Chapter 1
Photosensitivity: materialities and operations

> "man's disregard for the material basis of his life still causes him to err in a serious way".
> George Bataille[1]

In the recent past, a common way to open a discussion of media art was to unfold the principles and aesthetics of technical images.[2] It has been challenging to detach the emergence of technical images[3] from the role of light and the supremacy of the sense of sight. In consonance with a general neglect of the world's materiality, light plays a predominant role in media theory and history, where one also finds an emphasis on the geometrical qualities of optics and its derivative apparatuses that reinforces the visual aspects of media.[4]

Since there has been a great deal of theoretical work casting light and image as the protagonists of media aesthetic discussions[5], the challenge here is to shift the perspective by means of excavating and analysing the other side of the light-matter

1 Bataille, George. *The Accursed Share. Volume 1: Consumption*. 1991. p. 21

2 Flusser 2008.

3 Vilém Flusser's use of the more general term 'technical image' implies overcoming the notion of image as a bi-dimensional space merely resulting from an incidence of light and visual perception. Other important expansions of the notion of image are found in the works of the philosopher Régis Debray and in *Bildakt Theorie*, headed by art historian Horst Bredekamp, who points to other theoretical frameworks to transgress the prevailing mimesis in the theory of pictures.

4 A few important publications from the last three decades that support our argument are, for instance, Jonathan Crary's *Techniques of the observer* (1990), Ulrike Hick's *Geschichte der optischen medien* (1999), Friedrich Kittler's Optical Media: Berlin Lectures 1999 (2000), Siegfried Zielinsky's *Deep time of media* (2006) and Sean Cubitt's *The practice of light* (2014).

5 For instance: Weibel, Peter; Jensen, Gregor (Eds). *Lichkunst aus Kunstlicht: Licht als Medium der Kunst im 20. und 21. Jahrhundert.* Catalog for an exhibition "Light Art from Artificial Light: Light as the Medium of Art in the 20th and 21st Centuries" at the Zentrum fur Kunst und Medientechnologie in Karlsruhe, Germany, 2006. and Cubitt, Sean. *The practice of light: a genealogy of visual technologies from Prints to Pixels.* Cambridge, Massachussetts/London, England: MIT Press, 2014.

interaction: the photosensitive elements. This object of analysis was strategically chosen as a means to consider media artworks in their expanded, heterogeneous, relational and dynamic expressions.

As active materials, photosensitive elements are inextricable from the processes and relationships in which they take part. This perspective draws on the physicist and new materialist Karen Barad's (1956-) agential realism[6], which deals with matter (such as meaning) not as a static entity but as a doing and sees its ongoing historicity as part of the constant stabilizing-destabilising process of the world's iterative intra-activity. As a new materialist approach, it envisions the inseparability between epistemology and ontology[7] by means of investigating similarities and differences in the materiality of photosensitive elements. Through this process, the accumulated knowledge they enclose is revealed, and the findings are complemented by aesthetic implications for media art.

In this sense, my approach has also been directly influenced by the notion of active matter expounded by science and media historian Wolfgang Schäffner (1961-). Schäffner analyses the paradigm shift in the role of materiality in the humanities by observing the developments in the multiple ways of understanding the materiality of knowledge, ranging from the passive materials of Kantian philosophy to the active materials of quantum physics and contemporary new materialist approaches. His analysis defines the form of an object as a diagram of forces, thereby making materiality and its related operations interdependent[8].

One of the premises to bear in mind is that every material is somehow sensitive and reactive to physical or chemical stimuli, with each reacting differently in time and according to specific contextual changes, such as temperature, pressure, moisture, and so forth. Photosensitive matter is just one among a multitude of possible case studies.

General contemporary explanations of sensors by biologists and engineers[9] show surprising consensus. Biologist and neurologist Friedrich G. Barth states that *"all sensors absorb some kind of energy (an exception being cold receptors responding to loss of thermal energy), typically in minute quantity, and generate electrical signals"*[10]. This func-

6 Barad, Karen. *Agentieller realismus: Über die Bedeutung materieler-discursiver Praktiken*. Berlin: Suhrkamp, 2012.

7 Barad 2012.

8 Lecture "*Materialität und operationen I: Active Matter*" by Wolfgang Schäffner, in the *Ringvorlesungen* at *Humboldt-Universität zu Berlin*. January 28th 2015. A parallel and historical perspective complementary to this approach is the work by Sir. D'Arcy Wentworth Thomson's (1860-1948) *On Grown and Form* (1917).

9 For an introduction to our basic understanding of sensors, see: Barth, Friedrich G; Humphrey, Joseph A.C.; Secomb, Timothy W. (Eds.) *Sensors and sensing in biology and engineering*. Wien/New York: Springer, 2003; and Fraden, Jacob. *Handbook of Modern Sensors: Physics, Designs and Applications*. New York, Berlin, Heidelberg: Springer-Verlag, 2004.

10 Barth 2002: 3-4.

tional aspect of sensors is crucial to the understanding of photosensitive elements and has important implications for cultural studies, which will here be discussed in relation to artistic practices.

Knowledge of the atomic world and its quantum mechanics has led to new methods for handling matter and constitutes the main foundation of current approaches to the diverse expressions of active matter. It is now known that the physicochemical properties of a certain chemical element are predominantly given by the configuration of its electrons; more precisely, by the structure of the outermost layers, where the so-called valence electrons are located. The mobility of these electrons enables the rearrangement of atoms and molecules, that creates every activity of matter by means of chemical reactions that change its physical properties. The mobility of valence electrons is also what generates electric current, which is the physical basis of phenomena related to electricity and magnetism.[11]

Curiously, although atomist theories emerge from the obstinate human drive to find the minimal and indivisible part of matter, the more scientists discover, the further they are from finding a minimal end point in the atom or a maximal one in the expansion of the universe. Recent studies on quantum physics have shown that sub-atomic particles also exhibit wave properties.[12] Such discoveries have led to dynamic conceptions of matter.

Furthermore, the dual quality of light (physically described as electromagnetic radiation with wave-particle properties) that enables the "magical" light-matter interactions, offers an interesting example to deconstruct the prevailing dichotomous relationship between material and immaterial. What has been thus far discussed is enough to realize that photosensitive matter is just as responsible for the development of media devices and techniques as light is, and an image in the traditional sense is only one of the manifold possible outcomes of photosensitivity.

This opening chapter intertwines the realms of materialities and operations related to photosensitive matter in order to build the foundation for a discussion of issues relevant to media art aesthetics. Due to the relational aspect of the sensing phenomena, the operations involved in the analysed materials are simultaneously addressed. They often address concepts, models and methods that have been systematised in order to be learned, reproduced and, if possible and/or necessary, improved.

Each part of the chapter articulates a thought based on the increasing complexity of the technical ensembles analysed, recalling Gilbert Simondon's perspec-

11 Kohen, Elli; Hirschberg, Joseph; Santus, René. *Photobiology*. San Diego, CA: Academic Press, 1995. p. 20.

12 Ibid: 16-19.

tive,[13] articulating both concrete and abstract instantiations of knowledge. These range from models for understanding molecular activity in photosensitive materials, through their concretizations in media devices to their implementation and operations in artistic contexts. Artificial classifications and chronological threads have been avoided, being the photosensitive elements recruited along the text according to their usefulness in clarifying the thesis argumentation.

The information above provides the conceptual and technical tools to deconstruct the historically embedded dichotomous material-immaterial relationship within media art. In what follows, this topic is unfolded through the notion of informational aesthetics and the analysis of the media artwork *Luzes relacionais* (2010), by Ernesto Klar.

1.1 Light and photosensitive matter

One of the very first premises of this study is that light *"only becomes evident when it interacts with matter"*[14]. Therefore, it is only possible to discuss the effects of light from a relational perspective. The interaction between light and matter has been observed, understood, depicted and controlled in a huge variety of ways in the history of culture. For instance, in the Middle Ages, *"scholastic metaphysics classified light as a substance, an embodied spirit, which distributes divinity to all God's creation"*[15]. The scholastic attribution of the divine to light can likewise be experienced in the architecture of gothic cathedral. Architect and theoretician Philip Tabor explains further: *"through the stained-glass windows, Divinity radiated more through light as essence than through the images depicted on the windows. Light's primary role was performative. The medium was the message"*[16].

Interestingly, the approach becomes much more distinctive if one compares it with the symbolic role of light related to reason and rationality that came to predominate in the Enlightenment. When the first sprouts of the scientific method as known today emerged, light was subjected to empirical tests in order to depict and

13 In *Du mode d'existence des objets techniques*, Simondon elaborates his theory of the concretization of technical objects based on their 'evolution' through processes of individuation and/or the organized collection of individuals. (Simondon 1958:75)

14 Le Grand, Ives. *Introduction to photobiology: The influence of light on life.* London: Faber and Faber, 1970, p. 15.

15 Tabor, Philip. Striking home: telematic assault on identity. In: *Doors of Perception 2*. 1994. Available at <http://museum.doorsofperception.com/doors2/transcripts/tabor.html> Accessed July 5th 2016.

16 Ibid.

explore its nature. The physicist Isaac Newton's (1643-1727) experiments in optics[17] in the seventeenth century are the most significant to mention here. Indeed, the history of the birth of chemistry as a discipline in the eighteenth-century is very much related to findings concerning photosensitivity, photochemical effects and studies on the materiality of light, which required distinguishing between fire and light, and between light and heat[18].

Since the focus here is on media history and aesthetics, these brief aforementioned examples are mentioned merely to briefly outline the phases of the exploration of light in its empiric, abstract and symbolic levels. More relevant is how light in association with photosensitive elements, not only gave birth to visual media but participates in its deconstruction as well. The transformation of light sensitive materials into sensors that translate luminous stimuli into electrical signals opens an enormous field of possibilities for expanding the concept of the image beyond that of the mimetic traditional, where it is viewed as something inscribed and seen only by light. Yet this entails an exponential expansion as it requires one to go beyond the human eyes' visible light spectrum, which, according to the calculations of the physicist Augustin Fresnel (1788-1827), ranges from wavelengths of about 400nm to about 750nm[19]. In addition to this spectrum there are non-visible forms of radiation, such as infrared and ultraviolet[20].

In communication theories influenced by the mathematical and engineering perspective of Warren Weaver (1894-1978) and Claude Elwood Shannon (1916-2001), the role of sensors in transforming light into electric voltage has been defined as part of a system's receiver, constituting an interface through which input data is enabled. The "captured" data (which is essentially electric voltage changing inside a microprocessor's circuits) can be sequentially processed and programmed to turn the initial electric energy (input) into any other physical manifestation (output). As a sort of membrane, sensitive matter demonstrates how permeable and modifiable things can be. Artworks that embed sensors, using their technical principles as aesthetical means, manage to drive artistic experiences to another epistemological layer encompassing the manipulation of matter subjected to implications of data processing and programming. In this sense, media artists may participate more deeply in the process of shaping the forces that govern the activity of matter. The following pages discuss how photosensitive elements both found in nature and

17 Among other studies, the English physicist explored the refraction phenomenon of light, demonstrating through a prism the existence of monochromatic light and the intimate relationship between light and colour. (Kittler 2010: 122-123)

18 In Western culture, before the birth of chemistry, since the Greek Antiquity, the elements that every being in the world were defined only through the elements of fire, air, water and earth. (Kittler 2010:122)

19 $1nm = 10^{-9}$ m.

20 Kohen et al 1995:12.

created by humans present and enable this permeability of dynamic systems. It is precisely this quality of sensitive matter as an interface that testifies to the dynamic materiality of media art.

Since it is impossible to include the immense variety of existing photosensitive materials and their correlated techniques, key examples have been chosen that indicate stronger relationships to media history and have had a broader impact on the aesthetics of media art. These examples include, for instance, light-sensitive proteins, silver salts, selenium, sensitization technique, photolithography with semiconductors, and others. In order to better understand how photosensitivity is possible, it is crucial to briefly address the basic structures and principles governing light-matter interactions on the molecular level.

1.1.1 Molecules act

Photochemistry is the established field in charge of modelling light-matter interactions. It describes the agents and mechanisms involved in chemical reactions caused by the absorption of light, from ultraviolet and visible light to infrared radiation. Due to quantum theory, elaborated in the beginning of the 20th century[21], the theoretical basis of photochemistry today has established a solid basis that enables scientists and artists to investigate and play with the rules of photo-biological processes and other photoelectric effects incorporated in sensor engineering.

The valence electrons present in the outermost orbits of an atom allow the molecules to be recombined, altering the qualities of matter and/or producing a variety of specific physicochemical effects. The photoelectric effect[22], which according to classical electromagnetic theory corresponds to the transfer of the energy of light to an electron of a specific material, is one of these and has been used extensively in the development of photosensitive artefacts. In photobiology such physicochemical effects are associated, for instance, with bioluminescence, photosynthesis, phototropism and other related phenomena[23].

Scientific observations of the photoelectric effect have, moreover, contributed to the current understanding of the wave-particle characteristics of light. It was ex-

21 In 1908, Johannes Stark (1874-1957) and Albert Einstein (1879-1955) published the "Law of photochemical equivalence". (Le Grand 1970:26) Moreover, quantum mechanics has been enhanced since the discovery that electrons also have wave properties, which enabled more complete calculations to be made by the physicists Erwin Schrödinger (1887-1961) and Paul Dirac (1902-1984).

22 The photoelectric effect was "*first noticed by Heinrich Hertz (1857-1894) when he was in the process of discovering radio waves ca. 1887*". (Kohen et al 1995:14)

23 In photobiology, when a specific beam of radiation is "*absorbed by biomolecules, the outermost electrons, e.g., those involved in atom binding, are affected. As a result, chemical changes can occur during light absorption*". (Kohen et al 1995: 22)

periments on the photoelectric effect and Max Plank's theory that energy exists in small and discrete pieces called *quanta* that served as the point of departure for Albert Einstein's 1905 proposal on the dual nature of light. As the photoelectric effect occurs *"when light strikes a solid in a vacuum and electrons are ejected from the surface"*[24], the quantity and energy of the emitted electrons from the surface form an electric current that can be measured[25].

Another discovery concerning the interaction between light and matter that is relevant to media history harks back to Newton's 1666 experiments showing that white sunlight is not a single entity but a spectrum of infinite colours. Today, this principle has been extended to the idea of colour's immateriality and its absolute dependence on physical properties of the light spectrum and material it is in contact with.[26] When isolated, the energy of a monochromatic beam of radiation is related to its wavelength and frequency – measuring parameters commonly used either in scientific or aesthetic investigations.

Nonetheless, the immaterial condition of colour is questionable if one regards photosensitivity through the molecular structure of pigments. Visual pigments of vertebrates, for instance, share structural features in their molecular level, being basically constituted by an opsin apoprotein plus a chromophore.[27] Opsin, a group of light-sensitive proteins found in the photoreceptor cells of animals' retinas, mediate the conversion of a photon of light into an electrochemical signal. Chromophore is the part of the pigment molecule responsible for the colour (light spectrum) to be absorbed by the cell[28]. Photon capture through the photoisomerization[29] of the chromophore is the first step in the visual transduction cascade and the only light-dependent phase.[30]

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24 Kohen et al 1995:14-5.

25 Also, according to Kohen et al. (1995), when electrons are bound to atoms and molecules they have well-defined quantities of energy. The rise to the condition of radiation (absorption of quantum or emission of photon) only happens when they 'jump' from one orbit to another.

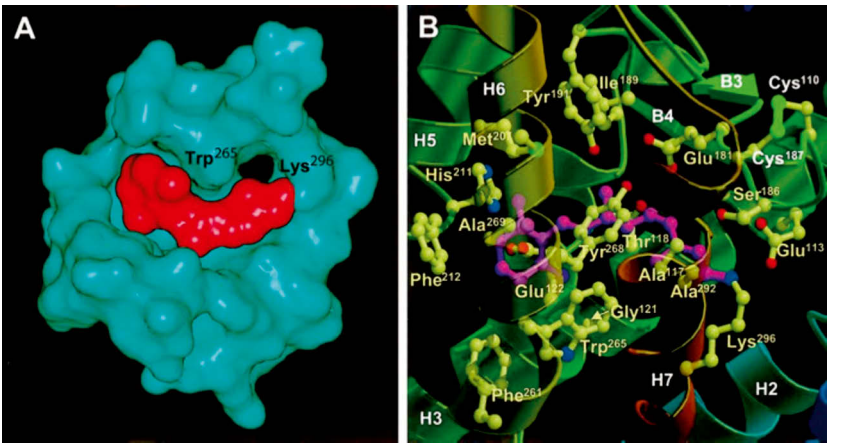
26 A complete publication bridging Science and Art in relation to the conceptual and phenomenological principles of colour, and its immaterial quality is Pedrosa, Israel. *Da cor à cor inexistente.* Rio de Janeiro : Léo Christiano, 1977.

27 Menon, Santosh T.; Han, May; Sakmar, Thomas P. Rhodopsin: Structural Basis of Molecular Physiology. In: *Physiological Reviews.* Vol. 81, n. 4, October 2001. p. 1660.

28 Parihar, Parul; Singh, Rachana; Singh, Samiksha; Tripathi, Durgesh Kumar; Chauhan, Devendra Kumar; Singh, Vijay Pratap; Prasad, Sheo Mohan. Photoreceptors mapping from past history till date. In: *Elsevier - Journal of Photochemistry and Photobiology, B: Biology* Vol. 162, September 2016, pp. 223–231.

29 An isomer corresponds to a molecule that presents more than one chemical structure for the same formula. Photoisomerization is the molecular behavior caused by photoexcitation that changes the molecule structures, although its formula remains the same.

30 Menon et al 2001:1661.



1.1: Detail of a chromatophore on a visual pigment in molecule model. A: Part in red; B: Part in magenta; Source: Menon et al 2001: 1663.

Concerning photosensitivity in the so-called inorganic side of photochemistry, a prominent role is ascribed to the chemical element silver and its derivate compounds, namely the silver halides (AgX)[31], such as oxide of silver, silver nitrate, silver chloride, silver bromide, silver iodide and iodate.

The pre-history of photography is attributed to the first experiments conducted by polymath Johann Heinrich Schulze (1687-1744) around 1725.[32] After observing that a leftover chalk and nitric acid into which some silver had been dissolved was darkened by sunlight, Schulze made experiments combining several materials with silver nitrates. One of them was to apply that same paste of silver nitrate and chalk in a glass bottle and wrap it in a piece of paper containing cut out letter shapes, which darkened after being exposed to light. Schulze's experiments, however, did not provide permanent images, which were mostly achieved by using objects (letters) as masks placed between the light source and light-sensitive surface.[33]

31 Many of the halides are salts, binary compounds with a halogen atom [fluorine (F), chlorine (Cl), bromine (Br), iodine (I), and astatine (At)] plus an element or radical that is less electronegative (or more electropositive) than the halogen. Fujita, Shinsaku. *Organic chemistry of photography.* Berlin/Heidelberg: Springer Verlag: 2004. pp. 39-44.

32 Hage, Wolfgang. Die Entropie der Fotografie. Skizzen zur einer Genealogie der digital-elektronischen Bildaufzeichnung. Referat Oberseminar Friedrich Kittler at Humboldt-Universität zu Berlin. July, 10th 2001. Available at <http://www.whagen.de/PDFS/11049_HagenDieEntropiederFot_2001.pdf> Accessed May 19th 2017.

33 Watt, Susan. Silver in photography. In: *The elements: Silver.* New York: Benchmark Books Marshall Cavendish, 2003. p. 21-24.

Although historians assert that Schulze's light-writing experiments anticipated photography[34], media archaeologist Friedrich Kittler (1943-2011) claims that this would be acceptable only for the literal meaning of the word 'photography', but not for the photographic process itself, which involves many more complex combined techniques. Kittler alleged that what was at stake in Schulze's experiments was encoding data rather than storing images by means of light: "*Schulze did not want to store the contingent nature of the real (in Lacan's sense of the word) in a technical medium, but rather he wanted to introduce the symbolic, namely a written code, into nature*".[35]

Predecessors of Schulze in the history of the photosensitivity of photographic technique – Joseph Nicéphore Nièpce (1765-1833), Louis Jacques Mandé Daguerre (1787-1851), William Henry Fox Talbot (1800-1877) and others[36] – were, in contrast, far more explicit in their intentions to fix and reproduce images due to its promising commercial and industrial purposes. Nevertheless, what is significant in Kittler's thinking is his media-archaeological ability to establish atemporal relationships among the operational qualities of media. This sort of analysis is possible so long as an accurate look at the materialities and operations is involved. If one compares the technical knowledge of materials and techniques with learning a language, the more one is acquainted with the grammar, the bigger the chances are that one uses one's own repertoire to create relevant information, or, in cases of artistic intent, poetry.

The chemical term 'emulsion' refers to the mixture of two or more liquid solutions; in photography, it refers to the photosensitive layer coated on the support being used, whether glass, cellulose acetate, celluloid, paper or other. Photographic emulsions are basically made by blending a neutral solution of silver nitrate[37] with any soluble halide and a medium to bind the emulsion to the surface.

At the molecular level of photochemical processes with silver halides, silver's photosensitive quality is explained by the breaking down process of silver nitrate into pure metal by the agency of light. For the same reason, many other silver-based compounds are photosensitive and are used not only for coating but also for developing films and, subsequently, in the transfer of the image to paper or another surface.[38]

The first experiments by the painter and physicist Louis Daguerre aimed at fixing an image using a camera obscura were done with silver iodide coated in a polished copper plate, which was later immersed in mercury vapour. The process

34 Eder 1978: 62 apud Kittler 2010:122.
35 Kittler 2010:122.
36 Hage 2001.
37 Silver nitrate ($AgNO_3$) is a compound formed from the mixture of silver metal (Ag) and nitric acid (HNO_3). Watt 2003: 15.
38 For more details see Fujita 2004.

resulted in expensive unique images, which later became commercially obsolete with the reproducibility enabled by the use of negatives and paper[39].

The photographic film still in use today is coated with silver bromide, the most common compound used in negative emulsions. Silver bromide is formed of positively charged silver ions (Ag^+) and negatively charged bromide ions (Br^-). When excited by a photon, a bromide ion starts a reaction that discards an electron, thereby becoming a bromine atom. The released electron joins the silver ion, forming a silver atom.[40] In this process, a latent image is formed, in which the clearest parts of the photographed image are the darkest parts marked in the emulsion, and vice-versa. The inverted colour nature of the latent image in the film is the reason why it is called a negative.

The quality and origin of the binding medium also influences the sensitiveness of the emulsion and was initially the albumin, or egg white[41], which was a pioneering and commercially successful method of producing photographic prints on paper from a negative. Another organic material that supplanted albumin was gelatine, a substance extracted from animal's bones, horns and paws. In 1871, photographer and physician Richard Leach Maddox (1816-1902) invented gelatine negative plates[42], which was more practical for commercial purposes than the former collodion wet-plates process. On paper, in turn, gelatine was applied in 1885, when photo-chemist Johann Baptist Obernetter (1840-1887) developed a gelatine-chloride emulsion printing-out paper.[43]

1.1.2 Toward more complex technical ensembles: immediate and colourful

The documentation of the technological environment of the industrial period shows that due to financial convenience or even military purposes[44] there was a constant search for more sensitive emulsions, that is, reactively faster materials, and the instantaneity of photographic processes. It is not by chance that technicians developing instantaneous cameras like the Polaroid managed to overlap film and paper functions. Such merging of functions in a single technical ensemble represents a

39 In 1841, chemist William Talbot introduced the negative-positive method in photography by using paper soaked in silver iodide to form an image. The technique was named calotype or talbotype. (Kittler 2010:132-136)

40 Watt 2013: 23.

41 The albumen silver print method was developed by the photography enthusiast Louis Désiré Blanquart-Evrard, who published his findings in 1847. Newhall, Beaumont. 60,000 Eggs a day. In: *IMAGE Journal of Photography of the George Eastman House*, Vol. IV, n. 4 April, 1955.

42 Viebig, Reinhard. *Tudo sobre o negativo – revelação, correção e sua aplicação.* São Paulo: Editora Iris, 1975, p. 13-15.

43 Newhall 1955.

44 Kittler 2010 and Viebig 1975.

trend toward convergence that has been accelerated by electronics and digital technology.

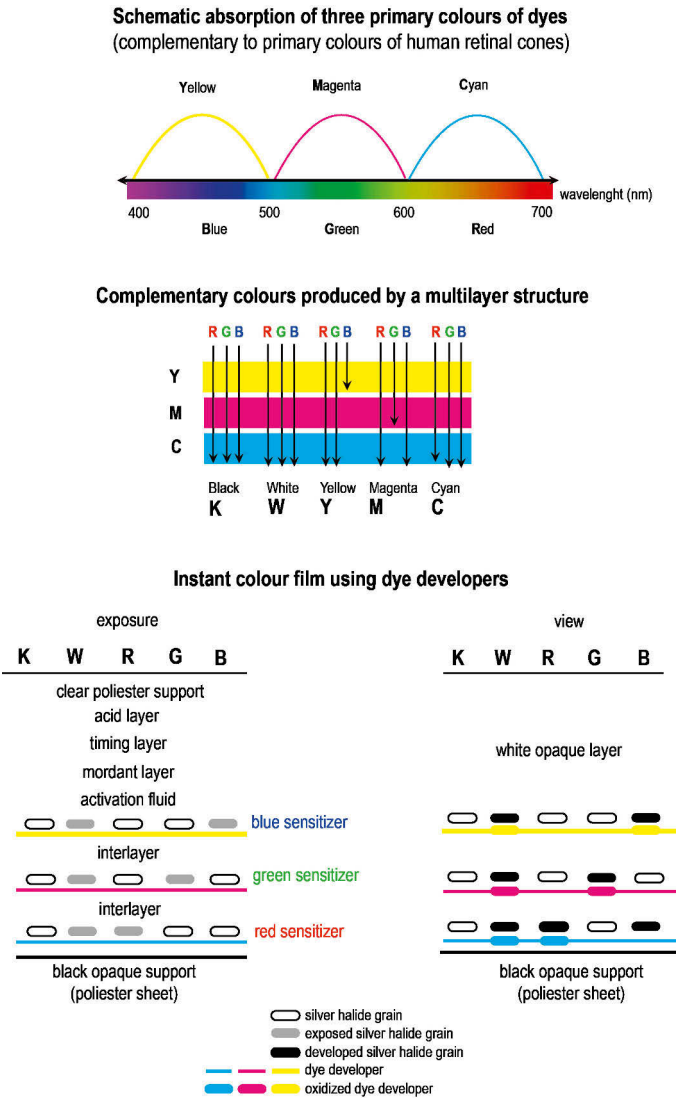
Another result of the supremacy of vision in western culture and the related drive to obtain images more attuned to the capacities of the human eye were demands for the development of colour film. Instead of one layer of light-sensitive particles, colour film has three light-sensitive layers, each sensitive to a specific range of the light spectra: blue, green and red. This combination from the RGB colour model, which was based on the Young–Helmholtz[45] theory of trichromatic colour vision, was developed at the beginning of the 19th century and influenced by studies on the photoreceptor cells of our eyes[46]. Young and Helmholtz's research results guided the development of colour-film, motivating the creation and application of dyes able to absorb or reflect each of the RGB light spectra. According to Kittler, the pioneer in converting the new colour physiology into a technical ensemble was James Clerk Maxwell (1831-1879)[47], who was the first to develop long-lasting colour photography.

The figure below relates the Young-Helmhotz theory to a multilayer structure model of how an instant colour film works during exposure and after development:

45 Thomas Young (1773-1829) was a British polymath who contributed to the fields of vision, light, solid mechanics, energy, physiology, language and Egyptology. Hermann von Helmholtz (1821-1894) was a German physiologist, physicist psychologist and philosopher. His treatise on physiological optics is the basis of modern studies on vision. Gregory, Richard Langton. *Eye and Brain – The psychology of seeing*. Oxford/Tokyo: Oxford University Press, 1998. p. 103

46 Kittler 2010:204.

47 Ibid.



1.2: A schematic from human cones sensitivity to the implementation of multilayer structure of instant colour film during exposure and after development; Source: Adapted from Fujita 2004:377-378.

The model didactically shows how the three primary colours, i.e., yellow(Y), magenta(M) and cyan(C) dyes react differently to red(R), blue(B), green(G) light spectra, forming a sort of filter cascade. Y dye absorbs B light so that G and R light

pass through transparent materials and, following the same logic, M dye absorbs G light; whereas C dye absorbs R.[48]

Colour film also faced an intriguing issue in its history when professionals noticed that emulsions of colour films were based on light-skin standards[49], and denounced the Caucasian bias behind the development of such a technical object. The polemic arose when this fact became a problem for the market itself, when photographers, for instance, had difficulties making adequate pictures of darker wood furniture. The fact became even more evident when people of colour started to be represented in mass and mainstream media more frequently. This case shows why scientists working on the very material aspects of things in their laboratories should not work in isolations from the ethical and political implications of their work. Half a century later, similar problems showing the lack of diversity in technological industry still arise, as in the creation of algorithms for face, smile or blink recognition. These examples can be used as an impetus to reflect on how problematic Western culture's traditional divisions can be, where the natural sciences are opposed to the humanities, and the natural world is opposed to man-made cultural objects.

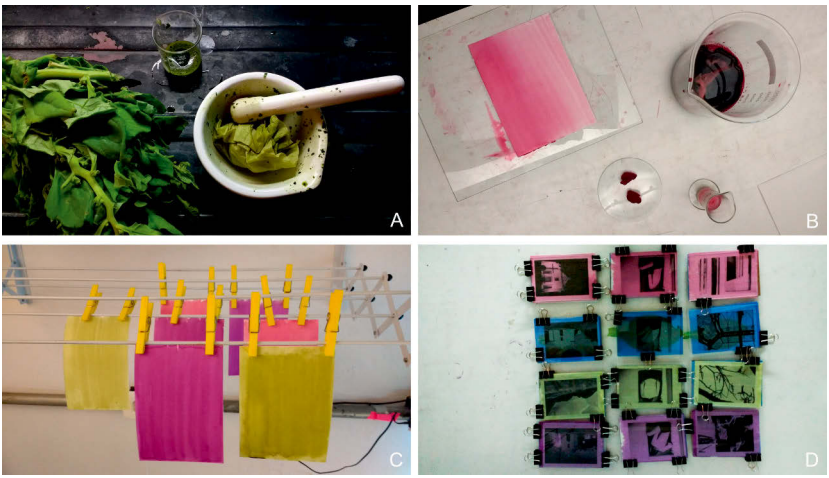
Recognizing that the absorption of specific wavelengths is colour-dependent, the use of dyes in sensitizing methods have been developed and used in several disciplines ranging from biology, to engineering, to art. An example of an aesthetic use of this can be observed in the production of Anthotypes through a technique to print photographic images using photosensitive matter from plants and sunlight. Like other image production techniques, it has emerged as the result of the inventions and discoveries of many people. Prominent historical examples include the pharmacist Henri August Vogel (1778-1867), who in 1816 noticed that plant juices were light–sensitive; and polymath John Herschel (1792-1871), who conducted extensive and systematic research on the topic, publishing it in 1842. The work by polymath Mary Fairfax Greig Somerville (1780-1872), who researched the action of rays on vegetable juices, has gained acknowledgment more recently.[50] Today the technique is still executed according to the following main steps: extracting the emulsion from the plant using either pestle and mortar or an electric blender, adding water or alcohol as diluter if necessary; coating the paper surface with the emulsion; framing the positive image or masking objects with the paper; and ex-

48 Fujita 2004:106.

49 More detailed explanation of this aspect of film colour history can be seen at <https://www.youtube.com/watch?v=d16LNHIEJzs> Accessed March 17th 2017.

50 According to Fabbri, Sommerville was not able to publish her ideas and findings simply because she was a woman. Fabbri, Malin. *Anthotypes – Explore the darkroom in your garden and make photographs using plants.* Stockholm: Alternative Photography, 2012. p. 12.

posing it to sunlight for bleaching.[51] The time of exposure and the transformations in colours vary widely depending on the light spectrum to which each pigment is sensitive, which is determined by its molecular composition (as already explained when introduced the chromophore). It is also known that pigments are generally more sensitive to UV light, the major "molecular destroyer" radiation.



1.3: Sequence of procedures for making an anthotype. A: Crushed spinach with pestle and mortar; B: Coating process with beetroot extract; C: Coated paper drying. D: Framed anthotypes ready for exposure to sunlight. From above to below: pigment from beetroot, tobacco leaves, pigment from spinach and red rose. Anthotypes produced at the workshop of Simone Wicca at Imagineiro in January 2017 in São Paulo. Photos: Graziele Lautenschlaeger.

After the anthotype is unframed, if the image formed is kept exposed to sunlight it will continue bleaching, resulting in its total disappearance. There remain difficulties even today when it comes to fixing the image from natural pigments on the surfaces, a problem encountered when using natural dyes for fabric as well. This, coupled with its non-immediate results, left anthotyping quite marginalised, but it continues to be used by artists and alternative photographers. Contemporary practitioners of this technique are the artist Malin Fabbri[52], who has systematized a series of experiments she made using fruits, leaves, flowers and roots from temperate regions and the artist Simone Wicca, who has been doing similar work using tropical plants.

51 A more detailed and didactic tutorial can be found on the webpage Alternative Photography: <http://www.alternativephotography.com/anthotypes-making-print-using-plants/> Accessed May, 5th 2017.

52 Ibid.

The search for immediacy is related to the human compulsion toward the materialization of memories and the desire for eternity, as has been frequently discussed in the history and theory of photography and the image by many authors[53]. Nevertheless, the extreme increase in the speed of image production and consumption through digital and networked technologies has contradictorily reinforced the elusive aspects of imaging. In this sense, a paradoxical outcome of media development is an invitation to revisit the elusiveness of life.[54]

Curiously standing out is the difference between the darkening effect of silver salts in photography and the bleaching effect of organic matter. In the first case, the photoreduction of silver ions into silver metal produces the effect, and the colour shade changes according to the energy and intensity of the irradiating light source. The higher the concentration of the salts is, the earlier the colour changes. In the second case, the molecules are also broken apart by UV light, in a process that is different for each pigment, and chromatophore cannot be seen anymore.

1.1.3 The knife gets sharper: fragmenting, black-boxing, converging and operating

This survey of a few of the methods and materials relating to photosensitivity in photographic techniques clarifies how photochemistry enables artists to manipulate materials on the atomic level to achieve specific, and sometimes unexpected, aesthetic results. This kind of exploration, beyond the direct capacities of the human senses, has become more and more refined. As Vilém Flusser used to state regarding the advances in precision, miniaturization and the corresponding abstractive processes in the development of cultural objects: *"The knife is getting sharper"*[55]. When diving into the molecular universe, it is the logic of quantum mechanics that rules. Matter is understood as energy, whose measurement is, incidentally, also dependent on our understanding of the nature of light and its discrete amounts of energy, called photons and quanta.

The scientific discoveries that led to nanotechnology were crucial for the development of semiconductor materials and devices. Among other properties (passing current more easily in one direction than the other, showing variable resis-

53 One of special significance for this work is Debray, Regis. *Vida e morte da imagem. Uma história do olhar no ocidente*. Petrópolis, RJ: Vozes, 1993.

54 Perhaps the emergence of more sustainable biological matter-based techniques also constitutes a side-effect of the aforementioned desire for eternity, as a human attempt to avoid the extinction of their own species.

55 From the original in German: "*Das Messer wird immer schärfer*"; Flusser's sentence was discussed and debated at panel discussion *Flusser Talks "Entwerfen" – Im Dialog mit Vilém Flusser*, as part of the exhibition *Bodenlos - Vilém Flusser und die Künste*, held in Berlin at the Akademie der Künste in Nov, 25th 2015.

tance) they are also heat and light sensitive – turning the distinctive borders of these two physical qualities blurred again. Semiconducting materials include, for instance, silicon or germanium, whose semi-conductive behaviour was first recorded with the use of silver sulphide crystal in 1833. Nowadays, technologies like CMOS (Complementary Metal-Oxide-Semiconductor), CCD (Charged-Coupled Device) and QIS (Quanta Image Sensor), which constitutes one of the essential photosensitive components of digital cameras, are completely based on the special behaviour of those materials. More details about these devices will be explored in the following chapter.

Important now is to notice that in the era of quantum physics, in which energy and matter are proportionally related and human hands are too large for the scale of atoms, it became necessary to build bridges between the capacities of the human sensory apparatus and the materialities being handled on the nano scale. Curiously, the further things are removed from the human senses, the more radical the possibilities for material modifications are.

When the miniaturization process started leading to devices becoming even more radically opaque, media history again experienced a turning point. Miniaturization triggers both the black boxing effect, as Flusser and cyberneticist Ranulph Glanville (1946-2014), each in his own way, have reflected[56], and the convergence of techniques. Black boxing refers primarily to electronic devices whose circuits and way of working are hidden in their containers. Glanville, however, expands the concept from the cybernetic perspective:

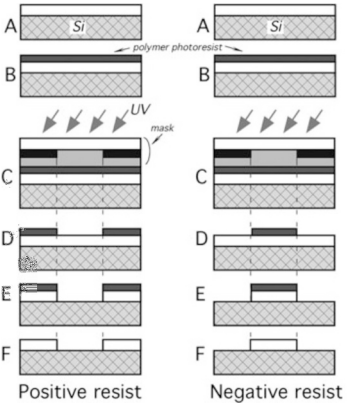
> Black Box is not a physical object, but a concept (a phantasm) we use in order to develop what Bateson calls an explanatory principle, which we evoke when we are faced with an uncertain confusion. It has no substance, and so can neither be opened, nor does it have an inside. Its function is to allow the creation of an explanation of some observed behaviour and any object/mechanism that seems to generate this about which we are uncertain. It is the invention of the observer.[57]

Convergence, in turn, concerns the merging of techniques and the emergence of multi-task technical objects. A key technique related to photosensitivity that addresses this issue is photolithography, a sort of photoengraving procedure that plays a crucial role in the transition and intersection between analogue and digital media objects. Photolithography is a microfabrication process that transfers shapes from the template of a photomask to the surface of a photoresist on a substrate. The photolithographic process demands many precisely stipulated procedures, tools and materials, executed through three main phases: coating, light ex-

56 Flusser, Vilém. *Filosofia da caixa preta*. São Paulo: Annablume, 2011. Glanville, Ranulph. *Objekte.* Berlin: Merve Verlag, 1988.

57 Glanville 2009:154.

posure and development; it is, however, a mixture of photographic and printing techniques that can be repeated many times, layer over layer, depending on the chip geometry[58].



1.4: Positive and negative photolithography steps; Source: Fraden 2004: 627.

Photoresists are photosensitive chemical substances that can be either positive, if after the exposure to light it becomes soluble to the photoresist developer, or negative, in the opposite case. The substrate, popularly called wafer, is a solid planar substance onto which a layer of the photoresist adheres. In solid-state electronics, the materials used as substrates are thin slices of silicon, silicon dioxide, aluminium oxide, sapphire, germanium, gallium arsenide (GaAs), an alloy of silicon and germanium, or indium phosphide (InP). These make up the material basis of electronic components such as transistors, diodes and integrated circuits.

From an historical perspective, according to the media theoretician Sean Cubitt, *"it is in the highly technical craft of the photographic print that the major shift toward electronic image forms begins"*[59]. In the nineteenth century, photolithography had already stimulated the industrialization of image production, *"providing fast, cheap, mass circulation reproductions of photographs that themselves were far faster and cheaper to produce than traditional etched or drawn forms"*[60]. Currently applied in microprinting electronic circuits, photolithography is among the main techniques now used in the production of printed circuit boards (PCBs), integrated circuits (ICs) and

58 Fraden 2004: 548-549.
59 Cubitt 2014: 80.
60 Ibid: 89.

microcontrollers. Each of these is based on the operations enabled by semi-conductors[61], the protagonists of the electronic and digital era.

After the 1950's, when *"photolithography ha[d] become the major tool for printing circuit boards for computer components"*[62], the automation process of image production transformed the former merely representational image into a working and functional image as well, an image whose visual content is far from having the same importance as it had been accustomed to having in media history. Scanning and photocopying techniques at the beginning of the electronic era[63] were the prelude of how electronic components, led by electronic media, triggered a transformation in the creative world. In this context, the photolithographic technique and the manifold logic-based electronic components confirm that photosensitive materiality has long been playing a major role in media development. This is even more apparent if one considers the light-sensitivity based fundamental electronic components, such as photodiodes, photoresistors, phototransistors and photomultipliers.

The idea of a printed circuit as a functional and operative image can serve innumerable purposes since one can designate its function and content, and therefore link other electronic components to create a more complex technical ensemble. By bringing the materiality and programmability of electronics together, the dichotomous distance between analogue and digital techniques becomes less formidable and could elucidate a way to see both as a continuum[64].

Another milestone related to photosensitive materialities in media history dates from the discovery of the "semiconductors' grandfather", the chemical element selenium[65]. Although it was discovered in 1817 by chemist Jöns Jacob Berzelius (1779-1848), it was only more than half a century later, in 1873, that the electrical engineer Willoughby Smith (1828-1891) demonstrated selenium's photosensitivity and its ability to transform light energy into electricity. In *The Moon*

61 According to sensor engineer Hans Meixner, "*With LIGA procedures (lithography, electroforming, molding), microstructures can be implemented from a wide range of materials, such as metals, plastics and ceramics. Silicon clearly dominates the materials used at present, but metals, plastics and glasses are gaining in importance*". (Meixner 2003: 23)

62 Cubitt 2014: 83.

63 Ibid: 5.

64 In other words, this can also be discussed through the interdependence between software and hardware, as Wendy Hui Kyong Chun has elaborated in *Programmed Visions* (2011).

65 According to the physicist Allan Mills, together with sulphur and tellurium, selenium falls into Group VI of the periodic table, sharing similar chemical properties. Sulphur has been known since ancient times since it occurs in the free state around the vents of active volcanoes. The discovery of selenium by Berzelius was based on its separation "*from a deposit formed in a lead chamber used for making sulphuric acid from roasted iron pyrites. Tellurium was isolated from the same source in 1832. Nowadays, both elements are obtained from the 'anode slimes' that are by-products of electrolytic copper refining.*" Mills, Allan. Selenium and light. In: *eRittenhouse* Vol. 24, 2013. pp. 1-7.

Element (1924),[66] the physicist and chemist Edmund Edward Fournier d'Albe (1868-1933) presented the wonders of selenium and its main known applications at that time, ranging from the construction of automatic systems, through experimental devices for voice, text and image transmission to other future speculative uses. The discovery of selenium has in fact led to the development of the technology of television as well as subsequent technologies for the transmission of images through electric current – i.e. image fragmentation for transmitting purposes. Observing this material technological episode, it is possible to confirm what Cubitt has already stated, namely that the technological transition to electronic media can also be seen as a shift of focus from storage to transmission. This coincides with the efforts made in the 1970s to concentrate strategic research and development goals primarily on microelectronics[67]. According to Kittler, it is probable that *"the history of the development of television was the first realization through electronics of all of the functions named in Shannon's information theory"*[68]. This point is likely one of the foundations of the dichotomy between analogic and digital, which Kittler clearly distinguished, without, however, sticking to any particular class of media. In his view:

> In principle there are two possible solutions: in the first case, the signal generated by the sender corresponds proportionally to the message, which means that it follows all of its changes in space and/or time. This is called analog communication, as in the case of gramophone, microphone, radio or even photography, and while it is more familiar it is also unfortunately more difficult mathematically. In the second case, the message is broken down into its pure constituent elements prior to transmission in order for it to fit the capacity of the channel, which is in principle always physically limited. These elements are entirely of the same type,

66 Fournier D'Albe, Edmund Edward. *The Moon Element – An introduction to the wonders of selenium*. New York: D. Appleton and Company/London and Aylesburry: Hazell, Watson &Viney, 1924. Bell, Alexander Graham. The Photophone. In: *Science* Vol. os-1(12), September 11, 1880, p. 130-134.

67 According to Hans Meixner, the focus of scientific research in the 1980s shifted to materials research and information engineering. The 1990s was marked by miniaturization and the integration of functionalities. Meixner, Hans. Sensors and Sensing: An Engineer's View. In: Barth, Friedrich G; Humphrey, Joseph A.C.; Secomb, Timothy W. (eds.) *Sensors and sensing in biology and engineering*. Wien/New York: Springer, 2003. p. 18. It is possible that beginning in the 2000s an intensification and simultaneity of all the previous trends occurred, culminating in the search for cross-disciplinary research and making simple linear progressions absolutely impossible.

68 Kittler 2010: 208. Shannon's general model of a communication system and its internal mechanism is based on the following elements: (a) data source(s), translator(s), channel(s), receiver(s) and data sink(s).

> such as letters in the case of a spoken message or numbers in the case of computer technology or the individual pixels of a monitor.[69]

Kittler goes on to further explain how the mathematical information processing leads to its fragmentation: *"in partial contrast to film, which consisted of a discontinuous or discrete sequence of many analog photographs, television began as radical cutting: it not only cut up movements in time, but it also disintegrates connections or shapes into individual points in space"*.[70] This disintegration is becoming more radical with the enhancement of algorithms behind the codecs currently applied to digital images[71], irrespective of the purpose they are developed.

1.2 Photosensitive materials and related operations

Sunlight is one of the prerequisites for life on Earth. It governs several biological processes in plants and animals, directly and indirectly influencing the basic cultural developments towards measuring the physical properties of the world and systematizing daily-life. Light has been perpetually used and analysed by humans, both as a means of control and as a force that controls us.

The circular dynamic between photosensitive elements and their surroundings leads to the understanding that photosensitivity cannot be conducted in isolation. Photosensitive materials and devices are embedded in broader technical ensembles in order to execute operations that are more or less pre-determined by their context. Some of the operations in which photosensitivity may be implicated are signalling, measuring, calculating, computing, controlling, automating, regulating, self-organizing, and many others.

The human appropriation of the photo-sensing phenomena in the history of culture emerges, therefore, as acting upon the contingency of the world, with expressions that can assume a variety of forms, from neglecting and resisting, to accepting and adapting to external influences. Understanding the correlations between photosensitivity and these possible operations is aesthetically valuable for media art, whose creative processes are often sustained by the interplay between accident and control.[72]

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69 Kittler 2010: 45.

70 Kittler 2010: 209.

71 Cedeño Montaña, Ricardo. *Portable moving images: a media history of storage formats*. Berlin: De Gruyter, 2017.

72 This dynamic in media art was outlined by the author in her master's thesis *Arte Programmata: entre acidente e controle*, defended at University of São Paulo in 2010. The same principle as an aesthetic motif in *Neue Musik* in the 1950's was discussed in the publication Lammert, Angela; von Amelunxen, Hubertus (Ed.) *Kontrolle und Zufall - Iannis Xenakis*. Berlin: Akademie der Künste: 2011.

An advance in the human attempt to master contingency turned sensors into protagonists of the current Internet of Things (IoT) phenomenon. In IoT all kinds of sensors can be embedded in networked objects and bodies, providing companies with the largest possible amount of data on people's actions (from personal biometric data to physical movements on the planet) in order to better understand the behaviour of their potential consumers. On the one hand, IoT represents a market-driven commoditization of the immaterial side of information society. On the other hand, the large scale of data collected and made available for analysis offers the chance for informatics experts to make new discoveries related to the implementation of algorithms in Artificial Intelligence (AI). The novelty here lies less in advancements in mathematics or programming than in the increase of infrastructures, which range from faster and faster processors to more and more widely distributed internet, and the enhanced implementation of already known techniques on the molecular level[73].

A reflex response to these two trends in contemporary media art aesthetics can be seen in the guidelines of important media, technology and society events, such as the Transmediale 2017 exhibition on *Alien matter*[74] curated by Inke Arns and Ars Electronica's 2016 *Radical atoms and the alchemists of our time*[75], inspired by Hiroshi Ishii's theory and practice at the MIT Media Lab/Tangible Media Group and complemented by comments and critiques by Joseph Paradiso, Siegfried Zielinski and others.

In order to establish a dialog between photosensitive elements, their operations and their influence on the aesthetics of media artworks, four of the manifold possible operations involving photosensitive elements have been selected: measuring,

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73 Bensaude-Vincent, Bernadette. Materials as machines. Paper read at the workshop "Science in the Context of Application: Transformations of Academic Research" at the *Zentrum für interdisziplinäre Forschung*. Bielefeld, Oct 26–28th, 2006. Later published In: Nordmann, A. Carrier, M. (Eds.) *Science in the Context of Application*. Dordrecht: Springer 2010. pp. 101-114.

74 Curatorial statement from the exhibition's program: "*'Alien matter' refers to man-made, and at the same time, radically different, potentially intelligent matter. It is the outcome of a naturalization of technological artifacts. Environments shaped by technology result in new relationships between man and machine. Technical objects, previously defined merely as objects of utility, have become autonomous agents. Their capacity to learn and network throws into question the previously clear and dominant division between active subject and passive object. 30 exhibiting artists from Berlin and around the world present works about shifts within such power structures, raising questions about the state of our current environment and whether it has already passed the tipping point, becoming 'alien matter'. Content-wise, the works cluster around four thematic focal points: Artificial Intelligence, plastics, infrastructure, and the Internet of Things – subcategories that are deemed to merge into the nascent great machine and thereby, to speak with Günther Anders, are future obsolete*". (Arns 2017: 3)

75 Stockler, Gerfried; Schöpf, Christine; Leopoldseder, Hannes. *Radical atoms and the alchemists of our time.* Linz: Hatje Cantz, 2016.

automation, controlling and self-regulating. The next sections introduce how these operations are dependent on the combination of techniques and symbols present in their specific technical ensembles. Analogously to the potential articulations of elements in a language, the combinations of technical elements are infinite and can be made to serve a variety of purposes.

1.2.1 Measuring

The earliest known use of measuring coincided with the birth of ancient civilizations in Mesopotamia and Egypt about 5000 years ago. Measuring is part of what the philosopher of technology Bernard Stiegler (1952-) intended to describe with his idea of 'prosthetic human beings', whose nature is necessarily characterized by being makers and users of tools[76]. The idea of being human has become inseparable from the behaviour of measuring the objects as a strategy to understand and act upon the perceived and the non-perceived worlds. This human behavioural trend is intensified during epochs in which rationalization dominates society. In Western culture since the Enlightenment the scientific penchant toward measuring, codifying and classifying has increased exponentially.[77] In this context, measuring has been used as a strategy for comprehending phenomena that one cannot perceive directly with the limited human sensory apparatus.

One of the most ancient uses of light as a parameter for measurement was to measure time by grading the variation of projected shadows from obelisks and solar clocks. This concerned measuring another physical entity through light, which is different from measuring light itself, a task that became the subject of early scientific experiments in the Enlightenment and continued into the modern era. It was through measuring experiments focused on the nature of light that Western thinking transitioned from geometrical optics[78] to wave optics. At the same time, such experiments have led towards the deconstruction of a concept of light based strictly on human visual perception. The current understanding of light in physics holds that: *"light is only a very small part of the enormous range of electromagnetic radiation. It is those wavelengths to which the retina of the eye is sensitive"*[79].

76 Based on Stiegler's writings, Cubitt states that humans have "an insufficient body that requires, for its survival and for its relation with the world, the supplement of technology". (Cubitt 2014: 14)

77 Hausmann, Raoul. Mathematischer Beweis ist das Hauptargument des europäischen Menschen. Berlin, 19.Feb 1927 In: *Dada-Wissenschaft: Wissenschaftliche und technische Schriften*. Hamburg: Philo Fine Arts/Berlinische Galerie - Landesmuseum für Moderne Kunt, Fotografie und Architektur, 2013. p. 140.

78 Geometrical optics deals with light as rays, exploring its behaviours in reflection (Kohen et al 1995: 3-4), refraction (Ibid: 4-5) diffraction (Ibid.: 11-13).

79 Kohen et al 1995: 3.

Only a few years after Newton's pioneering work on the particle theory of light, the astronomer Christiaan Huygens (1629-1695) proposed around 1678 that light might consist of waves. Later, at the beginning of the nineteenth century, Thomas Young empirically confirmed this proposition by measuring light wavelengths.[80] The measuring apparatus used to study light spectra individually and in combination is the spectrophotometer, a device whose construction was made possible by technical advances related to photosensitive materials. Light wavelength as a measurable parameter enabled further discoveries, such as the existence of infrared radiation by Sir William Herschel (1738-1822) in 1800 and of ultra-violet radiation by Johann Wilhelm Ritter (1776-1810) in 1801, when the latter noticed that the photochemical action of blue and violet light in silver chloride continues into ultraviolet[81].

These historical examples briefly introduce how the act of measuring has continuously led to new discoveries about light's nature and the emergence of new postulates in optics, as well as how it later contributed to the origin of quantum physics[82]. Furthermore, the field of spectrophotometry, defined as *"the quantitative measurement of the reflection or transmission properties of a material as a function of wavelength"*[83] plays a crucial role for several kinds of research concerning photosensitive materialities, due to the intrinsic relationship between photosensitivity and pigment colours, measured as wavelengths.

A much simpler light measuring technique that is nevertheless highly relevant to the photography industry is the photometer (synonymous with light meter or spot meter). It was initially produced as a separate device in the second half of the nineteenth century, with what were considered as successful models already available on the market in the 1860s.[84] Following the increase in automatic features of the photographic process, the photometer had become a built-in device in cameras for the first by the end of the 1930s, but they only became more accessible in

80 This outline of scientific experiments with light was mainly extracted from Kohen et al, 1995: 2-14 and Le Grand, 1970: 2-4.

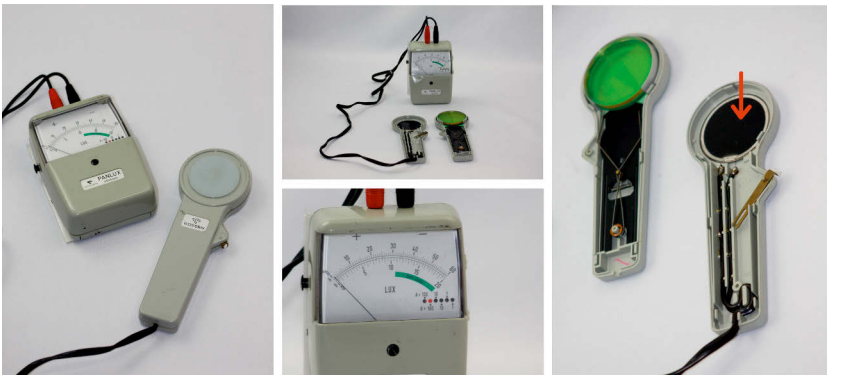
81 Kohen et al 1995.

82 Quantum theory developed from the combination of Max Plank's (1900) and Albert Einstein's (1905) theories. Plank's theory stated that "all energy exchange between matter and radiation takes place in a discontinuous manner, by multiples of a fundamental energy unit or quantum" while Einstein merged wave-particle principles, promulgating the dual nature of light and bringing "the quantum into a mainstream of scientific thought". (Kohen et al 1995: 13)

83 NIST – National Institute of Standards and Technology from the U.S. Department of Commerce. <https://www.nist.gov/programs-projects/spectrophotometry> Accessed February 15th 2016.

84 Johnston, Sean. A history of light and colour measurement: science in the shadows. Boca Raton, FL USA: CRC Press Taylor & Francis Group, 2001.

the SLR cameras of the 1960s[85]. However, since the embedded photometer could not be placed close to the photographed object, it remained a professional tool for obtaining more specific and precise data samples of light incidence.



1.5: Gossen's PANLUX Electronic Luxmeter. Photo: Graziele Lautenschlaeger; Source: Media Archaeological Fundus/Institut für Medienwissenaschaft/Humboldt-Universität zu Berlin.

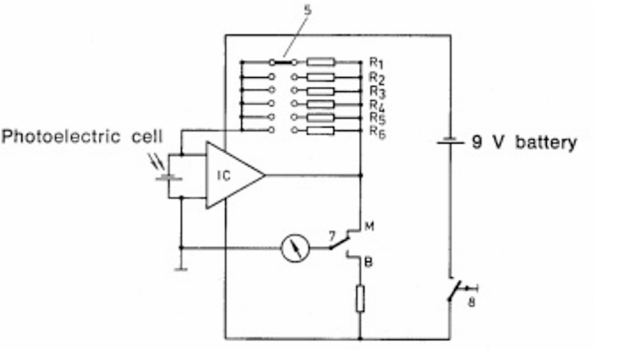
The functionality of this device is based on the material behaviour of the selenium cell, the thin dark round-shaped plate placed in the so-called cell unit by the fabricant[86], indicated in figure 1.5 by the red arrow. By means of designing selenium cells, light became measurable through changes in the material's resistance.

As one can observe in figure 1.6 below, the schematics of the photometer's circuit consist basically of a variable resistor (photoelectric cell) coupled with a switching mechanism (indicated by number 5) attached to a voltage divisor, represented by the series of resistors R_1-R_5. A voltage divisor is a typical technique used in electronics to produce an output voltage (V_{out}) that is a fraction of its input voltage (V_{in}), and it is often implemented to measure the resistance of a sensor. The sensor, in this case the photoelectric selenium cell, is wired in series with known resistances to form a voltage divider. Since a known voltage (9V) is applied across the divider, it is possible to measure the resistance variation caused by light in the

85 SLR means Single-Lens Reflex. As opposed to the Twin-Lens Reflex, SLR cameras present a mirror and prism system (hence "reflex" from the mirror's reflection) that permits the photographer to look through the lens and see an identical image of what will be captured by the camera.

86 Gossen's Panlux Electronic Luxmeter's operating instructions. April 1974. Available at <http://www.cameramanuals.org/flashes_meters/gossen_panlux_electronic_luxmeter.pdf>. Accessed April 18th 2017.

selenium cell. Changes in resistance are then transferred to the mechanical angular change of the pointer over a graduated scale in the display of the photometer, indicated in figure 1.6 by the arrow in the circle on the left side of switch number 7.



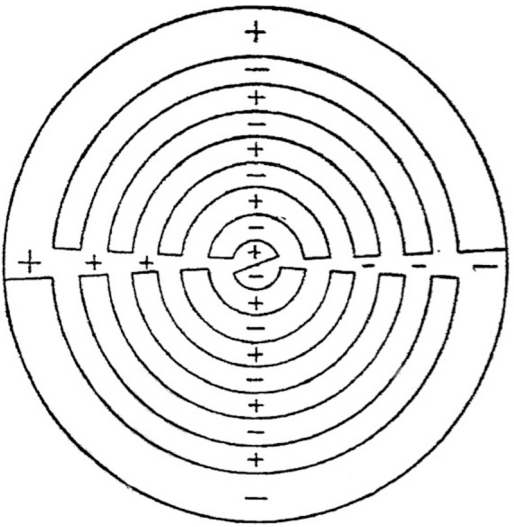
1.6: Internal circuit of Gossen's Panlux Lightmeter; Source: Gossen's Panlux Electronic Luxmeter's operating instructions p. 5.

To more sensitive cells, a crucial hurdle in the design of the cell had to be overcome. The challenge consisted in finding a bigger range of resistance variation. Presser's selenium cell, shown in figure 1.7 was considered by Fournier D'Albe one of the most successful attempts in the early 20th century, when initial experiments on the semi-conductive[87] behaviour of selenium were made. Presser's achievement was to come up with a configuration that optimized the area and the distance between the negative and positive poles of the cell.

According to Fournier D'Albe, the discovery of selenium inaugurated, among other things significant for the history of media, the possibility of measuring light independently from human eyes.[88] Before the invention of photometers, the measuring of light was based on estimations made by human eyes, which, as a biological element, is subject to the specificities of each individual being. The eye-brain system responsible for visual perception has the ability to adapt itself to new light conditions. An elucidating example is our ability to see and recognize the brightness of white either in shadow or direct light, at dawn or mid-day, under artificial or natural light sources, and so on. Photo and video cameras, on the contrary, disregard this adaptive feature and require one to set the parameter for what should

87 Among other properties, such as current flowing more easily in one direction than the other and showing variable resistance, semi-conductive materials are sensitive to light or heat. Examples include silicon and germanium, whose behavior as semiconductors was first recorded through the use of silver sulphide crystal in 1833.

88 Fournier D'Albe 1924: 36.



1.7: Presser's selenium cell; Source: Fournier D'Albe 1924: 41.

be considered white, called the white balance, in advance. Light meters likewise operate according to predefined parameters and standards, corresponding to the film or image sensor being used in the situation. Contradictorily, other defined standards in photometry, such as luminance[89] or luminous flux[90], include human senses and perceptive abilities as parameters for light measurement. This also explains the continuous efforts in image technology engineering to match machine perception with that of the human eye[91]. Radiometry, in turn, is the measuring science that insists on the supposed objectivity of the measuring act, providing unit scales for physical light, such as wavelength and frequency.[92]

89 Luminance measures the luminous intensity per unit area of light travelling in a given direction, either emitted or reflected from a specific area (cd/m²candela per square meter) (SI). It is often used to characterize emission or reflection from diffusing surfaces, indicating how much luminous power can be detected by a human eye looking at the surface from a specific viewpoint. (Fraden 2004: 129-132) In electronic imagery equipment it refers to the displays' brightness. (Kittler 2010: 204)

90 In photometry, luminous flux, or luminous power, is the measure of the perceived power of light by means of parameters that reflect the varying sensitivity of the human eye. It differs from radiant flux, the measure of the total power of electromagnetic radiation, including infrared and ultraviolet spectra. For more details see Fraden 2004: 129-132.

91 Flaxton, Terry. HD Aesthetics and Digital Cinematography. In: Cubitt, Sean; Palmer, Daniel; Tkacz, Nathaniel. *Digital Light*. London: Open Humanities Press, 2015. p. 81.

92 Cubitt 2014: 276-7.

Within this circular movement between the desire for objectivity in the act of measuring and its interdependence with subjective human perception, Cubitt also draws attention to the fact that light is measured by creating units from a continuum, just like the measurement of colour, in which polychromatic light spectra are divided into wavebands defined as a monochromatic spectrum. Another example of the fragmentation of the continuum is seen in the experiments around the photoelectric effect, which enabled the atomic "packets of light" (photon or quantum) to be measured as an electric current. In these examples, measuring as an act of fragmentation or discretization signifies the paradigmatic way that humans understand and act upon the world.

The development of increasingly complex measuring devices would not be possible without the parallel developments in operational images and circuitry formed by ever tinier elements, such as photoresistors, photodiodes and photomultipliers and phototransistors. The internal elements of a photometer are photoresistors, which can now be made of a variety of semiconductor materials, such as cadmium sulphide (CaS), cadmium selenide (CaSe), lead sulphide (PbS), indium antimonide (InSb), etc. When applied in counting and measuring contexts these materials enable a physical entity to be translated into an abstract system of units. Even though measurement strives towards objectivity, it nevertheless requires data interpretation. The act of measuring implies the abstraction of matter in such a way as to adapt the physicality of the world to the human senses and cognitive abilities.

1.2.2 Automating

To a certain extent, measuring and automating are intimately related. One cannot automate without first measuring, calculating and programming. Harking back again to the classic example of photography, in the golden age of film negatives measurement was crucial to the dawn of image production automation, from image capture to its reproduction. The integration of photosensitive materials in image production by the technical ensemble of the photographic apparatus triggers its automation process[93], which is a trend that goes hand in hand with the obsession with fixing, storing, reproducing, transmitting, and even generating the image in the fastest way possible.[94]

Behind photographic image creation, there is an intense manipulation of values and parameters[95] by professional photographers, who work hard at finding the

93 Couchot, Edmond. "The automatization of figurative techniques: towards the autonomous image". In: Grau, Oliver. (Ed.) *Media Art Histories.* London, Cambridge: The MIT Press, 2007.

94 Adams 1995b, 29ff, 181 apud Cubitt 2014: 87.

95 They are, for instance: Illumination conditions, distance to the object/subject, focal length, aperture, exposure time, lenses efficiency; film speed or image-sensor architecture and sensibility, if analog photography: type of developer, duration, temperature and agitation during

correspondences between all the technical variables and the material image that results. In *The Negative* (1948), although speaking about image values and developing "The Zone System"[96], Ansel Adam's recalls *"that photography is not only the recording of light but also its complex translation into the peculiarly granular texture of the print"*[97].

The manipulation of mathematical parameters, whether in photography or any other media, is, however, open to creative intervention, which is imperative if one wants to achieve symbolic and poetic results normally present in what is culturally understood and named as art. Sean Cubitt's analysis of Ansel Adam's work asserts that an *"obsession with technical prowess cannot substitute for an intuitive grasp of these variables (...) The richness of photography is that it is irreducible in Adam's world, to automation. (...) he (...) seems quite happy that manufacturers of light meters fail to agree on a common standard"* [98].

Nevertheless, the openness of the instantaneous photographic act can paradoxically be joined with its related automatic processes. For Flusser, who also wrote a theory of photography[99], the concept of automation entails the rapid computation of coincidences, i.e. of the blind and inert junction of atoms (and other elements) by chance.[100] From the standpoint of this definition, Flusser's concept of software *"means the automation in the precise instant in which the desired coincidence takes shape"*[101]. Flusser's definition of software suggests a compromise between automation and the openness required by aesthetic propositions. This is a powerful perspective when adopted in the context of media art, where artists aim at making poetry out of the development of automata and other automated processes through an extensive variety of techniques.

The emergence of automata, which are often based on the implementation of light-sensitive materials and devices, has followed the internal dialectic of culture and its logic of constant creation and removal of obstacles[102]. So long as human beings need to solve ever more complex problems using measured and collected data, whether from the surrounding environment or from their own body, it will

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the development process, type and duration of fixing and the care taken in washing and drying the negative; type and quality of printing materials and paper, duration of exposure for different areas of the negative, the final viewing conditions of the print and so forth.

96 Adams, Ansel. *The Negative.* Boston, New York, London: Little, Braow and Company: 1981. pp. 47-98.

97 Cubitt 2014: 88.

98 Cubitt 2014: 87.

99 Flusser 2011.

100 From the original excerpt in Portuguese: "*significa rápida computação de coincidências, junção cega e inerte de átomos (e outros elementos) ao sabor do acaso*". (Flusser, 2008: 76)

101 From the original excerpt in Portuguese: "*significa a automação no instante preciso no qual a coincidência desejada se forma*". (Flusser 2008 : 76)

102 Flusser, Vilém. O design : um obstáculo à remoção de obstáculos? In: *Uma filosofia do design: A forma das coisas.* Relógio D'Água, 2010. pp. 57-61.

be a necessity to create machines able to process that data. This is one of the reasons for the perpetual birth of new automatons and computers, as well as the increasing human dependence on automated systems. However, since wishing to stop this historical cultural engine is futile, one of media artists' duties is to engage in selecting the 'most desired coincidences'.

In the history of techno-cultural objects, automatons – self-operating machines[103] – have existed in Ancient Egypt, Hellenistic Greece and, later, in 13th century Islamic Culture, some of the exemplars of which were documented by polymath Al-Jazari (1136-1206) in the *Book of Knowledge of Ingenious Mechanical Devices* (1206)[104]. In late medieval Europe, the documented survivors of time include the praying monk automata from circa 1560, located at the *Deutsches Museum* in Munich[105] and the Jaquet-Droz family's writing and drawing puppets from the 18th century, some of which are in the collection of the *Musée d'Art et d'Histoire of Neuchâtel*, in Switzerland. The most recent examples of automata have emerged from the hybridization of machinic principles with life sciences, with the development of nanomachines and biosensors[106]. Besides the miniaturization of automated technical objects, the technology currently available points towards the physical concretization of the old dreams that have long fed initiatives on animated matter, the foundations of animism and the sensualist movement.

Automating possibilities were boosted and enhanced by the development of computing machines, the technology with which the notion of automata is most popularly associated. Early exemplars of computing machines featured a series of devices called relays, electrically operated switches able to perform logical operations that, among other things, enabled controlling a high current circuit using a separate lower current circuit as a binary actuator.[107] Historically relays stem from the last decade of the 19th century, when they were used as technical solutions for telephone networking[108] and in machines for accounting and tabulating. Among

103 In the glossary opening *Filosofia da Caixa Preta*, an automaton is defined by Flusser as "*apparatus that obeys a software that develops at random*". (Flusser 2011: 17)

104 Nadarajan, Gunalan. "Islamic Automation: A Reading of Al-Jazari's The Book of Knowledge of Ingenious Mechanical Devices (1206)" In: Grau, Oliver (Ed.) *Media Art Histories*. Cambridge, MA: MIT Press, 2007, pp. 163-178.

105 According to Siegfried Zielinski, the figure is 39cm high, can speak, move his arms and legs and roll over its 60cm² base three times, if the spring is fully wound. The figure is driven by a mechanical system based on a key-wound spring, a technology that has been used since the 14th Century in timepieces. Zielinski, Sigfried. Expanded animation: a short genealogy in words and images. In: Buchan, Suzanne (Ed.). *Pervasive Animation*. New York/Oxon, UK: Routledge, 2013. p. 41

106 Bensaude-Vincent 2006.

107 Miyazaki, Shintaro. *Algorhytmisiert. Eine medienarchäologie digitaler signale und (un)erhörter Zeiteffekte*. Berlin: Kultur Kadmos Verlag, 2013. pp. 45-60.

108 With much of the research conducted at Bell Labs. (Miayazaki 2013: 55-60)

the main figures to implement relays in computing machines were the informatics pioneer Allan Turing (1912-1954)[109], mathematician and electrical engineer Claude Elwood Shannon (1916–2001)[110], the engineer George Robert Stibitz (1904-1995)[111] and Howard Hathaway Aiken (1900-1973)[112].

As previously noted, sensors, as relational objects, have no utility if isolated and not connected to another mechanism. This is why many of the explorations conducted after the discovery of selenium were based on coupling selenium cells to relays, which were triggered when they received enough light. The applications ranged from the simple automatic lighting of harbour buoys at dusk to more complex systems such as the sorting of coloured objects by adjusting the relays to various shades of light spectrum.[113]

It is possible that artist Marcel Duchamp (1887-1968) was aware of this technology when at the *Exposition International du Surréalisme* (Paris, 1938), he

> had thought of installing 'magic eyes' so that the lights would have gone on automatically as soon as the spectator had broken an invisible ray when passing in front of the painting. Duchamp's wish proved unfeasible, but Man Ray adapted the idea for the opening night, turning out the lights and handing out flashlights at the entrance so that visitors could use them to view the artworks "on display"[114].

This case exemplifies the rise of the artistic interest in automation techniques capable of integrating the artwork and its reception. Although the installation of magic eyes was not accomplished as Duchamp initially imagined, the solution implemented retained much of Duchamp's original intention to bodily engage the audience in the artwork. Decades later, when such devices became more popular and accessible, it would have been far less difficult to carry out Duchamp's idea. The combination of photosensitive sensor and switch-relay continues to be extensively used today as an automation solution in a variety of contexts, and the mechanism can be considered among the early devices of machine vision and surveillance technology.

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109 Turing wrote On computable numbers (1936) and built a relay computer (1937). (Miyazaki, 2013: 44)

110 Under the supervision of Professor Vanevar Bush at MIT (Massachusetts Institute of Technology), Shannon wrote his master's thesis A symbolic analysis of relays and switching circuits, submitted in 1937. (Miyazaki 2013:47)

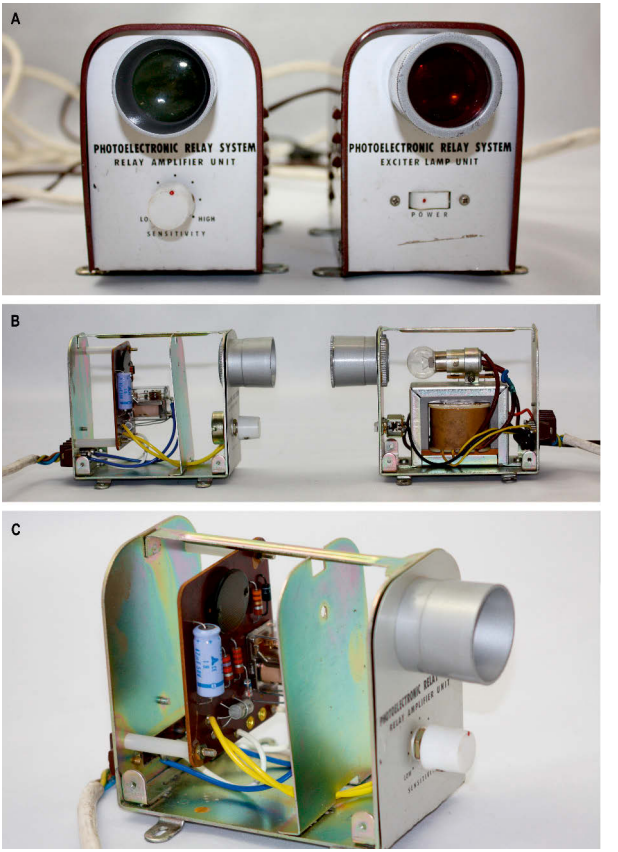
111 Since the end of 1938 Stibitz has worked at Bell Labs on the Complex Number Computers. The machines were the concretization of the emergence and convergence of relays and Boolean algebra. In 1946, the group of developers was already working on the fifth model. (Miyazaki 2013: 49)

112 Between 1943 and 1944 Aiken led the project of the Automatic Sequence Controlled Calculator (ASCC), later called Harvard Mark I, developed jointly by the US Navy, IBM and Harvard University. (Miyazaki 2013 : 50)

113 Fournier D'Albe 1924 : 67.

114 Filipovic 2009.

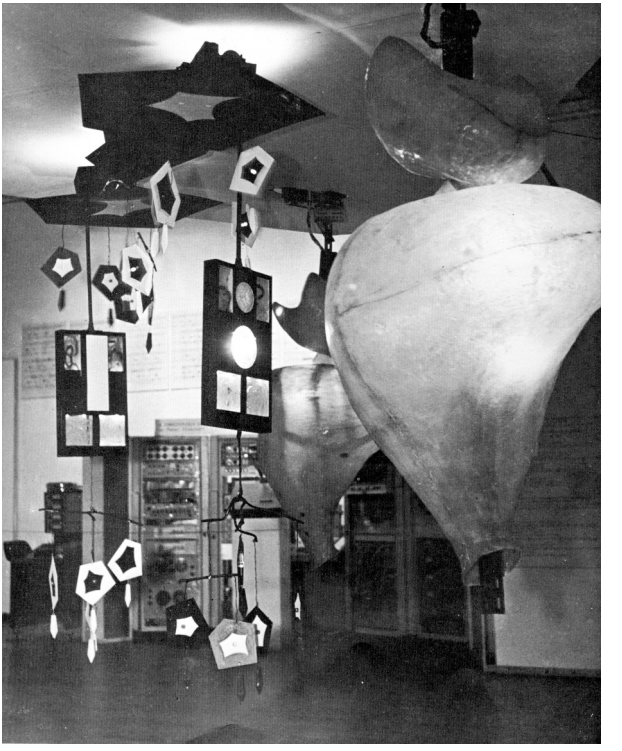
By means of detecting the presence (or absence) of an object (or subject) crossing the field, the photosensitive cell-switch relay can either serve Duchamp's notion of "magic eyes" or the panopticism described by the philosopher Michael Foucault.[115] For illustrative purposes, a popular commercial model sold in the 1960s and 1970s is shown below:



1.8: Photoelectronic relay system. A: Covered equipment: emission and reception parts; B: Lateral view of both parts; C: Detail of the circuit and the light-sensitive component. Photos: Graziele Lautenschlaeger; Source: Media Archaeological Fundus – Institut für Medienwissenschaft of Humboldt-Universität zu Berlin.

115 Foucault, Michael. *Surveiller et punir : Naissance de la prision.* Paris: Éditions Gallimard, 1975.

One of the pioneers in building automata in art exhibitions was the cybernetician and artist Gordon Pask (1928-1996), who exhibited the *Colloquy of mobiles* in 1968 at the exhibition Cybernetic Serendipity in London. This artwork was a computer-based social system, in which "male" and "female" rotating machines could establish communication through basic patterns of light and sound.



1.9: *Colloquy of mobiles* (1968), by Gordon Pask, at the exhibition Cybernetic Serendipity, ICA London. Courtesy of Jasia Reichardt, Hermione Pask and Amanda Heitler; Source: Medien Kunst Netz.[116]

According to art critic and curator Margit Rosen (1974-), the communication system created by Pask in the *Colloquy of mobiles* invokes analogy to sexual relationships. As she described it:

> after a phase of inactivity, the females (made of fiberglass) began to glow more intensely, and the three males emitted a ray of light. When the ray of light struck

116 Available at <http://www.medienkunstnetz.de/works/colloquy-of-mobiles/> Accessed August 10th 2017.

> the mirror inside the female mobile's structure, by way of rotating the mirror, she tried deflecting the ray back at the free-hanging light sensors above and below the male's aluminum body.[117]

The system was programmed so that "the goal of communicating was to achieve moment of satisfaction, and the mobiles learned to optimise their behaviour to the point where this state could be reached with the least possible use of energy".[118] Furthermore, the exhibition visitors could also take part in the conversation and learning process by using light emissions from flashlights and reflections from mirrors to assume the role of another machine.

This kind of artwork shows that intuition, openness, sensitivity and automatism can coexist simultaneously, to the contrary of fears associated with industrial trauma[119]. Indeed, in the context of Pask's artwork, the sensibility of the machine can be seen as a key element of uncertainty that introduces a margin of indeterminacy. For Simondon, it is sensitivity that enables the existence and concretization of a technical ensemble, rather than the augmentation of its automatism.[120] An argument can be made that the creative process in media art is primarily based on this paradox.

While Simondon depicts the conflicting nature of the relationship between humans and machines he also has an optimistic outlook rooted in a wish for balance and envisioning human beings as the organisers of a society of technical objects that requires being conducted in the same way as musicians in an orchestra[121]. The metaphor he uses represents something harmonious and beautifully organized, whose execution is dependent upon and takes advantage of the ability of each musician but is coordinated by a central control, represented by the figure of a conductor. Flusser used a similar metaphor for technological society when he spoke of chamber music in the conclusive chapter of Universo das Imagens Técnicas – elogio da superficialidade. However, he envisions the cooperation among the musicians as a playful activity, whose beauty and meaning emerge from the interaction itself, as an open space for unpredictability and uncertainty.[122]

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117 Rosen, Margit. 'The control of control' – Gordon Pasks kybernetische Ästhetik. In: Glanville, Ranulph; Müller, Albert (Ed.) *Pask Present. An exhibition of art and design inspired by the work of Gordon Pask, cybernetician and artist.* Wien: Echoraum, 2008.

118 Rosen: MedienKunstNetz.

119 For Simondon the conflict emerges when machines start to substitute for the human workforce: "*la frustration de l'homme commence avec la machine qui remplace l'homme*". (Simondon 1958 : 162)

120 Simondon wrote : "*C'est cette marge qui permet à la machine d'être sensible à une information extérieure. C'est par cette sensibilité des machine à de l'information qu'un ensemble technique peut se réaliser, bien plus que par une augumentation de l'automatisme*". (Simondon 1958: 12)

121 Simondon 1958: 12.

122 Flusser 2008: 198-199.

Whereas engineers avoid uncertainty and indeterminacy while they are developing sensors and functional machines, artists use these traits to aesthetic advantage. Automation is inherent to the media art aesthetic mainly due to characteristics of the tools used in media artworks. This aspect has probably fuelled the myth that technological apparatuses freed artist's hands. Friedrich Kittler was among those who promoted that idea. According to him "The era of analog media – that of optical media proper – frees the act of visual depiction from the human hand and the act of visual perception from the human eye"[123]. For those more involved in artistic practice, however, such a statement is not strictly true. Flusser stresses the issue on an existential level: "the hands do not manipulate blindly: they are under control of the eyes. The coordination of hands and eyes, of praxis and theory, is one of the subjects of human existence"[124]. Whether or not the artist stresses automation conceptually, to automate within an artwork the hands are also necessary: and, indeed, the maker and the Do-it-Yourself (DIY) cultures rose in media art when automatism was already significantly present in society.

Embedding the photometer in the camera apparatus made image production even more automatic and fast. Polaroid represents the automation of image developing. The grouping together of technical elements in technical ensembles, which later can be merged with other technical ensembles, makes the tools available for artistic expression increasingly complex. In this process one can again observe similar automating phenomena: the new tool (technical ensemble) performs the previously laborious task by incorporating a software (and/or mechanism) that executes it – which can be carried out perpetually and infinitely. This is the case, for instance, with scientific calculators, software for image processing, or even high-level programming languages which, in opposition to low-level ones, abstract and automate necessary steps to communicate with the material aspect of the machine. In this sense, the automating tools used by artists aim to shape the emergence of specific corresponding aesthetics. Reflecting on this point, one can propose that if, on the one hand, automation is an advanced stage of the human attempt to condition matter, on the other hand, it reciprocally shapes human beings and their creative attitude towards the world.

1.2.3 Controlling

Controlling is another operation enhanced by using sensors. A considerable part of the notion of control in media art is related to the uses, criticism and subversive

123 Kittler 2010: 11.

124 From the excerpt in Portuguese: *"as mãos não manipulam cegamente. Elas estão sob o controle dos olhos. A coordenação das mãos com os olhos, da praxis com a teoria, é um dos temas da existência humana*". (Flusser 2008: 17)

possibilities of surveillance media systems, which are often represented by a huge variety of devices, such as cameras, radars and presence sensors. Sean Cubitt, in his analysis of the control over light, shares this perspective:

> Control over light, and its mediations through visual technologies, matters because it alters the constitutive grounds of sensing, knowing, and relating to one another and to the world. The genealogy of visual technologies traces a historical dialect between the urge to control, even to fascistic excess, and the constant reemergence of entropy[125] in the interstices of devices designed to curtail and command the excess of light.[126]

There is a series of artworks that stresses the controlling aspect of media as an aesthetic motif forming a branch of surveillance art, which is exemplified by the situationist group Surveillance Camera Players[127] and the already classic and worldwide recognized work of Harun Farocki (1944-2014), whose documentaries and video-installations frequently stress the role of technological apparatuses and image machinery in shaping society and feeding contemporary warfare.[128]

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125 Like the cyberneticists, Vilém Flusser and Sean Cubitt base much of their reflections on the principles of the Second Law of Thermodynamics, which states that "*in all systems, entropy tends to increase over time. While this simply means that differences in heat or energy tend to equalize over time, it is also understood to mean that order breaks down overtime, and that organization decays into chaos within both individual systems and the whole of the universe*" Asaro, Peter M. Heinz von Foerster and the bio-computing movements. In: Müller, Albert; Müller Karl H. (Ed). *An unfinished revolution? – Heinz von Foerster and the Biological Computer Laboratory | BCL 1958 – 1976*. Volume 3 of the series Complexity | Design | Society. Vienna: Echoraum, 2007. p. 259. Cubitt reflects: "*an increase in an absence – as entropy increases, there will be less and less difference… in a thermodynamic logic what is increasing is lack, or loss*". (Cubitt 2014: 3-4) "*Entropy is the opposite of information, of form*" (Ibid: 4). Flusser, in turn, based on the principles of thermodynamics, asserts that everything happens by chance (Flusser 2008: 18) and it is along a series of chance occurrences that we advance towards entropy and chaos. Here, programming, also associated with the notion of controlling, is presented as a human response to disturbances and novelties in the surrounding environment.

126 Cubitt 2014: 3.

127 Surveillance Camera Players (SCP) is a collective of media activists founded in New York in 1996. Inspired by the Situationist International (SI), they performed a series of performances in front of publicly installed video surveillance cameras, inquiring and manifesting their opposition to the violation of privacy. More information available at <http://www.medienkunstnetz.de/kuenstler/surveillance-camera-players/biografie/> and at the group's official website <http://www.notbored.org/the-scp.html> Accessed August 16th 2017.

128 Although not based on light-sensitive devices, a more recent artwork that tackles similar issues and is worthy of mention is the winner of the 2016 Golden Nica prize in the Interactive Art+ category Can you hear me?, by the Swiss artists Christoph Wachter and Mathias Jud. The artistic intervention was hosted by the Swiss Embassy in Berlin, located on *Pariser Platz*, very close to the German parliament and the several other embassies; it is also the main area where the NSA (National Security Agency of the United States of America) and the GCHQ

Control here can be understood as the authoritative use of the measurement and automation of matter. The misuses of controlling or automating constantly cause conflicting reactions by artists, especially because freedom and symbolic and interpretative openness are among the most valuable requirements of the artworks and the artistic practice itself. Media artist David Rokeby (1960-), famous for his series *Very Nervous System* (1982-1991)[129] and artworks addressing digital surveillance, states that the computer stimulates people to believe that everything can be controlled. However, the essence of such an illusion relies on the fact that the control works effectively only in the ideal conditions carefully constructed in the vacuum inside the machine.[130] In his opinion, the computer is a result of the fetishism of control, and his artworks are at their base, therefore, attempts to enact the opposite paradigm by creating inexact control systems. In Rokeby's words:

> Control is over-rated... Or perhaps it is better to say that we need to learn to balance control which is very useful in surgery or driving, with other sorts of engagements with other things and otherness that are looser than control relationships where we allow ourselves to be open, engaged and willing to be surprised. Otherwise life is dead.[131]

Nevertheless, apart from the context of surveillance and other similarly negatively connotated areas, the notion of control has also been revisited by cybernetic approaches. Cybernetics emerged in the mid-1940s from cross-disciplinary meetings among scientists and humanists from a variety of fields. Despite emerging without a name under the scope of the series of Josiah Macy Conferences on *"circular causal and feedback mechanisms in biological and social systems"*,[132] it was mostly associated with mathematician Norbert Wieners' (1894-1964) book *Cybernetics or control*

(United Kingdom's Government Communications Headquarters) have long been listening to the whole district's communications, including chancellor Angela Merkel's mobile phone. The artists took advantage of the privileged position of the Swiss Embassy, in cooperation with the Akademie der Künste on the opposite side, to build a series of antennas that enabled free access to the population, inviting people to engage in communication with the security agencies anonymously and drawing attention to the lack of regulatory rules over digital communication and its subsequent control, regardless of which radiation spectrum is being used.

129 In *Very nervous system* Rokeby develops a system of visual computing to compose music with the body in space. Through this artwork Rokeby anticipates the power of ubiquitous computing much earlier than hardware that facilitated and popularized this sort of technical implementation was available on the technology market.

130 Rokeby 2003 apud Glynn 2008: 2.

131 Ibid: 3.

132 Scott, Bernard. Second-order cybernetics: An Historical Introduction. In: *Explorations in Second-order Cybernetics: Reflections on cybernetics, psychology and education.* Vol.17 of the series: Complexity Design Society. Wien: Echoraum, 2011. p. 385

and communication in the animal and the machine (1948). It was Wiener who first gave a name to the new field of study, parallel to the emergence of the General Systems Theory.[133] Nevertheless, the appropriations of cybernetic conceptual models by contemporary interlocutors of the post-war period[134] were still characterized by an objectivist worldview. This led Heinz von Foerster at the end of the 1960s to distinguish first-order from so-called second-order cybernetics:[135] cybernetics subjected to its own concepts and able to acknowledge the role of the observer in the act of observing a system. Since then cybernetics has been used continuously as an inter- and transdisciplinary framework to handle issues on control and communication, learning and adaptation, self-organizations and evolution.[136]

Cybernetician artist Gordon Pask, who presented second-order concerns in relation to education and epistemology in *A comment, a case history and a plan* (1968), stated that *"man is prone to seek novelty in his environment and, having found a novel situation, to learn how to control it"*[137]. This premise, according to Pask, links the notion of control to the human fascination for solving problems, which constitutes the basis of human curiosity and the construction and assimilation of knowledge. Pask's artworks approach technological tools as an element to trigger curiosity and conversations by implementing propositions in which the controlling dynamic of a machine goes far beyond an authoritative perspective.

The revised idea of control elaborated by the cyberneticists and revitalized by the media criticism of Flusser and Simondon places the notions of automation and control outside the simplistic and linear logic of cause and effect. Suggesting circular models of comprehension and constant changes of perspective between humans, other living beings, machines and environments, they consider more complex relationships. Less dichotomous approaches to technological apparatuses are possible when material and technical issues cease to be seen only as misused weapons in the hands of a "controller" against the "controlled". From a systemic and cybernetic standpoint, controlling is much more closely related to the self-regulating and self-organising properties of complex systems. By approximating the complexity of machinic and biological entities, this paradigm is able to formalize

133 Ibid.

134 Kittler's scientific investigations related to media development, too, have much to do with his post-war experience, identifying the concept of information as a component of military strategy. His argument is clearer when he addresses the origin of radar technology and its abstractive act, as, for instance, when he approvingly quotes Paul Virilio's (1932-) statement that, "*radar is an invisible weapon that makes things visible*", "*because it converts objects or enemies that do not want to be seen or measured at all into involuntary and compulsive transmitters*". (Virilio 1989: 75 apud Kittler 2010: 216)

135 Foerster, Heinz von. *Cybernetics of Cybernetics: The control of control and the communication of communication.* Minneapolis, MA: Future Systems, 1995.

136 Scott 2011: 383-398.

137 Pask 1968: 76.

a common ground, and thus offer a more appropriate framework, to create and analyse media artworks as aesthetic and social systems.[138]

1.2.4 Self-regulating and self-organising

Sensors fundamentally operate recursively through spatio-temporal transformations that occur when elements exchange updates of their previous physico-chemical states. If one considers biosensors, for instance, this exchange is significantly complex beginning at the molecular level and involving chains of transducing processes.[139] In their material and operational dynamic, sensors are commonly inserted into self-regulating and/or self-organizing systems.

Self-regulatory principles in media art emerge parallel to the criticism of authoritative uses of technology and its associations with controlling and automating. Much of this appropriation was introduced and supported by second-order cyberneticists[140], who embraced principles from biology and ecology, such as the autopoiesis (self-creation)[141] and self-organization of living organisms.

Self-organization has been a valuable concept for some artists, designers and scientists, especially those influenced by cyberneticist and founder of second-order cybernetics Heinz von Foerster (1911-2002) and his work at the BCL Biological Computer Laboratory, which he founded in the late 1960s at the University of Illinois.[142] Discussions on self-organization emerge from studies on thermodynamic laws and paradoxes between organization, chaos and entropy. In the book *What*

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138 Lautenschlaeger, Graziele; Pratschke, Anja. Don't give up! Media art as an endless conversational process. In: *Kybernetes*. Vol. 40 n.7/8, 2011. pp. 1078-1089.

139 Fraden 2004 (1996) 519.

140 *"Second-order cybernetics (...) was developed between 1968 and 1975 in recognition of the power and consequences of cybernetic examination of circularity. It is cybernetics, when cybernetics is subjected to the critique and the understandings of cybernetics. It is the cybernetics in which the role of the observer is appreciated and acknowledged rather than disguised as had become traditional in western science: and is thus the cybernetics that considers observing, rather than observed systems".* (Glanville 2001: 03)

141 For cyberneticist biologist Humberto Maturana (1928-) *"a circular, autopoietic form of organization distinguishes living beings, from the amoeba to humans. Living systems form a network of internal and circularly enmeshed processes of production that make them bounded unities by constantly producing and thus maintaining themselves. Autopoietic systems are autonomous"* (Poerksen, Bernhard. *The certainty of uncertainty: Dialogues introducing contructivism*. Charlottesville: Imprint Academic: 2004. p. 47). Glanville adds to this that *"the basic consequence of the autopoietic organization is that everything that takes place in an autopoietic system is subordinated to the realization of its autopoiesis, otherwise it disintegrates".* (Glanville 2001: 15)

142 Müller, Albert. A brief history of the BCL. Heinz von Foerster and the Biological Computer Laboratory. In: Müller, Albert; Müller Karl H. (Ed). *An unfinished revolution?—Heinz von Foerster and the Biological Computer Laboratory | BCL 1958—1976*. Vol. 3 of the series Complexity | Design | Society. Vienna: Echoraum, 2007. pp. 278-299.

is life? (1948), physicist Erwin Schrödinger (1887-1961) challenges the second law of thermodynamics by stating that biological systems, instead of losing information, tend to increase in complexity over evolutionary time. Facing this objection, von Foerster contends that *"biological organisms and other complex systems consume energy and order from their environments. And so, while entropy will steadily increase globally, locally organisms can capture and transform energy and produce islands of increasing order"*[143]. His philosophical statement recalls the existential of 'being-in-the-world' and the dynamics and mutual influence of the observer (subject) and system being observed (object). The body organizes the world to organize itself and the interface between subject and object are the senses. The attention towards the sensors of non-human organisms and the variety of sensitizing techniques of objects is therefore a sort of concretization of the post-humanist ideals. Considered by many as an esoteric perspective, von Foerster's ideas led to an innovative scientific agenda at the BCL, influencing the next generation of artificial intelligence and neural network researchers in the following decade, and serving as a source of inspiration for cyberneticist artists today.

Among the pre-organizing tasks involved in self-organising mechanisms – filtering, periodic functions, pattern recognition –[144] filtering is probably the one in which sensors are most directly related, since *"systems, organisms or machines, did not deal with the totality of the universe, but only dealt with certain aspects of it and filtered the rest out"*[145].

There are numerous artists, designers and architects[146] whose aesthetic experiments also approach cybernetic understandings of self-organization and adaptive systems. In order to acknowledge non-mainstream artists, the artwork selected to address the topic is *Equilibrium* (2008), by Guto Nóbrega. As a hybrid organism, the piece is a system in which a plant and an artificial mechanism share a mutual relationship based on self-regulating principles. As described by the artist, the system consists of two motors, solar cells, microchips, light beams, photoelectric sensors and a plant. A central axis holds two opposed sides in a symbiotic relationship: On the one side, there is an artificial system, a simple BEAM[147] robot equipped with

143 Foerster 1960 apud Asaro 2007: 259-260.

144 Asaro 2007.

145 Ibid: 262.

146 To mention only a few, there are the Gordon Pask's followers Ruairi Glynn, Usman Haque and many others who have attended the Bartlett School of Arts and Design in London. Glanville, Ranulph; Müller, Albert. (Ed.) *Pask present. An exhibition of art and design inspired in the work of Gordon Pask, cybernetician and artist.* Wien: Echoraum, 2008.

147 BEAM robotics (acronym of Biology, Electronics, Aesthetics and Mechanics) refers to a branch in robotics that primarily uses simple analogue circuits instead of microprocessors favoring simple design. Although not as flexible as microprocessor-based robotics, BEAM robotics can be more robust and efficient at performing the assigned task. A set of the analog circuits and

propellers and programmed to move clock- or anticlockwise according to photovore[148] behaviour. On the other side, there are a plant and two solar cells responsible for feeding the artificial system. A circular symbiotic interaction is established: The robot needs the energy collected by the plant while the plant needs the robot's mobility. The plant signals the robot when light is needed, activating its engines to turn the system towards light.

1.10: *Equilibrium* (2008), by Guto Nóbrega. Courtesy of the artist.

With autonomous behaviour, Equilibrium "belongs to a class of artificial hybrids emerging from contemporary art practices concerned with the creation of new man-made organisms"[149]. The artist suggests that such a proposition might push the interaction between artwork and audience to a more complex level than mere cause-effect. An inattentive observer can perceive Equilibrium as a simple plant-based kinetic sculpture. However, with this sort of artwork appearance is not the only parameter for interpretation, and a systemic approach is required. The formal combination chosen by the artist frames a dynamic interaction between two light inter-dependent entities, placing the hybrid technical ensemble in a self-regulatory context in which the recursion of feedback exchange dissolves the initially diametrical opposition.

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mimicking biological neurons can be implemented in order to facilitate the robot's response to its environment.

148 Biological term for "searching for light".

149 Nóbrega, Guto. *Equilibrium.* Available at <http://cargocollective.com/gutonobrega/Equilibrium> Accessed December, 4th 2015.

Directly influenced by writings by the biomathematician Sir D'Arcy Wentworth Thompson (1860-1948),[150] Nóbrega manages to implement, via his artistic and academic practices, systems that consider matter through its activity and its corresponding diagram of forces.

Due to their relational characteristics, artworks based on the creation of hybrid systems are very good at elucidating how it is possible to overcome the series of dichotomies that surround media art. Moreover, they exhibit new approaches to how sensitive elements and their inherent operations mirror the current paradigmatic changes in contemporary material culture. They are particularly related to new materialist ideas like Karen Barad's "agential realism", a theory that merges epistemology and ontology while strongly embracing ethics in its acknowledgment of relational dynamics.

A preliminary conclusion gleaned from this brief discussion is that self-regulation and self-organization are models of abstraction that provide a theoretical framework able to deal with materialities as dynamic systems, and thus, as active matter.

1.3 (Im)materiality of an informational aesthetic

Each of the operations related to (photo)sensitive matter discussed above is naturally prone to intersect and interact with the others. They were discussed separately for didactic purposes, as useful elements to understand, produce and analyse media artworks and their operational aesthetics.

Viewing photosensitivity as electric and electrochemical changes in materials, one can grasp how media artworks result from the tension and friction between the abstractions of mathematical and physical models and their material instantiations. The selected examples of light-sensitive elements have provided an idea of how operations of abstract models (data, information, ideas, knowledge) physically shape contemporary electronic and digital technical ensembles and vice-versa.

Moreover, the technical and aesthetical transformations experienced since the advent of technical images testifies to the relevance of photosensitive materials in cultural development, reinforcing the interdependence between materiality and immateriality. In the material-immaterial dynamic of creative processes, one

150 Wentworth Thompson's book *On growth and form* (1917) has strongly influenced a series of artists that were prone to work in the intersections between biology and mathematics. He considered that his contemporary scientists overestimated Darwin's evolutionary perspective in relation to the form and structure of living organisms, to the detriment of up to then available knowledge in Physics, Mathematics and Mechanics. Therefore, the aforementioned book consists of establishing similarities between biological and mechanical structures through the applications of mathematical transforms.

jumps to the realm of information production and exchange by manipulating matter in the form of energy. That is the reason why the media art niche is imbricated with communication theories, and why here one can discuss the materiality of media artworks through the lenses of an informational aesthetics.[151]

The possibility of aesthetically combining elements that exchange information makes media artworks communication systems.[152] Reflecting more deeply on (photo)sensors' roles in operations of measuring, automating, controlling, self-regulating and self-organizing, one realizes that they are simultaneously material and epistemological objects, whose exchange of phsycochemical stimuli may generate data that leads toward the production of relevant information.[153] This process of exchange is a natural way that complex systems attempt to inhibit the tendency to move toward chaos and disinformation.

In *Forma e matéria* (2010)[154], reacting to misuses of the notion of 'immaterial' culture, Flusser suggests that a more appropriate term for materialities on their atomic and molecular levels would be 'high energy', based on the scientific fact that matter can be transformed into energy (fission) and vice-versa (fusion). Through the wordplay "information/in-formation" and by explaining that information could then be stored and transmitted through electromagnetic fields, he proposes that the field of informatics has obliged humankind to reconsider the concept of matter as the *"temporary fulfilment of eternal forms"*[155] – thereby prefiguring a new materialist approach already in the 1980s. Flusser's argumentation is useful to approach (photo)sensitive materials in terms of the physical capacity of each object and/or subject to communicate and interact. Through the understanding of photosensitive interfacing qualities, the material-immaterial interplay becomes a key aesthetical parameter for creating and analysing media artworks. Nevertheless, despite the obvious interrelationships, one can still identify vestiges of conceptual frameworks in media art history that cling to one or another side of the material-immaterial dichotomy. What is at stake if one or another pole is emphasized? Here lies a central

151 Bense, Max. Das Existenzproblem der Kunst. In: *Augenblick*. Stuttgart/Darmstadt, n.1, März, 1958.

152 Luhmann 2000.

153 There is an important distinction between data and information. Data can be only noise. Information is more valuable because meaning and/or functionality has been attributed. Information is activated, "useful", actualized data, which belongs to the realm of virtual/potential. A more detailed analysis on the topic can be consulted at Moles, Abraham. Information und Redundanz. In: Ronge, Hans. *Kunst und Kybernetik. Ein Bericht über drei Kunstwerziehertagungen Recklinghausen 1965 1966 1967*. Köln: DuMont Aktuell: 1968. pp. 14-27.

154 Flusser 2010: 15-22.

155 From the original excerpt in Portuguese: *"Actualmente, porém, com o impulso da informática, estamos a voltar ao conceito inicial de 'matéria' como enchimento temporário de formas eternas"*. Flusser, Vilém. Forma e matéria. *Filosofia do Design – A forma das coisas*. Lisboa: Relógio d'Água, 2010. p. 16.

crux. Were this not the case, there would not be polarization between, on the one hand, contemporary scholars pleading for more embodied scientific and artistic initiatives and attention to the materiality of communication,[156] and on the other hand, media art practitioners and theoreticians asking for better comprehension of the immaterial facet of media artworks while pointing out the current challenges facing the field.[157] The following discussion lays out possible reasons for this polarization and examples that simultaneously flourish within, resist and challenge it.

1.3.1 Vestiges of the material-immaterial dichotomy

There is something to learn about the material-immaterial dichotomy by looking back at pioneering exhibitions dealing with electronic and digital media, like *Cybernetic Serendipity* (1968, London/UK), *Ars Electronica* (1979, Linz/AT) and *Les Immaterieux* (1984, Paris/FR).

The *Cybernetic Serendipity* exhibition curated by art critic Jasia Reichhardt (1933-) at the Institute of Contemporary Arts (ICA) in London, and later touring in the United States of America, showed a series of pioneering computer-based artworks[158] from a time far before electronic and digital media had been considered as something immaterial. Reichhardt's exhibition featured electronic devices and *"environments that seemed to fulfill the promises of the epoch of communicating machines"*[159], which is a deeply provocative challenge to the bourgeois paradigm of art perception of that time. [160]

Documentation of the exhibition has demonstrated Gordon Pask's installation to be an outstanding example of dealing with the specificities of the formerly new media, enabled by his ability to materialize cybernetic principles such as feedback and self-regulation, as well as his own Conversation Theory into artworks, as exemplified by his *Colloquy of Mobiles*. Media art historian and curator Margit Rosen

156 Hayles 1999; Gumbrecht 1995.

157 Paul, Christiane. "From Archives to Collections: Digital Art in/out of Institutions" Lecture held at the conference "Challenges of Digital Art for Our Societies" at MUMOK, Vienna on Dec 4th, 2015. More detailed information is found in her book Paul, Christiane. *Digital art.* Berlin, München: Dt. Kunstverlag, 2011.

158 Among the artists participating in the exhibition were Gustav Metzger, Bruce Lacey, Nam June Paik, Jean Tinguely, Edward Ihnatowicks, Wen-Ying Tsai, Rowland Emett, John Whitney and others.

159 Rosen, Margit. Gordon Pask's Cybernetic Systems: Conversations after the end of the mechanical age. In: Bianchini, Samuel; Verhagen, Erik. *Practicable: From participation to interaction in contemporary art*. Cambridge, MA: The MIT Press, 2016. p. 25.

160 Ibid.

called attention to the posthumanist and new materialist approach of Pask's work, stating that, indeed, "*Pask decides to make the most of the freedom of things*"[161].

One decade later, at the first edition of Ars Electronica, the introduction by former Linzer mayor Franz Hillinger (1921-1991) presented an attractive sensuous and material discourse related to the new possibilities of sound composition through electronic technology recently transformed into aesthetic tools:

> Music is known worldwide as a language understood across all borders. In the "ars electronica" a new acoustic colour has grown forth, in which modern technology is intimately intertwined with human thought experiments to open up unimagined possibilities. Human beings have turned computer technology into an instrument in the service of their musical ideas, creating a substantial renewal and extension that was unthinkable before. I am sure that this new language melody will ultimately also be understood by all people, who can, with the help of electronics, even make music visible, translated into colour, contour, line and rhythm, which can be followed on the screen.[162]

An interesting element of Hillinger's presentation is the implicit connection between an elusive immaterial human mind and the possibility of making it tangible through the construction of electronic machines (computer) and their operations. Hillinger's words resemble Flusser's theory of the zero dimensionality of electronic and digital media, which has been a crucial conceptual framework for both the articulation of material and immaterial aspects of media artworks and the exploration of the particularities of their media. Flusser inserts media development in the history of culture as part of a history of four abstracting gestures.[163] The first human gesture was to abstract time, transforming the world into circumstance, a three-dimensional experience. Later, circumstances were abstracted into scenes, images, two-dimensional representations. The third gesture consisted of abstracting images into texts, which gave birth to history and linearity, the one-dimensional experience. Lastly, the linearity of texts was abstracted into numbers and

161 From the original in German: "*Pask entscheidet sich, die Freiheit der Dinge auszukosten*". (Rosen 2008: 179)

162 From the original in German: "*Die Musik gilt weltweit als Sprache, die über alle Grenzen hinweg verstanden wird. In der 'ars electronica' ist uns eine neue Klangfarbe zugewachsen, in der die moderne Technik sich mit dem Gedankenspiel des Menschen aufs innigste verbindet und ungeahnte Möglichkeiten eröffnet. Der Mensch hat die Computertechnologie zu einem dienenden Instrument seiner Klangvorstellungen gemacht und damit eine Substanzerneuerung und -erweiterung kreiert, die vorher nicht denkbar war. Ich bin sicher, daß auch diese neue Sprachmelodie letztlich von allen Menschen verstanden wird, läßt sich doch mit Hilfe der Elektronik Musik sogar sichtbar machen, umsetzen in Farbe, Umriß, Strich und Rhythmus, die auf dem Bildschirm mitverfolgt werden können*". Hilllinger, Franz. Zum Geleit! 1979. In: *Ars Electronica Center Online Archive.* Available at <http://archive.aec.at/print/#1> Accessed March 22nd 2016.

163 Flusser: 2008: 16-19.

calculations: the zero-dimensionality of electronic media. The zero-dimensionality of electronic media offers the possibility of grouping all materialities together in terms of their lowest common denominator and, in a second step, transforming them into other possible materialities[164]. It is precisely in reference to this media specificity that Hillinger envisions artists using electronic means to "*make music visible, translated into color, contour, line and rhythm, which can be followed on the screen*".

Through (photo)sensing, the world's materiality can be abstracted into its zero-dimensional form, the fundamental condition for all other potential characteristics of electronic and digital media: non-linear and algorithmic (instruction-based executions), immediate (real-time data processing) and therefore, time-based, automated and interactive (due to the openness of the involved systems).[165] Furthermore, electronic and digital media's zero-dimensionality also leads to a convergence culture[166], enhanced by the possibility of editing and programming matter. When light sensitive materials are transformed into sensors by their ability to translate luminous stimulus into electrical signals, an enormous field of possibilities for the transformation of light into other kinds of physical manifestations opens up. This condition invites (media) artists to play with light-sensitive optical media beyond the limits of the sense of sight, thereby expanding the concept of image and traditional mimetic approaches. In the creative processes of media art, this extreme openness requires media artists to systematically contextualize their choices in relation to the technical, aesthetic and semantic layers of their work.

The material-immaterial dichotomy within media art is also influenced by the diverse backgrounds of the artists. Since electronic and digital media are pervasive across all disciplines, artists usually display a broad range of formal paradigms of thinking and acting. Flusser has suggested the verb 'to inform' as a kind of unifying way to describe the creative field dealing with electronic media. The notion of information may dissolve the opposition between matter and energy, and Flusser suggests the ways in which approaches favouring one(matter) or another(energy) correspond to material and formal paradigms of thinking, respectively. The material paradigms that fed creative movements from antiquity (Plato) until the advent of electronic media were rooted in giving shape to the material available. In contrast, formal paradigms are based on materializing shapes from previously created abstract and conceptual models.[167]

Remarkably, both Hillinger's and Flusser's viewpoints are structured on distinguishing between immaterial minds and material bodies, as had been the tra-

164 This specific operation will be discussed in detail in chapter three through the analysis of light-to-sound translations.

165 Paul 2011.

166 Jenkins, Henry. *Convergence Culture: where old and new media collide.* New York: New York Univ. Press, 2008.

167 Flusser 2010: 15-22.

dition in Western philosophy at least until the embodied realism introduced by John Dewey (1859-1952) and Maurice Merleau-Ponty (1908-1961).[168] Similarly to the philosophic mind-body dichotomy, which also divides reason from the senses and overvalues the former to the detriment of the latter, discourses in neuroscience and informatics frequently correlate the human body and computers[169], as well as mind and memory, even though they still face arduous challenges to define where and how material and immaterial hook up. The still quite unknown potential of electronic and digital media has thus unsurprisingly triggered a great deal of science fiction concerning the simultaneously exhilarating and frightening coupling of disembodied minds and its utmost possible extension:[170] the collective mind[171] in cyberspace. In his book *Neuromancer* (1984), e.g., William Ford Gibson defines cyberspace as a consensual hallucination, as graphic representation of data abstracted from every computer in the human system.[172] Such representations of cyberspace have led to it frequently being associated with virtuality and immateriality in the popular imagination.

Simply by recalling the etymology of the term 'virtual', the philosopher of information Pierre Lévy (1956-) emphatically clarified that there is no opposition between the virtual and the concrete, but rather between virtual and actual.[173] According to him, 'virtus' refers to 'potential', i.e. to the realm of possibilities yet to be actualized. Using the example of a tree being virtually contained in a seed, Lévy tries to undo the misunderstandings behind the frequent association of digital with immaterial. Nevertheless, there remains an abstract notion of human mind

168 Lakoff, George; Johnson, Mark. *Philosophy in the Flesh: The embodied mind and its challenge to Western thought.* New York: Basic Books, 1999, p. 97.

169 Current research on neuroscience and cognitive robotics, such as that by Prof. Dr. Jakob Macke, holds that there are indeed surprising correlations, despite there being many more differences between biological neural networks and artificial cognitive neural networks than there are similarities. He expressed this position in his lecture "Making Sense of Light: Processing Visual Information in Neural Systems" at the Wo/Man Mind Machine – Interdisciplinary Conference. The event was held at the Berlin-Brandenburg Academy of Sciences and Humanities, organized by *Die Junge Akademie* and The Israel Young Academy. Berlin, June 13-14th 2016.

170 Clark, Andy; Chalmers, David. *The extended mind*. In: *Analysis* Vol.58 (1) Jan 1st 1998.

171 Lévy, Pierre. *A inteligência coletiva: por uma antropologia do ciberespaço.* São Paulo: Loyola, 1998.

172 Another strong example is *Ghost in the shell* (book: 1989; film: 1995) and, within media art, valuable paradigmatic changes can be observed in the evolution of statements by artist Stelarc on the relations between body and technology. The artist systematizes the following narrative: Absent body/Obsolete bodies/Redesigning the body/The hum of the hybrid/The anaesthetised body/The sheding of skin/high-fidelity illusion/phantom body/Fractal flesh. <http://stelarc.org/?catID=20317> Accessed June 12th 2018.

173 Lévy, Pierre. *O que é o virtual?* São Paulo: Editora 34, 1996.

in his philosophy, too, since Lévy considers the realm of concepts, meanings and symbols, whose materiality is still ungraspable, as immaterial.[174]

In the 1990s cybernetics was still strongly criticized by postmodern literary critics like Katherine Hayles (1943-) for its disembodied discourses that constantly failed to be put into practice. Except for the concrete machines built for scientific, artistic or design purposes, cybernetic abstractions created in order to depict and reflect on information exchange and interactions among working systems often end up stretching more their immaterial models. Hayles dedicates a chapter of her book *How we became post-human?* (1999) to discussing the materiality of informatics, criticizing cybernetic approaches that had emerged since the Macy Conferences as well as Foucault's archaeology and the erasure of embodiment. According to Hayles,

> it is not coincidental that the Panopticon abstracts power out of the bodies of disciplinarians into a universal, disembodied gaze. On the contrary, it is precisely this move that gives the Panopticon its force, for when the bodies of the disciplinarians seem to disappear into the technology, the limitations of the corporeality are hidden.[175]

To a certain extent, Hayles characterizes Foucault's viewpoint as grounded in a disregard of matter as an active entity that also constantly shifts power structures. Her criticism of the cybernetic discussions points to how information became a theoretical entity divorced from meaning.[176] Later in the same decade, in a similar attempt to dissolve the immaterial-material borders of the human mind and body the cognitive linguist George Lakoff (1941-) and the philosopher Mark Johnson (1949-) published *Philosophy on the Flesh: the embodied mind and its challenge to western thought* (1999) to propose a new materialist approach to mind and other conceptualization processes. The authors conduct a substantial review of philosophical statements based on the body-mind division through the lens of the most recent discoveries in neuroscience.

To return to media art exhibitions, the highly influential *Les Immatériaux* (Centre George Pompidou, Paris, 1984) curated by Jean-François Lyotard (1924-1998) in collaboration with design theorist Thierry Chaput, already gave a sign of the emerging crisis related to the modern concept of materiality. The exhibition's name at first glance suggests that the French post-structuralist basis of *Les Immateriaux* might emphasise characteristics of disembodied technological artefacts and society, as Hayles' critique has suggested. Moreover, according to Yuk Hui and Andreas Broeckmann (1964-), the exhibition aimed to express that

174 Ibid.

175 Hayles, Nancy Katherine. *How we became posthuman: virtual bodies in Cybernetics, Literature and Informatics.* Chicago and London: The Chicago University Press, 1999, p. 194.

176 Hayles 1999: 50-83.

> the immaterial is fundamentally material. The point was not to appreciate the new materiality brought by the telecommunication technologies, but rather to question the relation between man and his desire to become the master of matter. The aim of calling it "immaterial", like the designation of the "post-modern", was to liberate man from the modern paradigm, and to release material from the prison of the industrial revolution.[177]

The role of art in this context was to anticipate and deepen the discussion of the current cultural situation and the discursive oscillation between material and immaterial. Similarly to what was presented at *Les Immateriaux*, this first group of photosensitive elements and their operations introduces what might be the (im)materiality of media artworks and how media artists can play with it. At the nanoscale, the 'manipulated' elements are called data rather than matter. As media theorist Wendy Hui Kyong Chun (1969-) explains, data refers to signals that propagate in space and time,[178] and *"logic gates can only operate 'logically' – as logos – if they are carefully timed."*[179] Chun corroborates her statement by citing Philip E. Agre's *Computation and Human Experience* (1997), which elaborates in detail how the materiality of data operates inside the integrated circuits of machines: *"the digital abstraction erases the fact that gates have 'directionality in both space (listening to its inputs, driving its outputs) and in time (always moving toward a logically consistent relation between these inputs and outputs)."*[180] Digital media are thus also based on space-time manipulation, although this 'manipulation' is done indirectly. In digital media, as a further development of electronic media, the semantic coincidence between finger and numeral in the word 'digit'[181] alludes to indirect manipulations, mediated relationships.

In consonance with Flusser's mindset, the abstractive processes of digital media described by Chun and Agre have their roots in Western culture in the birth of the atomist perspective in antiquity and Democritus' first atomic model.[182] The

177 Hui, Yuk; Broeckmann, Andreas. *30 Years after Les Immatériaux: Art, Science and Theory*. Lüneburg, Germany/Milton Keynes, UK: Meson Press, 2015, p. 10.

178 Chun, Wendy Hui Kyong. *Programmed visions: software and memory*. Cambridge, Massachusetts/London, England: The MIT Press, 2011.

179 Chun 2011: 26.

180 Agre 1997: 92 apud Chun 2011: 26.

181 Following Flusser's zero-dimensionality concept, the French term for digital art – *Art Numérique* – is more precise in addressing digital specificity, meantime it is a term that emphasizes the abstract side of it. Discourses pointing towards the idea of the "post-digital" are also present in the current material turn. Nevertheless, if one considers the specifics of digital media and the operations related to it, especially regarding Flusser's and media-archaeological perspectives on digital media, the currently fashionable concept 'post-digital' makes absolutely no sense.

182 Barad, Karen. Posthumanist Performativity: Toward an Understanding of How Matter Comes to Matter. In: *Journal of Women in Culture and Society*. Vol. 28, n. 3. The University of Chicago, 2003. p. 806.

search for the existence of an indivisible part of matter is part of the foundation of Western science. Under the influence of the Rutherford-Bohr atomic model and the experiences mediated by electronic-based technologies, a review on materiality and its operations has been progressing ever since the pioneers of electronic and digital art exhibitions.

Despite all effort to rectify misunderstandings about the nature of electronic and digital media, there still have been cases in which renowned and influential media artists and theoreticians have reinforced the idea of the supposed immateriality of electronics and digital media. Edmond Couchot (1932-), for instance, once claimed that *"the image-making processes are no longer physical (material or energy related)"*[183]. This affirmation suffers from two main neglects: firstly, that it does not take all scientific knowledge on quantum mechanics and related topics into consideration; and secondly, that it ignores all existent materialities that human senses cannot perceive.

The primary factor to be aware of in beginning to implement a post-humanist perspective is that there is an inherent gap between the capacity of the human sensory apparatus and the full apprehension of the world.[184] It is possible that some influential theoreticians and practitioners of media art, like Couchot, were introduced to the new possibilities of electronic and digital media without being aware of the interdependence of software and hardware and the physicochemical processes in the background. However, the presence of this false premise in texts used in many languages to introduce electronic and digital media to art students is severely problematic, especially when few or no other contrary perspectives are available.

Another possible association of media art to immateriality is inherent to art history discourses. On the one hand, one can identify it as a part or further development of conceptual art, which has been contributing to the dematerialization of art since the onset of modernism.[185] Through frequent conceptual confusion in artistic experiments based on electronic and digital media, media artworks have likewise been associated with immateriality,[186] contributing to the diminishing relevance of art objects.[187] At the technical level, one can argue that automatic programming, represented by abstract machines like interpreters, assemblers, compilers and ge-

183 Couchot 2007: 182-3.

184 Haraway 2000; Barad 2003; Bennett 2010.

185 As the art critic and curator Lucy R. Lippard (1937-) has shown at: Lippard, Lucy R. *Six years: the dematerialization of the art object from 1966 to 1972; a cross-reference book of information on some esthetic boundaries.* New York: Praeger, 1973.

186 Shanken, E.A. Art in the information age: technology and conceptual art. In : *Leonardo* 35. n°4. 2002. pp. 433-438.

187 Popper, Frank. *Le déclin de l'objet.* Paris: Chêne, 1975.

nerators, which are software designed to operate on or produce other software[188], could be considered as immaterial attributes of digital media.[189] However, although data and its operations are intangible, they are not properly immaterial. According to Kittler, who believed that *"there is no software"*[190], *"all code operations, despite their metaphoric faculties such as 'call' or 'return', come down to the absolutely local string manipulations and that is, I am afraid, signifiers of voltage differences"*[191]. The fact that software necessarily works interdependently with hardware is the existential condition of every electronic and digital media expressions. Even the meanings of conceptual artworks endure through their materiality.

On the other hand, when the communicative aspects of media artworks are emphasized, they have been seen in art history in the context of Relational Aesthetics[192], as participatory, performative and process-based. Still, this interpretation never implied the denial of their materiality. On the contrary, for media art curator and theoretician Christiane Paul, the negotiation with materialities is among the main challenges for curating and preserving electronic and digital art.[193] As an informational aesthetic manifestation, there is no way to escape from embracing the complex and conflicting movement between abstract and concrete instantiations in media artworks, a problem present not only when producing media artworks but when archiving them as well.[194]

A plurality of discourses is more than welcome. Nevertheless, dichotomous perspectives tend to impoverish the complexity of artworks' potentialities. The maturity of media art production seems to depend on the development and systema-

188 Chun 2011: 41. In other words they are higher-level programming languages.

189 In this case, electronic engineers and programmers managed to operate machines by creating abstract and metaphoric levels. Still today in an age of massive 'datafication' of human behaviours, this abstractive practice may induces the belief that digital technology is immaterial. The perception of an immaterial instance of life is understood by Katherine Hayles as the emergence of a new sort of subjectivity, rooted in the mesh between the immateriality of information and the materiality of informatics. (Hayles 1999:193)

190 Kittler, Friedrich. There is no software. In: Kroker; Arthur and Marielouise (Ed.) *CTheory.* 1995. Available at <http://ctheory.net/printer.aspx?id=74>. Accessed August 10th 2016.

191 Ibid. Quoted also at Parikka, Jussi. *What is Media Archaeology?* Malden/Cambridge: Polity Press, 2012. p. 80

192 Bourriaud, Nicolas. *Relational Aesthetics.* Dijon : Presses du Réel, 2009.

193 Paul, Christiane. From Archives to Collections: Digital Art in/out of Institutions. Lecture held at MUMOK, Vienna, at the conference "Challenges of Digital Art for Our Societies", organized by the Department for Image Science. Dec 4th, 2015. Available at <https://www.youtube.com/watch?v=283LtZNmy5M> Accessed July 30th 2016.

194 Tracking the historical paths and archiving issues of media art bring its materiality even more to the fore. Developments in the understanding of its nature provoked changes in the names of laboratories and media centres. An example is Oliver Grau's project and research group ADA – Archive of Digital Art, the former Database of Virtual Art. Available at <https://www.digitalartarchive.at/> Accessed July 28th 2016.

tization of an informational aesthetic through the convergence of material and formal ways of thinking. Cyberneticist philosopher Max Bense's (1910-1990) theoretical framework for aesthetical analysis focusing primarily on the artwork's materiality (*Materialitätsthese*) followed by its organizational (*Ordnung*), communicational (*Kommunikationsthese*) and symbolic (*Zeichentematischetehse*) levels, is an example of approach that overcomes the opposition between materiality and immateriality and supports a critical and relational perspective.[195] Considering all these variable elements and their dynamics one is well equipped to analyse media artworks.

1.3.2 (In)visible and (in)tangible: Blurring borders

Relational lights

As soon as one enters the dark room, one's eyes can just barely perceive two simple white lines projected onto the floor from above. The closer one approaches to them, the more one realizes that smoke lends an apparent solidity to those lines, turning them into curtains of light. One's body immediately wishes to touch this mysterious object, but one is surprised when one notices that they react to visitor's position and movement in the room. Other surprises await if one engages in play. The installation enacts a sort of magic on the senses, enthralling them in a highly immersive situation. As soon as another visitor approaches, the artwork can become even more playful. The line modes change and the challenges for the perceptual game are updated.

This is the prize-winner installation *Luzes Relacionais (Relational Lights)* (2010)[196], by artist Ernesto Klar, whose title and conception are a direct reference to Lygia Clark's (1920-1988) series of participatory artworks *Objetos Relacionais* (1975)[197], and specifically to her concept of the organic line. The main difference between Clark's and Klar's artworks has to do with the specific materials they used, which was a result of the totally different technological contexts in which they were created.

Klar's artwork is especially provocative in relation to the notion of a tangible interface, a concept spread mostly by computer scientist Hiroshi Ishii (1956-), head of the Tangible Media Group at the Massachusetts Institute of Technology (MIT).

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195 Bense, Max. Einführung in die Informatioinästhetik. In: Ronge, Hans (Ed). *Kunst und Kybernetik – Ein Bericht über drei Kunsterziehertagungen. Recklinghausen 1965 1966 1967.* Köln: M.DuMont Schauberg Verlag, 1968.

196 More information and videos about the artwork available in the official website of the artist: <http://klaresque.org/?p=63> Accessed March 14th 2016.

197 In the mid-1970s, Lygia Clark began to use her previous sensorial objects (developed since 1966) as therapeutic practice. She named them *Relational Objects* because the existence of the object occurs only in the relation with the participant. More information available at Butler, Cornelia; Péres-Oramas, Luis. (Eds.) *Lygia Clark: The Abandonement of Art 1948-1988.* New York: MoMA, 2014.

1.11: *Relational Lights* (2010), by Ernesto Klar. Photo: Mário Ladeira. Courtesy of the artist and photographer.

According to Ishii, tangible interfaces are those that explore the tactile richness of interactivity by embedding sensors in all kinds of objects for use as mediators[198] for person-to-person and/or object-to-object or object-to-person communication. By playing with the illusion of light's tangibility through smoke, Klar ironically sublimates the interface into an intangible and reconfigurable light beam. The lack of a graspable physical object, however, does not entail that the artwork does not have a

198 Ishii, Hiroshi. Radical atoms: Beyond the pixel empire. In: Stocker, Gerfried; Schöpf; Leopoldseder, Hannes. (Eds.) *Ars electronica 2016 - Festival for art, technology, and society. Radical atoms and the alchemists of our time.* Linz: Hatje Cantz, 2016: 20-21.

specific materiality. None of the magical effects emerging from the data exchange between the audience and the technological apparatuses would be feasible without both photosensitive structures (device and visitor's eyes), which enable the openness of each side of the proposed feedback-based system. It would be interesting to hear how a visually impaired person would describe her/his experience with the installation, which seems to offer considerable evidence of how sight and tactile senses are intimately related.

Max Bense's analytical categories (materiality, organization, communication, symbolization) can be used to explore the aesthetic aspects behind Klar's installation in a way that sheds light on the material-immaterial relationship.

On the material level, *Luzes Relacionais* consists basically of a dark room, a camera, a computer, a projector, loudspeakers and participants' bodies. These elements form a working system whose autonomy is completely based on the interdependency between each of them. In this sense, its materiality cannot be detached from the communication level: The system's responsiveness is based on visitors' movements, which are translated into light variations sensed by the camera hanging on the ceiling. The data received by the camera is processed by visual computing algorithms and sent to another software, programmed to give specific feedbacks to participants' movements, visualized in the lines' movements and heard through their corresponding sounds.

In interactive relational artworks the flow state of aesthetic appreciation simply does not happen if any of the elements fails to operate. That is why media artists' major concern is the proper functionality of the whole system they have created. How many times has one returned from media art exhibitions disappointed with the fact that many of the artworks unfortunately were not working? It is precisely in this working/not working dynamic that human confrontation with things and their materialities is located. Critical theorist Bill Brown, who in his 'thing theory' qualifies and examines thingness through the medial role of things while also observing the implications of the point in time when the interaction flux is interrupted, has written in this connection:

> A thing (…) can hardly function as a window. We begin to confront the thingness of objects when they stop working for us: when the drill breaks, when the car stalls, when the windows get filthy, when their flow within the circuits of production and distribution, consumption, and exhibition, has been arrested, however momentarily. The story of objects asserting themselves as things, then, is the story of a changed relation to the human subject and thus the story of how the thing really names less an object than a particular subject-object relation.[199]

199 Brown 2001: 4-5 apud Chun 2011:11.

Brown's perspective is a reminder that movements of human culture are strongly based on the creation and removal of obstacles. Within the larger cultural movement, creating media art has been characterized by a continuous effort to deal with things while taking into account the relational aspect between subjects and objects. In this sense, the practice of media art indicates a possible constructive alternative for enacting a materialist theory of relation. [200]

The organizational layer of Klar's installation can be considered in terms of its spatial and temporal distribution. Spatial and temporal elements are arranged according to what is called interaction design, which constitutes the elaboration of a strategically open structure sufficiently attractive to invite people to engage and interact with the artwork. The activation and operationalization of this structure[201] allow people to make sense of the experience. In *Luzes Relacionais* Klar had the perspicacity to choose a few simple elements capable of guiding interactions towards more complex situations. A variety of configurations of the lines suggested different interaction possibilities. The elements were also cleverly repeated, generating slight variations that altered the play modes once the saturation point had been reached, but with an open enough structure to allow the interaction to grow incrementally through coupling with other participants in the room.

Since symbolic forms[202] emerge from the combination of external reality inputs and internal perceptual-cognitive organization, it may be misguided to attempt a general interpretation of the symbolic layer of Klar's work. Since each visitor is free to make their own specific associations, I can only speak from my viewpoint as a participant observer at Klar's installation at the FILE (*Festival International de*

200 Cybernetics as theoretical framework has also advanced in this direction, however has being failing to be put in practice, as already pointed cybernetic anthropologist Margaret Mead (1901-1978) in her critics to cybernetic community itself that was not able to behave cybernetically. Glanville, Ranulph. Cybernetics: Thinking through technology. In: Arnold, Darrell P. (Ed.) *Traditions of Systems Theory: Major Figures and Contemporary Developments.* New York: Routledge/Taylor and Francis Group: 2014. p. 58.

201 in other words: an abstract machine, an algorithm, a software.

202 Ernest Cassirer's (1874-1945) concept of symbolic forms is here the grounding reference. At his lecture at the Warburg Library in 1921 Cassirer defined: "By 'symbolic form' I mean that energy of the spirit through which a mental meaning-content is attached to a sensual sign and inwardly dedicated to this sign. In this sense language, the mythical-religious world, and the arts each present us with a particular symbolic form. For in them all we see the mark of the basic phenomenon, that our consciousness is not satisfied to simply receive impressions from the outside, but rather that it permeates each impression with a free activity of expression. In what we call the objective reality of things we are thus confronted with a world of self-created signs and images." Cassirer, Ernst. *Der Begriff der Symbolischen Form im Aufbau der Geisteswissenschaften*. In: *Internet Encyclopedia of Philosophy.* Available at <http://www.iep.utm.edu/cassirer/> Accessed July 14th 2018.

Linguagem Electrônica) exhibition in São Paulo and Porto Alegre in 2010 and 2011, respectively.

Firstly, I appreciated the perceptual trick of the simple white lines gaining volume and provoking the spontaneous wish to touch them; and, once touched, the surprise of discovering that the curtains of light were movable. Secondly, I associated the experience to an inversion of Flusser's trajectory of increasing abstraction: from the zero-dimensionality of computing, bidimensional lines evolve into a evanescent three-dimensional presence, which is interrupted immediately when the tactile sense is frustrated by the hands searching for something to touch and finding only light and smoke. I also reflected about how the lines, although intangible, still split space into two opposing sides. It was a barrier, albeit a mobile one, which was under my control and easy to transgress. The lines state the limits between oneself and another participant, but, through interaction, connections and reconnections may occur – opening a space for contact and improvisation. In my experience, an incredible flux of philosophical questions was stimulated by the very sensuous experience interacting with the installation. I left the space amazed, wishing to prolong the recently experienced ecstasy for as long as possible. Once outside of the dark room, I immediately realized that the piece also takes advantage of its immaterial-material trick to ironically address the "touch/do no touch" signs of art museums and galleries, as means of molding audience behaviour.

Each of the operations discussed previously in the chapter can be identified by observing the artwork. The technical implementation of the hardware and software for tracking people's movements, triggering changes of the line positions and synthetizing real-time sounds are based on measuring, controlling and automating procedures. The self-regulating operation, however, only becomes effective when the visitor participates as part of the system. For effective interaction to occur both an investigative engagement by the audience as well as software and setups whose answers and updates are simultaneously accessible and challenging, on both the sensorial and cognitive levels, are required. The interplay between certainty and uncertainty is crucial to establishing the necessary balance. In media artworks a big part of this balance is achieved by how (photo)sensitive elements within technical ensembles are filtered and programmed. Once software is written to execute the responsiveness of the technical ensemble in a specific way, it is, contradictorily, the arbitrary act of programming that creates the element of uncertainty in the experience of the artwork.

Whether approaching the aesthetics of the interface or the technical solutions of the artwork, Klar's work offers a window into the typical dilemma faced by media artists dealing with interactive installations: how to find the optimal material organization to engage the audience within an informational system in a symbolic and meaningful way? Many other media artworks besides *Relational Light* could be used as examples to stress the relationships visible-invisible, tangible-intangible, mate-

rial-immaterial. Even if these relationships are not the main emphasis of the work, the creative process in media art always involves the interplay between materiality and immateriality. Max Bense's categories and the various uses of the operations discussed in this chapter are aides to thinking about the challenge embedded in the question above.

Ernesto Klar's *Luzes relacionais*, Gordon Pask's conversational machines and Guto Nóbrega's hybrids artworks series are all examples that challenge the automation of interactions, pushing the audience to search for the implicit relationships created by the artists, and arousing their interest in the technical and scientific knowledge that enabled such a construction. Instead of provoking alienating action-reaction behaviours between artwork and visitor, their work requires an attention and engagement from the public and has the potential to trigger curiosity, reflection and learning about the symbols materially organized. Creating and criticizing media art are therefore investigative practices conducive to knowledge production and sharing.

Relational aesthetics in the coming material revolution?

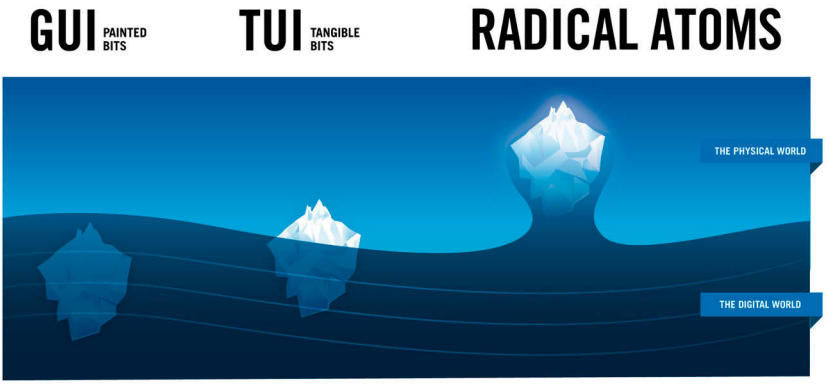
Looking in more detail at photosensitivity and its functions served to show that the communicational feature of media artworks implies the notion of an informational and relational aesthetics. This is why the in-between quality of communication processes has been the focus of cybernetic approaches to media art and is the basis of a theoretical framework that perhaps most closely approximates a post-humanist approach and the notion of active matter in relation to arts.

Nevertheless, the human drive to name and objectify things and phenomena in order to understand them has led to the objectification of the medial quality of sensing and communicating. This human mechanism to constantly distinguish object-subject – the phenomenological fundament of being-in-the-world – also led cyberneticists to fall into the same duality, expressed in their concepts of 'black-box' and 'second-order observer'.

Analogously to the objectification of software that occurred in patent offices in the 1970s[203], the notions of interface and interaction design have also been subjected to a blurring or annihilation of their relational qualities, due to the demands of the creative media industry. This can be observed, for instance, in the Hiroshi Ishii's conceptual-historical review in relation to his own group practices. To describe changes in the way they have been digitally handling materials, Ishii created a narrative based on the evolution of the various human-machine interaction

203 In opposition to Flusser's history of abstractive gestures, Chun identifies abstract to concrete processes in software history when, for instance, in the bosom of programming industrialization, US-American patent offices guided the "*transformation of software from a service, priced per instruction, to a thing*". (Chun 2011: 4)

approaches they have been working with. Using the over-simplified metaphor of an iceberg, Ishii discusses the interface's role in opposing 'digital' (the unknown and dark blue underwater world) and 'physical' (the known atmospheric light blue cosmos). Within this dichotomous metaphor, Ishii denotes a supposed linear progression from Graphic User Interface (GUI), to Tangible User Interface (TUI) and Radical Atoms.



1.12: Self-reflection of MIT Tangible Media Group on their own production according to changes in technological possibilities and their respective discourses; Source: Ars Electronica catalogue 2016 Radical atoms.

In the case of the immersed iceberg, which he calls GUI, Ishii criticizes the dominance of the visual features associated with digital media, calling pixels 'painted bits'. A superficial knowledge of the formation of technical images and the differences between colour as light and as pigment reveals the lack of scientific principles behind his narrative. While a metaphor is not to be confused with an explanation, in this case it is nevertheless difficult to understand the reasons why a scholar would use such simplified statements, ignoring the historical, scientific and aesthetic path of what he is discussing. Though it serves to sustain his questionable timeline, this kind of statement does not contribute to a mature and critical perspective on media creation or its valuable relational qualities.

By depicting TUI as an iceberg rising above the surface, Ishii refers to creations of interfaces that tend more to explore the tactile sensory possibilities, i.e. the shapes and dynamics of interfaces that go beyond mouse and keyboard, old-fashioned metaphors based on office work. The notion of tangible interfaces opened up promising creative possibilities for interaction designers simply because it presupposes that data can be exchanged between every material or object through the coupling of an increasing number and variety of materials, techniques and

sensors available on the technological market.[204] Nevertheless, Ishii omits alternative paths, such as merging visual and tactile stimulations through touch screen devices, and fails to consider that the tactile emphasis of their works is also extremely sight dependent: "extruded painted pixels". In terms of how it is digitally manipulated, there is practically no difference between a pixel on the screen or a solenoid motor in a machine.

As a further step in the development of digital interfaces, Ishii introduces the notion of 'radical atoms' to refer to an emergent technique of material science called "high-throughput computational design", which aggregates information and massive computations at the molecular level of material properties to synthetize new responsive materials.[205] According to his own words,

> Radical atoms symbolize our vision for the future of interaction with hypothetical dynamic materials, in which all digital information has a physical manifestation so that we can interact directly with it – as if the iceberg had risen from the depths to reveal its sunken mass. [206]

His interpretation envisions a Material Users Interface (MUI) based on material synthesis, where materials are dealt with as coded structures whose properties are predefined (hartness, conductivity, light refraction and others)[207] through parametric design[208] and often made of, inspired by or merged with organic matter,

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204 Concerning experimentations on tangibility of interfaces beyond office metaphors, besides the work of the Tangible Media Group at MIT Media Lab, it is also important to acknowledge the invention and world-wide distribution of the analogue-digital conversion boards, the hacking and do-it-yourself-cultures, circuit bending practices and the emergence of the 'Internet of Things' (IoT). Meanwhile, let us also remember that mobile technology and social media became pervasive as well, feeding the 'datafication' process of life. That aspect is the advanced aspect of what Paul Valéry has foreseen in his essay La conquête de l'ubiquité, dreaming a philosophy encountering the situation of delivering the sensible reality at home. Original excerpt in French : "*Je ne sais si jamais philosophe a rêvé d'une societé pour la distribuition de la Réalité Sensible à domicile*". (Valéry 1928 : 4)

205 Lecture "Matter, Material, Immaterial: Art, Philosophy and Curating Thirty Years After Lyotard" by Robin Mackay presented at the "Speculations on Anonymous Materials symposium held at the held at the Fridericianum in Kassel, Germany, Sept 29th, 2013–Jan 26th, 2014.

206 Ishii 2016: 21.

207 A sort of 'materials genome project" has been under collective construction at Materials Project. Available at <https://materialsproject.org/> Accessed June 7th 2016.

208 Parametric design techniques associated with special regard given to material behaviours also enhance the possibilities of manipulating pre-existent materials, as expressed in the use of wood in the work of the architect Achim Menges. Working within the computational material culture, Menges has explored the behaviours and properties inherent to the material through parametric design to create a series of sensitive and responsive architecture. In the fields of architecture and design, a variety of researchers are working on the question of how the computational practices in design processes trigger another kind of material awareness.

such as is the case in the production of biosensors. The technique encompasses a new age of material design in which matter is no longer fixed entity. Ishii's statement that *"all digital information has a physical manifestation so that we can interact directly with it"* thus amounts to an illusion associated with the birth of electronic and digital media as well as the GUI paradigm he depicts. The notion of *"direct"* interaction cannot be accomplished since humans are conditioned and limited by the subject-object dichotomy. Furthermore, the material design of 'radical atoms' is still mediated in the manufacturing process by traditional digital programming processes. What might be disruptive in the manipulation of 'radical atoms' is that the experiments being executed point toward the coincidence of input (sensors) and output (actuators) in the same structure, as is the case in living beings, thereby exponentially increasing the possibilities of creating hybrid systems.

One can see that this potentially revolutionary paradigmatic change is still difficult to imagine in practical terms in contemporary media artworks. To this date there has been no relevant documented artistic use of these techniques to enhance light-sensitive matter and light-based man-made biosensors. Relevant aesthetic experiments have mostly been based on material changes provoked by heat and humidity.[209]

Despite apparently overcoming the immaterial approach to digital manipulation, the new material turn still acknowledges the material aspect in a way that is attached to its pragmatic functional applications. While this is certainly a gain for the practice of relational approaches to materialities, however, the movement still lacks symbolic explorations that would enable advances on the communicational level as well. In this sense, Katherine Hayles' critique of cybernetics and the dissociation of information from meaning is still valid.[210]

Looking further at the issues at stake in the passage depicted by Ishii, some questions remain: Does the metaphor of the rising iceberg correspond to the wish to make the black-boxes of Flusser and the cyberneticists transparent? In other words, do these paradigmatic changes in the way matter is handled indicate that humans will have a more integrated relationship to the black boxes (or icebergs, or

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For more information about this topic see: Menges, Achim, Computational Material Culture. In: *AD Architectural Design*. Vol. 86(2), 2016, John Wiley & Sons, Inc., pp. 76-83 and Oxman, Neri. Programming Matter. In: *AD Architectural Design*.Vol.82 (2), John Wiley & Sons, Inc. 2012. pp. 88-95.

209 Besides the work of Achim Menges with wood, the series of objects bioLogic (2016), in which similar effects are achieved through the hygromorphic transformation of natto cells, also deserves mention. Yao, Lining; Ou; Jifei, Cheng, Chin-Yi; Steiner, Helene; Wang, Wen; Guanyun; Ishii, Hiroshi. Chin-Yi Cheng, Helene Steiner. Natto Cells as Nanoactuators for Shape Changing Interfaces. In: *ACM - CHI 2015*, Crossings, Seoul, Korea. pp. 1-10.

210 Hayles 1999.

interfaces, or things)? Does the relationship with the black-boxes change depending on whether they are manifestations of nature or knowledge condensed in the form of technical objects?

Whether they are named black boxes or icebergs, they refer to the eternal human endeavour to become integrated into the surrounding environment. The 'radical atom' technique cannot bridge the perceptual gap between the capacities of the human senses and the full apprehension of the physical world. Therefore, it also cannot dissolve the primordial object-subject relationship. This remains true even if one sees the iceberg as playing the role of imagination, as a bridging-element between material and immaterial levels of the creative process. This understanding is relevant to approach media art as a form of expression that emerges precisely between the rationalization of methods and the magical effects that take advantage of the limitations of the human senses[211]; in other words, through the articulation of what is, for humans, unknown.

Electronic and digital technology has enhanced the possibility of manipulating matter on a scale that the human senses cannot perceive, and many aesthetic experiments with the tools and techniques now available have driven artists, curators, art critics and educators to view media art as consisting of symbolic material arrangements based on the animation and 'editability' of matter. Yet, the physical properties of atoms have, of course, remained the same. *"Das Messer wird immer schärfer"*, and what one is witnessing is a deepening of the possibilities of *Ars combinatoria*.

In addition to misunderstandings due to ignorance of physical and chemical principles and the limitations of the human sensory apparatus, there is also the question of whether the changes are based on human relationships with matter or on the discourses surrounding them. Discourses like Ishii's, which simulate a linear progressive narrative regarding the materiality of interfaces, not only fail to consider previous media theories, histories and perspectives, but also fail to acknowledge properly the prior relational subject-object paradigm that grounds media art and its role in knowledge production.

Contrary to Ernesto Klar's *Luzes Relacionais*, Ishii's approach is more prone to eradicate the oppositions found between the physical and the digital worlds than to use them to aesthetic advantage. Ishii's perspective lacks engaging in dialogue with initiatives outside his context, diminishing the potential of grounding an aesthetic education upon it. In linear narratives of media development, the production

211 The fascination provoked by the magical effects of optical media is an established discussion in media history and theory. A brief panorama addressing this problem is available, for instance, at Hick, Ulrike. *Geschichte der optischen Medien.* München: Wilhelm Fink Verlag, 1999. p. 139.

of disruptive technologies can only serve as pretence to feed the demands of the technological market.

In conclusion, one can assert that both materiality and immateriality have always been essential elements in art. What differs is the attention devoted to each of them in the discourse of art critics, theoreticians and artists. The material-immaterial dynamics of media art's informational aesthetic are enigmatic but cannot be avoided in the process of creating significant artworks in the field. Sensitive apparatuses are one of the core elements for bridging the poles of this dichotomy and enabling, through communication strategies, relational material perspectives that can accommodate unknown otherness irrespective of the material actualization it presents. Even once an objects' agency has been acknowledged, as demonstrated here with photosensitive elements, it still remains the media artist's responsibility to regard the ethical and environmental implications of such a posthumanist approach.