, such as metal, wood, or rubber channels shaped specially for the purposes at hand, but various adhesives may also be used to hold glass in place and are also often used along the edges to seal an opening and to provide continuous support. Point connections via mechanical fasteners are also common. They must be attached to the glass either with strong adhesives or by making holes in the glass and using specialized headed fasteners (Schodek, 2005).

Appendix H: Overview of emerging processes in the glass field.

There are some emerging processes which as applications in the field of glass are still at an experimental stage.

Nanotechnology

Nanotechnology and nanoscience deal with a new and unique set of emerging behaviors of matter: those which are observed at the border of quantum mechanical effects that occur in the 1 to 100 nanometer range (Krar and Gill 2003).

Cryogenic tempering

Deep cryogenic treatment and tempering is a one-time permanent process that improves the physical and mechanical properties of various materials. It uses sub-zero temperatures to dimensionally stabilize, refine, and close structures, to release internal stresses for the life of the material, and produce longer wear life to parts subject to wear and abrasion. The cryogenic treatment reduces downtime, improves performance, and increases the life of metal tools (Krar and Gill 2003). Its application in the glass field is still under development.

Glass polishing technology using MR fluids

Magnetorheological (MR) fluids are smart materials that respond to an applied magnetic field. MR fluids consist of stable suspensions of particles in a carrying fluid such as silicone oils. Magnetorheological (MR) fluids are being used in glass polishing. MR fluids are considered as polishing fluids whose rigidity can be adjusted. Therefore, different polishing effects can be achieved by adjusting the strength of the magnetic field (Yan et al. 2007).

Precision machining of microstructures on electroless-plated NiP surface for molding glass components

Three-dimensional micro-surface structures, such as arrays of microgrooves, micro-pyramids, micro-needles, micro-lenses and micro-prisms, are required more and more in recent optical, optoelectronic, mechanical, and biomedical manufacturing. Glass and plastic are two major substrate materials for the micro-structured components. According to Yan, glass has predominant advantages over plastic in the aspects of hardness, refractive index, light permeability, stability to environmental changes in terms of temperature and humidity, and so on (Yan et al. 2009).

As an alternative approach, glass molding is a promising method to produce precision optical elements such as spherical lenses, Fresnel lenses, diffractive optical elements (DOEs), micro lens arrays, and so on. In glass molding, the fabrication of the molding die is an important issue. Although hard materials such as silicon carbide (SiC), tungsten carbide (WC), and fused silica (SiO2) are preferable mold materials for continuous surfaces, they have not been commonly used for molding microstructures because it is very difficult to generate microstructures on these materials. Nickel phosphorous (NiP) electroless plating has been known as an important mold surface preparation technology for manufacturing optical parts. NiP plating provides hard, wear-resistant and corrosion-resistant surfaces to glass objects maintaining at the same time excellent precision micro-machinability (Yan et al., 2004).

Some other examples of emerging processes in the glass field that were presented at the 52th annual conference of the Spanish Society of Ceramic and glass and that are of particular interest for the purposes of this thesis are:

Mosaic: Past, Present and Future (Lidenmller 2012a).This project aimed to use the latest digital and robotic technologies in the manufacturing of glass mosaics for architectural purposes.

Conservation and reconstruction of historical stained glass (Lidenmller 2012b). This project used the latest advances in digital technology for the conservation of stained glass.

Considerations on the future of ceramic digital decoration (Bakali). This research explained some uses of digital technologies in ceramic field, but they can be extrapolated to glass field.

Laserfiring oven (Guerrero et al.). This study explained how some coatings can reduce failure rate, enable new geometries, and help to avoid cracks.

Appendix I: Some recommendations to face environmental problems

Some particular recommendations to lessen some environmental problems are: 4Rs and Hannover Principles

4 Rs

A strategy to combat environmental damage caused by waste is called the "4 R's": reduce, reuse, recycle, and regulate.

Reduce

This strategy can be conducted on two levels: first, the designer can reduce the number of components in designed objects, and second, the user can reduce the number of items consumed. This strategy can alleviate in part the problem of saturation of objects.

Reuse

In places where resources are difficult to obtain, people creatively reuse materials to make new products; for example, they use car tires to make shoe soles. But this reuse can be dangerous, or even fatal; just because a material is reused or recycled, that does not automatically make it into something benign, especially if it was not specifically designed to be recycled or reused (McDonough & Braungart 2002).

Recycle

There are several types of recycling: down-cycling, where material loses properties and reduces quality at each recycling; danger-cycling, where a material designed for a specific use is recycled to be used in unplanned ways; and up-cycling where material is remade into a structured and concentrated high-quality material (Thorpe, 2007). In fact, most current recycling is actually down-cycling. Down-cycling presents several disadvantages: it can be expensive for companies, in part because it tries to force materials into more lifetimes than originally planned, a complicated conversion that uses energy and resources. For example, legislation in France requires all aluminum and polypropylene packaging to be recycled, but as these containers were not designed to be recycled into new packaging, this results in additional costs. Down-cycling may actually increase pollution when it mixes paints and coatings with raw materials (McDonough & Braungart 2002).

However, despite that most products can be recycled, only a few of them will be, because only products that are easy to disassemble can be chosen for recycling. Designers can increase the possibility that a product is recycled, and optimize its disassembly.

Regulate

According to McDonough and Braungart it is necessary to regulate the management of waste, because despite that well-designed products should not require any regulation at all, regulations may reduce the potential deleterious effects of technology products (McDonough & Braungart 2002).

Hannover principles

Some further strategies which can be used by designers are addressed in the Hannover principles:

1: To insist that humanity and nature are entitled to co-exist in a healthy, supportive, diverse, and sustainable condition.

2: To recognize interdependence. The elements of human design interact with and depend on the natural world, with broad and diverse implications at every scale. It is necessary to expand design conditions to recognize even distant effects.

3: To respect the relationship between spirit and matter. Consider all aspects of human settlements.

4: To accept responsibility for design´s consequences on human well-being

5: To create safe objects with a long-term value. Future generations do not have to take care of potential damage due to careless design of products.

6: To eliminate the concept of waste. Evaluate and optimize the full life cycle of products and processes to approximate natural systems, where there is no concept of garbage.

7: To understand the limitations of design. No human creation can last forever, and the design will not solve all problems.

8: To share knowledge with colleagues, manufacturers and users (as cited in Thackara 2005).

Thackara adds these recommendations to the Hannover principles:

9: To think about the design´s consequences before manufacturing, and to pay attention to cultural, natural, and industrial systems, which are the context of our design actions.

10: To consider all flows of materials and energy in all the systems we design (Thackara 2005).

The Industrial Design Society of America (IDSA) also recommends the following strategies:

11: To reduce overall material content and increase the percentage of recycled material in products.

12: To reduce the energy consumption of products.

13: To eliminate unused or unnecessary product features.

14: To use lightweight materials and therefore use less energy to transport.

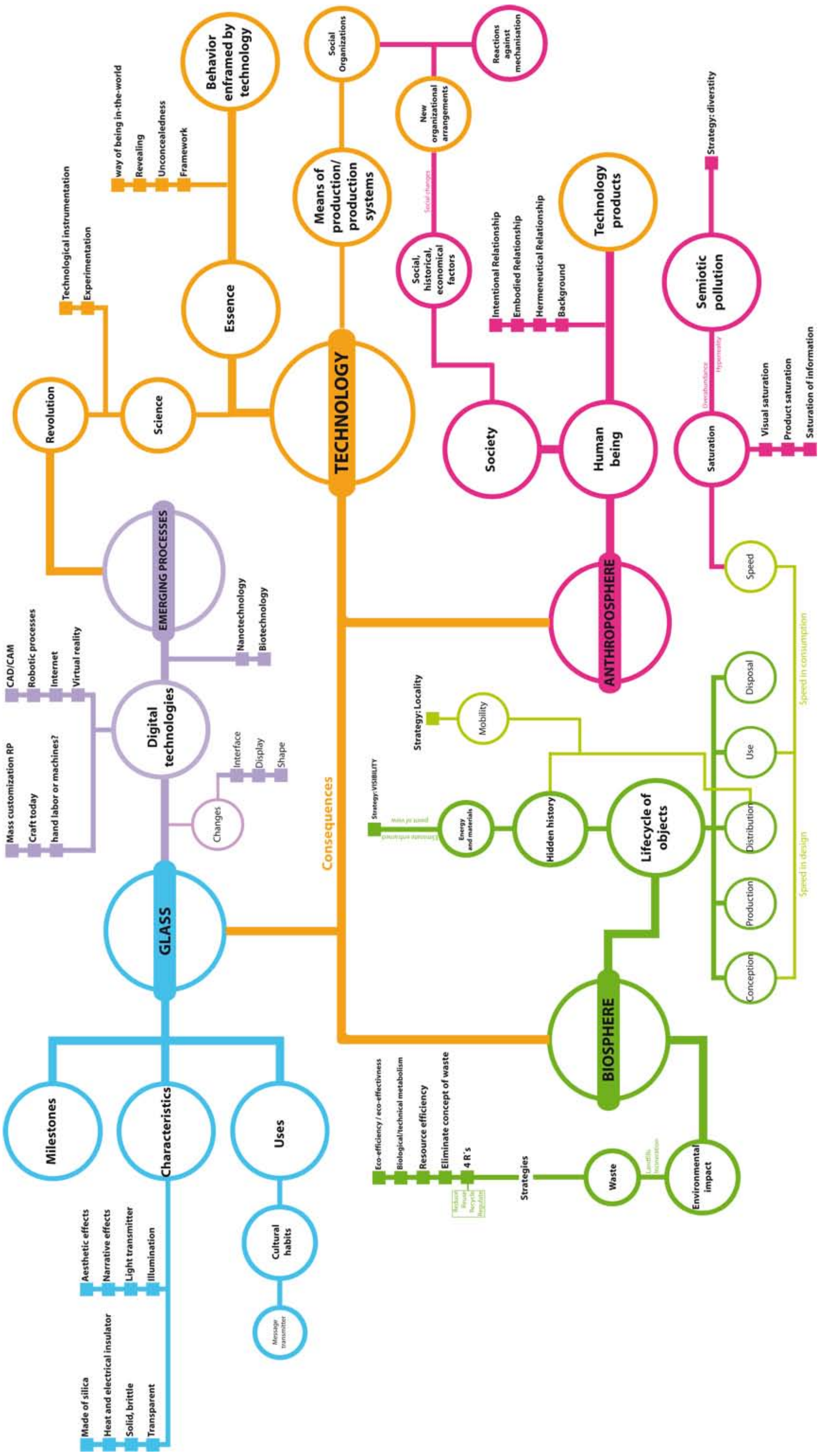
15: To design for easy, economical disassembly of major components prior to recycling.

16: To design products so that toxic components (electronics et al.) can be easily removed prior to recycling.

17: To consider all the ecological impacts from all of the components in the product over its entire life cycle, including extraction of materials from nature, conversion of materials into products, product use, disposal or recycling, and transport between these phases.

18: To encourage new business models and effective communication (Cuffaro 2006).

Appendix J: Mental map



Appendix K: Some precedents

Before starting the design process some precedents were revised, such as public spaces, technology precedents, airports, users, shapes, uses of glass in public spaces. In this appendix some of these revised precedents can be seen.

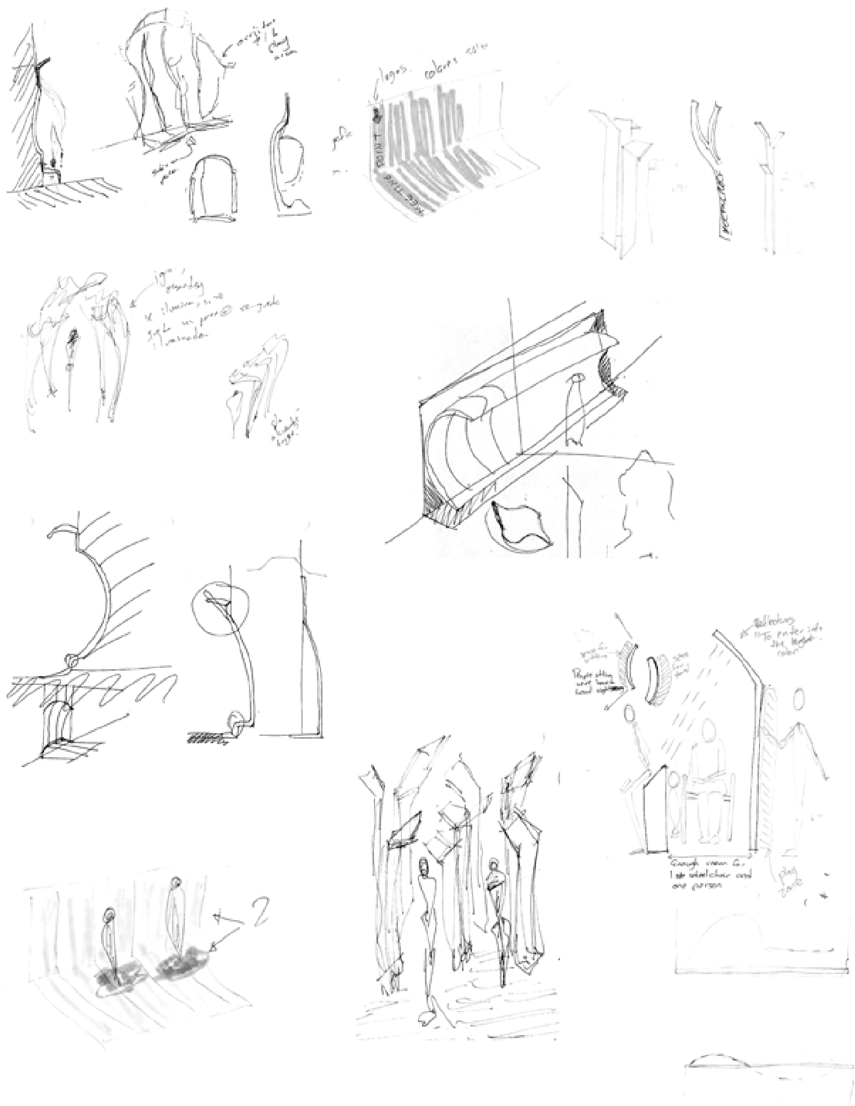
Image 58*:* *Precedents*

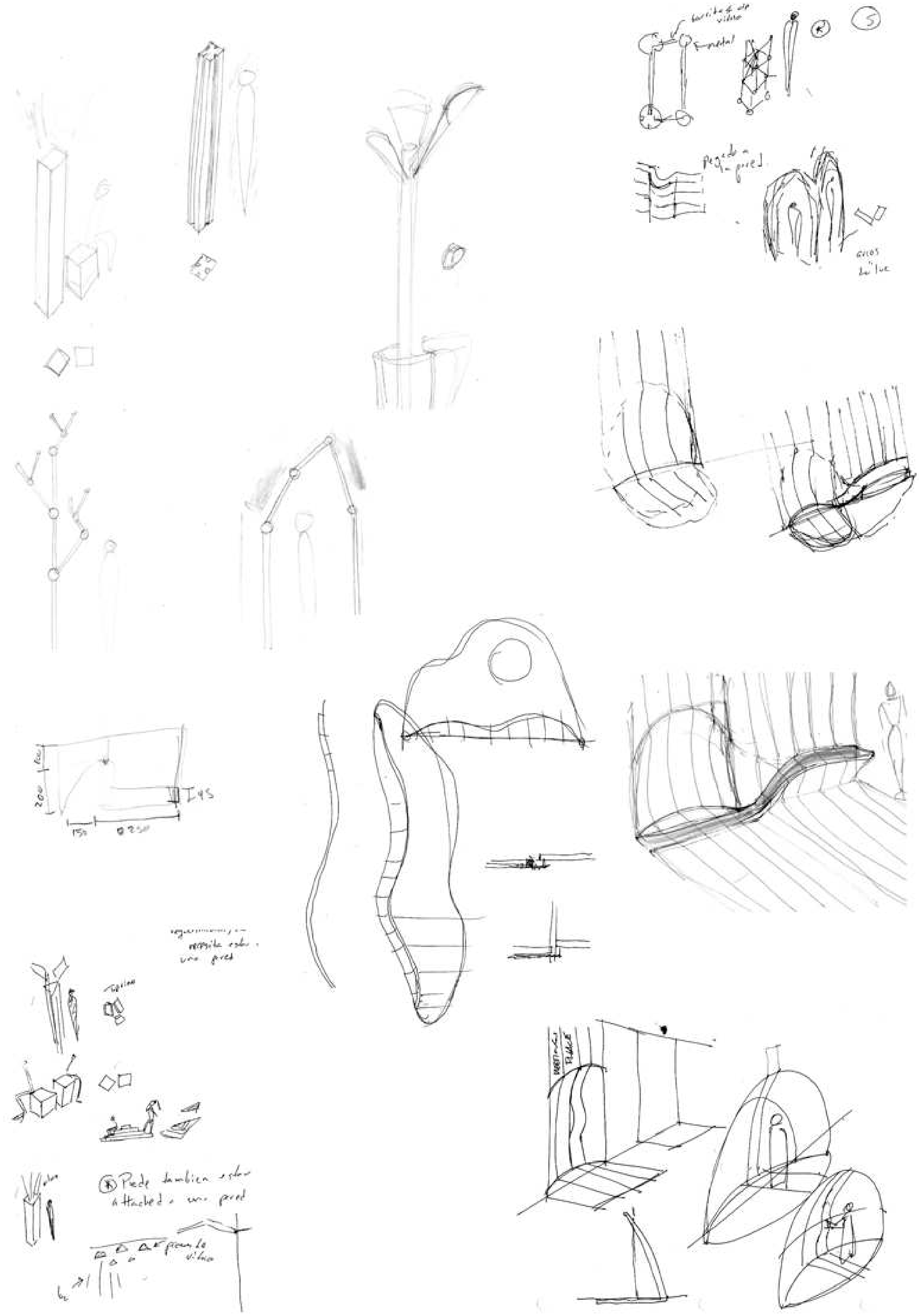
Image 59: *Precedents*

Image 60: *Precedents*

Appendix L: Sketching and interim design solutions

The MP was the result of an iterative design process. Before arriving to the final design solution, it was mandatory to make use of different tools, such as brainstorming, drafts, sketches and 3d models. The sketch work and the 3d work done can be seen in this appendix.



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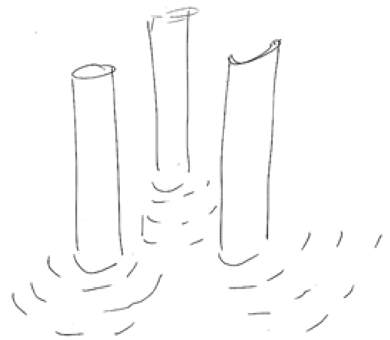

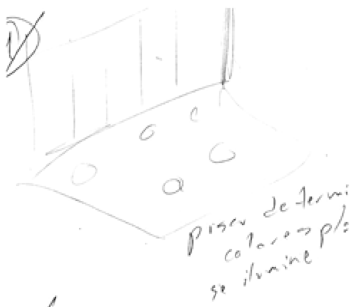

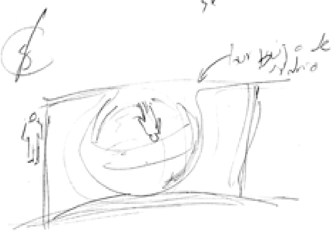

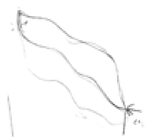

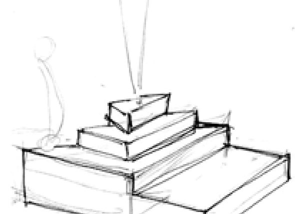

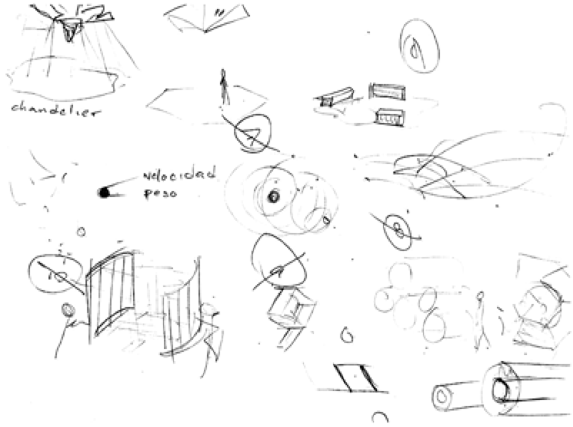
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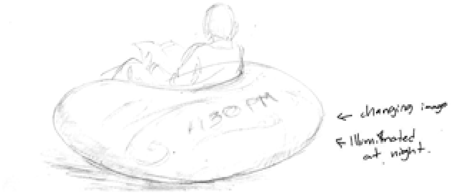
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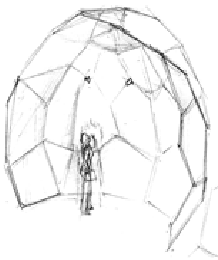
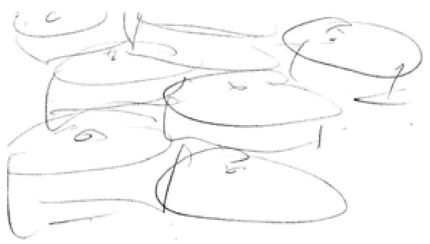
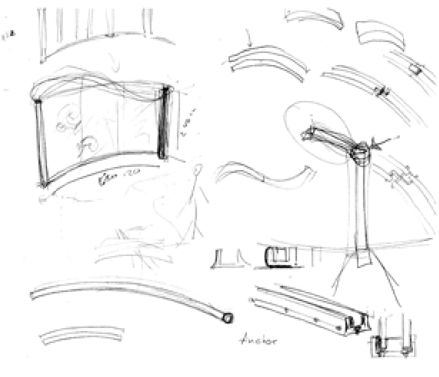
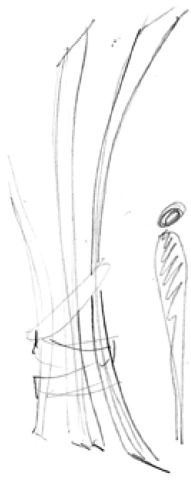
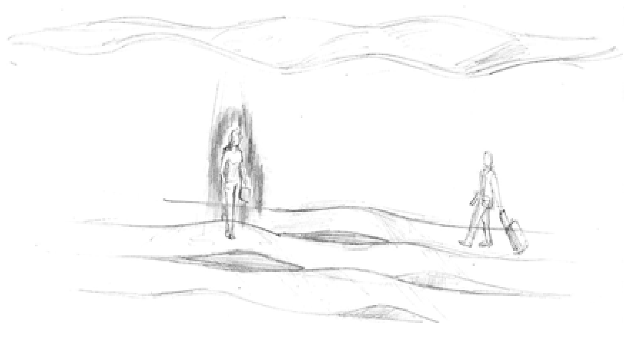
← Illuminated at night.

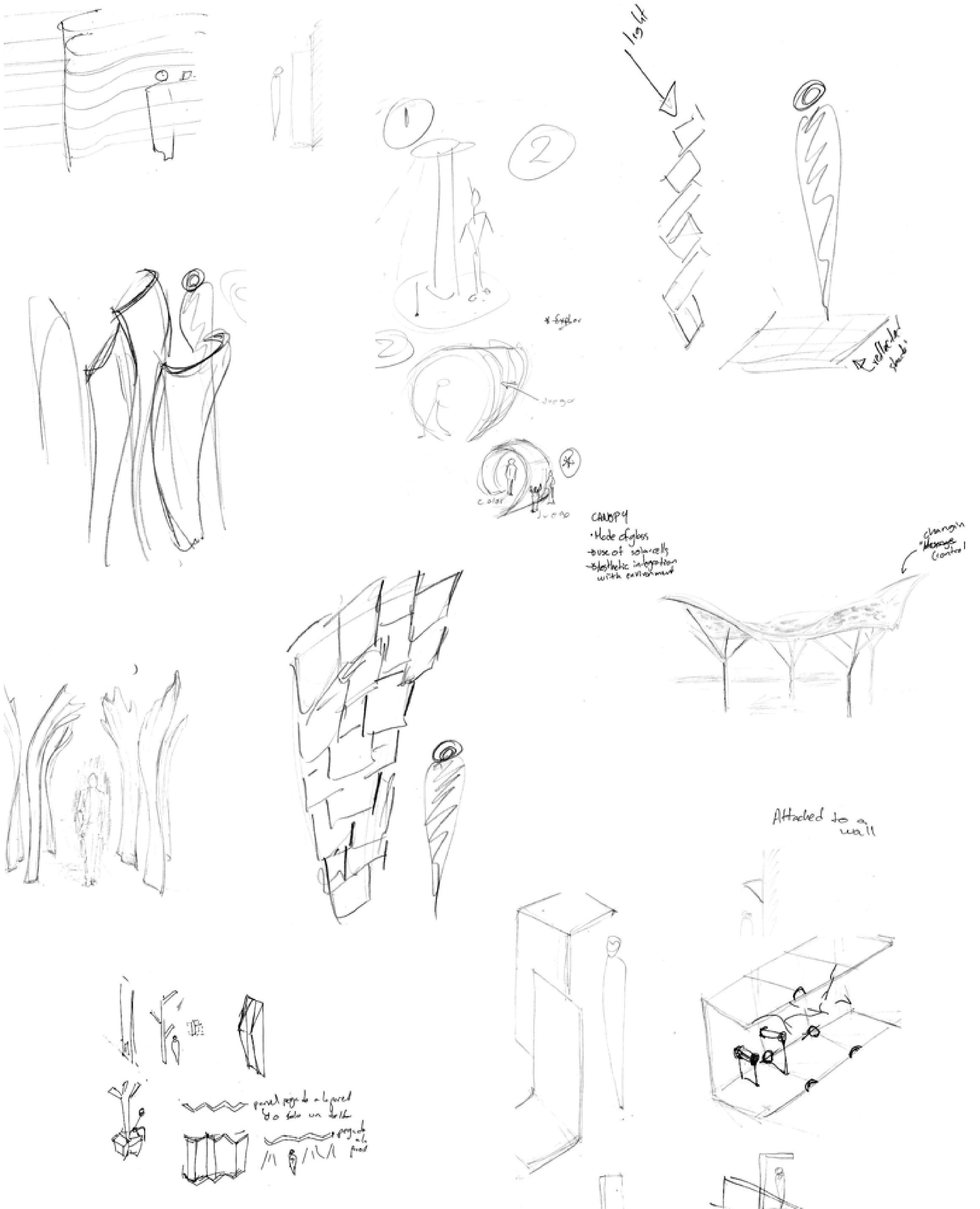


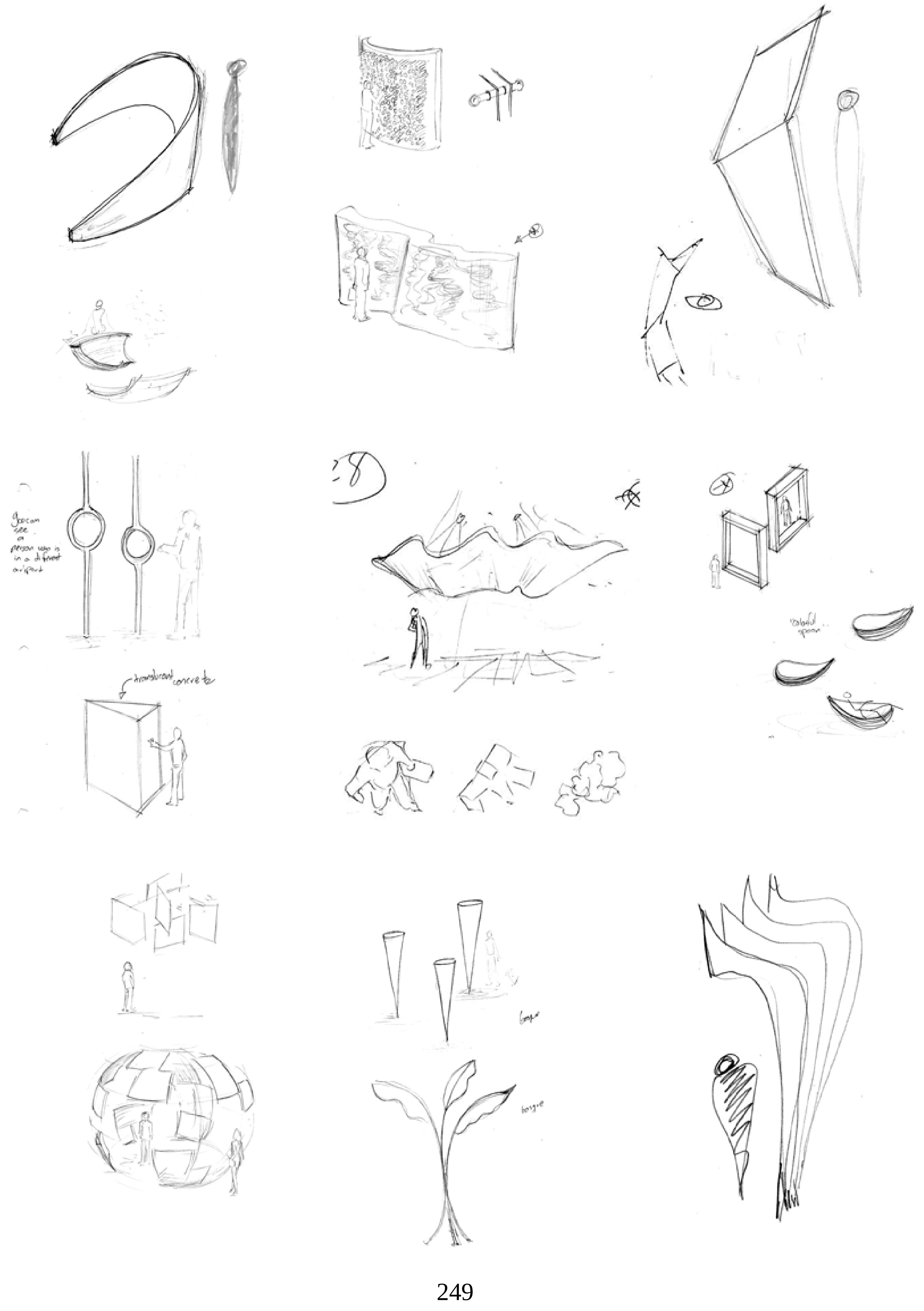


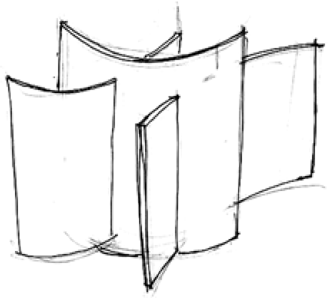

Anchor

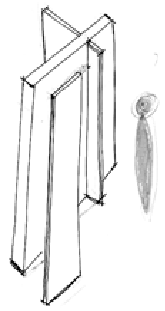
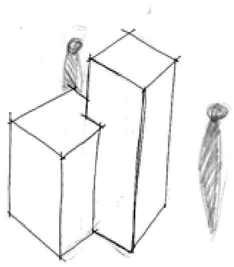


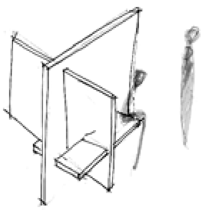
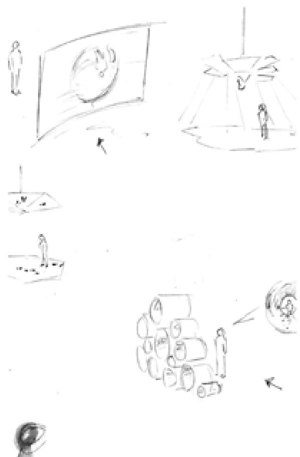


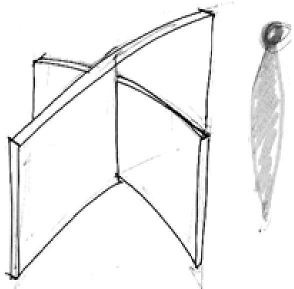

light
CANOPY
·Made of glass
·use of solar cells
·Aesthetic integration with environment
Attached to a wall
juego
color

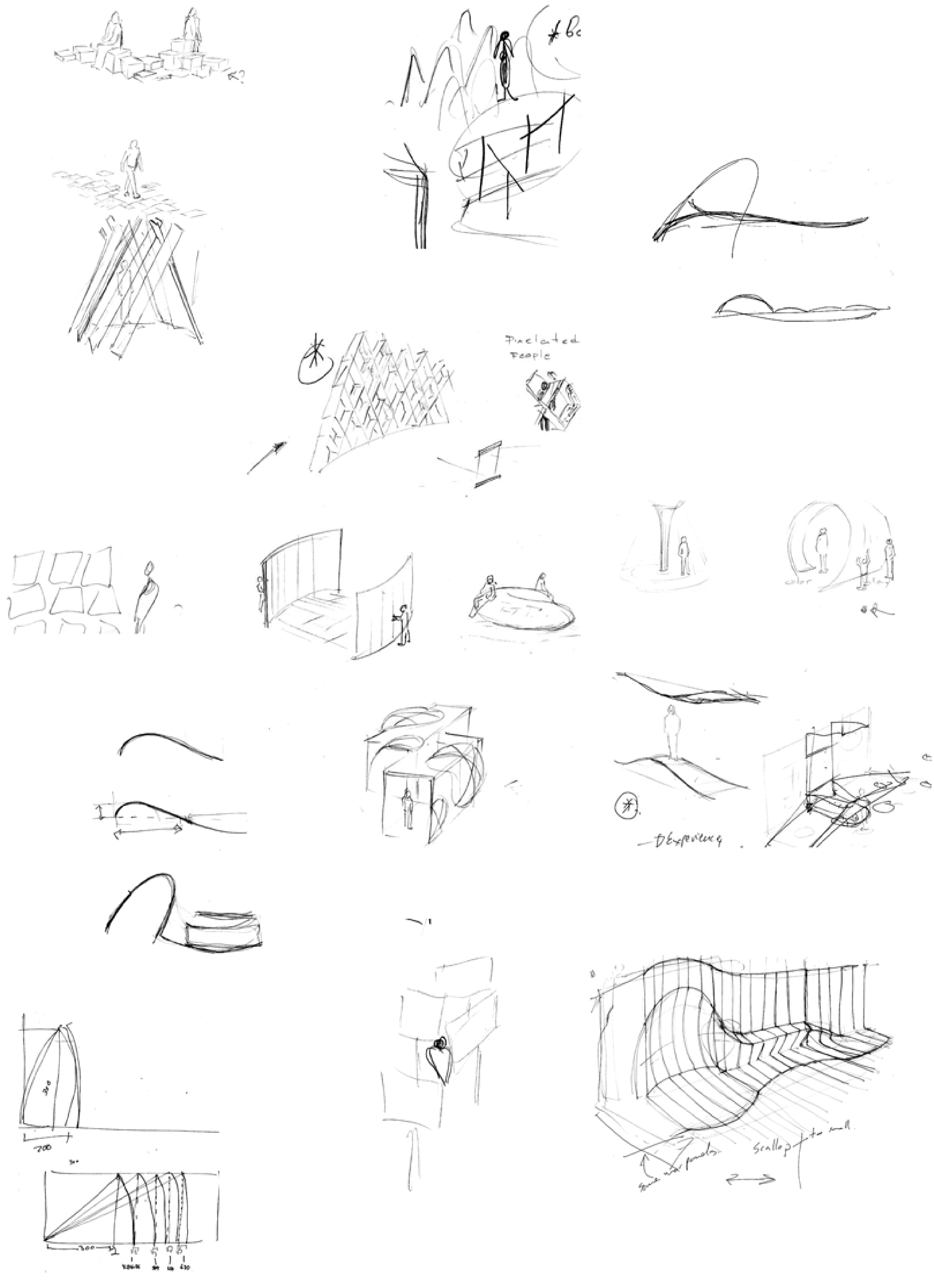

You can see a person who is in a different airport
translucent concrete
tongue

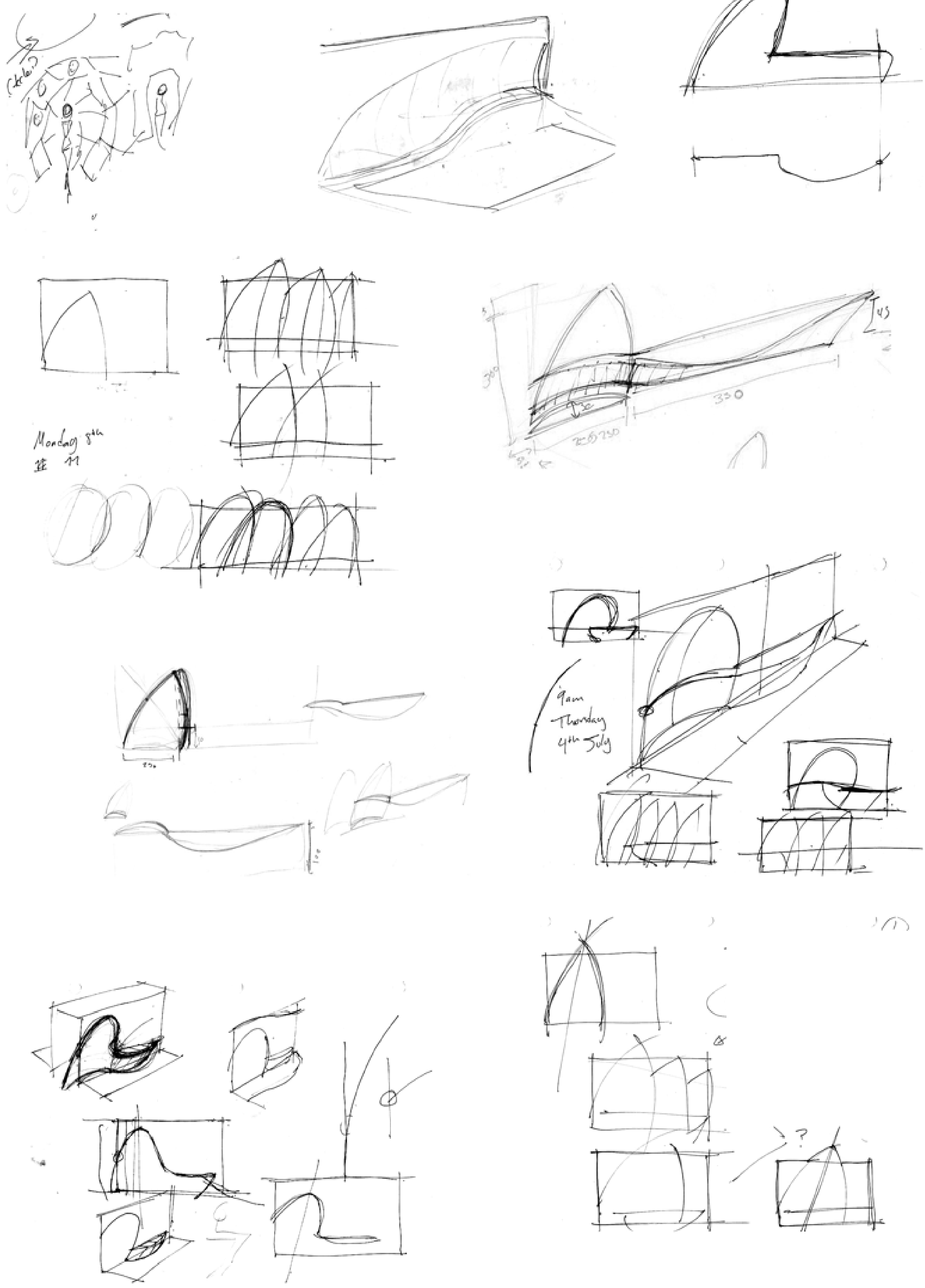





Pixelated People


9am
Thursday
4th July
330