TECHNOLOGY IN PHOTOGRAPHY:

A CASE STUDY TOWARD SIMPLICITY AND ENVIRONMENTAL RESPONSIBILITY

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In our current language, technology is synonymous with the personal electronic devices we are using every day for working, communication or entertainment. Cell phones, laptop computers, and GPS are the objects attached to the word "technology". Oxford American dictionary defines technology as *"The application of scientific knowledge for practical purpose*". In this paper, we illustrate how "technology" – a process of scientific innovations that takes place over the years and aims to solve human practical needs – has transformed the field of photography.

Technology in photography is exemplified in this paper with an exploration of three different inventions that have radically transformed the practice of photography at their time. In photography, technology has been applied to simplify and optimize the way up to the final image and ultimately to offer everyone access to the practice of photography

When photography was invented, the complex chemical processes and the convoluted methods necessary for accessing the final images, limited the use of photography to professionals and expert amateurs. The barriers that prevented the expansion of photography – complexity, cost, toxicity – were mostly technological. Over two centuries of photography history, the processes has been tuned-up and re-invented to finally become more simple, faster, and non-toxic, as the earlier inventors envisioned it.

Several different photography related techniques were invented over the past 184 years of photography history. The vast majority of these processes and equipments are now obsolete. The study of some of these defunct processes is of particular interest to understand what caused particular process to be commercially very successful, and what were the reasons attached to the end of their commercial life a few years later.

Since 1825 and the invention of the first photo process capable to catch a permanent image of light by Nicephore Niepce, the toxicity of the different chemicals involved in the multiple processes commonly called "photography" is a matter of concern.

In its early days, commercial photography based on the process invented by Daguerre was limited to specialists due to practical difficulties, toxicity of the involved chemicals, and their relative cost. Even if environmental impacts of the chemicals used were not a source of concern at that time, the main focus of the early practitioners was on simplifying the process to make it more reliable, safer, and able to deliver images that were as close as possible of human perception of reality.

The Daguerreotype (1840 to 1860) and the peelable Polaroid Polacolor (1963-1971) processes were presented to the public almost one century apart. Both revolutionized the approach to photography and redefine it, despite of their relative short lifetime. The discovery of these new technologies turned both processes into industrial success stories; however, both lacked the ultimate simplicity and practicability indispensable for expanding photography to a larger public.

Daguerreotype and Polacolor were processes based on chemical material that were potentially disruptive to health and well-being in such ways that when they started to be popular, the hazard and ecological risks became a major concern.

In fact, only relatively clean processes such as the Kodak chromogenic processes standards Kodacolor and Ektacolor, that take place in safe industrial processing facilities could answer to the limitless need of popular imagery. Over 50 years Kodak Co. has worked to improve these modern color photography processes (1954-2004), reducing significantly the amount of energy, water and silver needed to process photographic films and papers; processing effluents and environmental impact have been constantly reduced.

In the late 1990s, the search for simplification, automatization and optimization of the photographic process eventually led to modern digital photography, a technology where chemistry is virtually absent and which allows the instant gratification of on-camera screen visualization. Following the last photo revolution, as always dictated by commercial growth, today's popular photography practices have eliminated many - if not all - of the toxic chemicals that photographers have used for almost two centuries to process the images.

With the rise of digital communication, only electronic photography could respond the ever-growing need of photography on the Internet. In 2000, digital photography became the dominant system in professional and popular imaging, bringing the ultimate convenience – real time results – as well as a clean electronic process for end users.

This convoluted evolution of photography technology happened since – from the early days – simplicity, cost and toxicity were a major source of concern for the photographic industry.

1. Early Photography: Daguerreotype.

a. Timeline.

While the ancestor of modern camera is first documented by Leonado Da Vinci (1452-1519) who famously called it *camera obscura*, the invention of the first reliable chemical process able to capture the light on a tangible support waited until 1839.

The scientific goal to fix the image projected on the ground glass of the *camera obscura* gave birth to many different processes and techniques. However, one of the first processes that scientists and early photographers were capable to reproduce and utilize is named from the French inventor Louis Jacques Mandé Daguerre (1787-1851).

Daguerre worked in Paris, France with Nicephore Niepce who died in 1833 before the full completion of their invention. Their goal was as simple as a scientist dream: turn the *camera obscura's* projection into a material image.

Daguerre described his invention as a process "*to which I had given my name by titling it Daguerreotype. It consists in the spontaneous reproduction of the images of nature received in the camera obscura not with their colors, but with great delicacy of tonal gradations*" (Newhall 1971, 16). The rhetoric and the words used by Daguerre are of importance. Daguerre's own words *"reproduce the images of nature"* demonstrate a very humble and noble objective that from the very beginning of photography show a profound respect of the reality.

Dominique François Arago, a French scientist and politician, Director of the Paris Observatory, explained in full detail the invention to the public at a joint meeting organized by the French Academy of Science and the French Academy of Arts on August 19, 1839 in

Paris. This unique setting started a controversy that will never ends over photography as an art or a science.

Convinced by Daguerre himself, Arago proposed that the French government acquire the right of his invention and make it public for the *"common good"* (Newhall 1971, 18). While investigating the real potential of Daguerre's invention Arago had four concerns:

> *1. Is the process of M. Daguerre unquestionably an original invention?*
> *2. Is this invention, one that will render a valuable service to archeology and the fine arts?*
> *3. Can this invention become practically useful? And finally,*
> *4. Is it to be expected that the sciences may derive any advantage from it?*
> (Arago 1839, 15-16)

The word *"practically"* is one of crucial importance. Arago wanted daguerreotypy to become a process opened to the largest number of people, all over the World. From the very first time, when Arago heard about the invention's details, he understood daguerreotypy was a major step toward a new modern world based on communication, as far as the technology could be widely adopted.

After his first experience, personally processing a daguerreotype plate with the inventor in person, Arago acknowledged daguerreotypy was not an easy task to perform. Arago pressed Daguerre to publish a step-by-step manual to explain in great details how to replicate the process. The book, "*The Daguerreotype, A Practical Description"* became a best seller of the 1840s and was rapidly translated into English, Spanish, Italian, German and Swedish (Newhall 1971, 23).

b. Daguerreotype: description of the process.

Daguerre's invention is mostly a chemical innovation. Daguerreotypy is based on polished copper plates, coated with silver and passed over iodine and bromine vapors in order to make them light sensitive.

After exposure in a large format camera, the plate is processed over mercury vapors in a processing box. Metal particles (silver and mercury) aggregate on the plate areas which received light during exposure. To complete the process and make the image permanent, the plate is immersed in a sodium chloride solution, and then washed with distilled water afterwards the plate is air-dried.

All the daguerreotypes have to be sealed within a velvet-lined case since the delicate image is physically fragile and any mechanical contact will damage it (scratches). It is placed under a glass plate to protect the metal made image from corrosion, which would tarnish the delicate reproduction with black and undefined artefacts. The highlights (light parts) of the image present micro crystallization of mercury and silver while the shadows (dark parts) consist of silver sulphide (Newhall 1971, 19-20).

The fact that the observed final image is on the same plate that has been exposed in the camera and that no transfer or optical reproduction is necessary, makes daguerreotypes incredibly sharp, even according to modern standards. The image is seen on the silver coated plate by reflection of the light. Images remain crystal clear even on samples that are more than 150 years old. By changing the angle of the plate and light incidence, it is possible to see the photographed scene either in negative or positive, a unique characteristic of dagerreotypy.

The most recent researches about the technology invented by Daguerre have been lead at the Materials Research Laboratory (MRL) of Pennsylvania State University from 1979 to

1984 by M. Susan Barger. In her final paper, Barger defines daguerreotype as *"a photographic image on a silver plate which is made of metal particles whose size and spacing are on the order of visible light. The image is visible to the observer because of varying amounts of light scatter and specular reflectance from the plate surface"* (Wood 1989, 101).

c. Commercial lifetime of the Daguerreotype.

Every person who had a chance to see a daguerreotype was absolutely fascinated by the level of precision and details of the silver coated plate. *"Exuberant awe and fascination prevailed at the inauguration of photography in America, as it did everywhere in Europe"* (Wood 1989, 60).

Daguerre's process was introduced to the U.S by another famous scientist, Morse, who had presented his own invention – the electric telegraph – a few months before to Arago at the French Academy of Science. Impressed, Morse introduced the invention to the National Academy of Design in New York and asked the academy to elect Daguerre as honorary member. From the first book rapidly published by Daguerre, Morse learned how to replicate the steps of the new photographic process. In late 1839, he wrote a letter to Daguerre, "*The first brochure which was opened in America at the bookseller's containing your expose of your process, I possess*" (Newhall 1968, 21).

Morse and other American scientists thought very early on the opportunity of using daguerreotypy to take picture of people and applied the invention to the business of portrait photography. Gouraud, the first Daguerre pupil, arrived on the S.S. British Queen on

November 23, 1839 in New York to personally demonstrate the new invention and discuss with Morse about potential improvements and applications.

The original version of the process needed 10-30 minutes of exposure time, an exposure that was too long to allow portrait photography. Almost immediately after the publication of the first Daguerre's book, prices and awards were organized by a French organization (Societé d'Encouragement pour l'Industrie Nationale) to improve what was seen as the limitations of daguerreotypy. These awards were designed to encourage scientists to optimize the primary process invented by Daguerre: improve the light sensitivity and shorten the exposure time – a required improvement to shoot portraits – and find a parent technology in order to duplicate on paper the precious originals made on copper plates. Both sides of the Atlantic, scientists had been successfully working on optimizing the light sensitivity of the plates but failed on inventing a way to duplicate the originals (Bajac 2003, 33).

Within the next decade, daguerreotypy became a recognized and well established business in Europe as well as in the U.S. According to Susan Barger and William White who wrote "*The Daguerreotype: Nineteenth-Century Technology and Modern Science"*, it is estimated that from 1839 to 1860 about 30 millions of daguerreotypes were realised in the U.S. The vast majority of these being portraits, exclusively taken by professional practitioners. The rapidly growing industry based on an optimized version of Daguerre's primary invention represented 8 to 12 millions of U.S dollars per year by 1850 (Barger and White 1991, 2).

In New York City, the public was particularly excited by the exhibitions organised on Broadway Avenue. Portrait studios quickly opened all over the country thanks to the many practical improvements brought to the original process by the American practitioners.

Newhall wrote, *"Yankee ingenuity transformed Daguerre's technique to a perfection undreamed of in Europe, and Daguerreotypists in France and England boasted in advertisement that they worked 'The American Process'* (Newhall 1968, 35). Newhall estimates that in 1853, about 1,000 New Yorkers and over 10,000 operators within the U.S were making a living from the new profession called *daguerreian artist*, mostly from taking portrait photographs.

d. Daguerreotype's failure.

According to today's standards, at least two of the chemical components used on a daily basis by the *daguerreian artists* are classified as hazardous chemicals

The iodine vapors used to prepare the copper plates and make them light sensitive right before exposure are health hazardous. This substance is described as follows in Rempel's book on photo chemistry. *"Iodine: Do Not Use. Skin contact: Toxic-burns, may cause irritation. Inhalation: Toxic, may cause irritation of mucous membranes and lungs. Ingestion: Toxic, small amount may cause death. If heated to decomposition [vapor form], can emit toxic fumes of iodine gas and iodine compounds. Requires local exhausting ventilation, positive pressure fume hood, respirator, goggles, plastic apron and nitride gloves during processing"* (Rempel 1992, 104).

Plates processing, based on mercury vapors, is even more problematic. Mercury vapors are a dangerous cumulative poison. *"Mercury (mercuric chloride): The absorption of even small amount of mercury compounds, which are particularly toxic, can result in serious injury and in some case even death"* (Rempel 1992, 125).

In her book *"Overexposure: Health Hazards in Photography"* Susan Shaw comments on Daguerre's original process as *"Any method of daguerreotyping that uses metallic mercury or its salts is extremely hazardous, even if proper precautions are taken and expensive industrial ventilation systems are used. Acute or chronic mercury poisoning primarily affects the nervous system but also severely damages the gastrointestinal system and kidneys. Symptoms of chronic mercury poisoning such as muscle tremors, irritability and psychic disturbances were known by the mid-nineteenth century hatters who used mercuric nitrate to make felt hats. There is also evidence that some early daguerreotypists suffered from symptoms of mercury poisoning"* (Shaw 1991, 226).

By the end of 1880s, a majority of the *daguerreian artists* had moved from the original process to shot glass plates, using another chemical process based on transparent glass plates that could be duplicated on paper. The practice of Daguerre's original process was too costly to expand the new culture of popular portrait to everybody. Even if the quality of its image was unmatched by the new glass/paper process, the fact that daguerreotypes could not be duplicated was a real limitation. *"Finally the technology of daguerreotypy was displaced by wet-plate photography on glass. The wet-plate process offered faster exposure times; multiple positive enlargements made from a common negative; and, eventually, bound photographs tipped into texts and later still, photomechanical reproductions in ink"* (Wickliff 1998, 435)

Over the twenty years of Daguerre's process lifetime, the customers as well as the photographers were exposed to these harmful substances which residues went directly to the water streams of cities where portrait photography was the latest innovation. Accidents or negative impacts are apparently not documented in the literature that covers the history of daguerreotype. A technology based on such hazardous chemicals could not prevail for environmental reasons as well as basic human health security.

The days of daguerreotypy were over as soon as a safer, cheaper, and faster process called wet-collodion was invented.

2. Polaroid one-step photography, a dream come reality.

a. Dr. Land and his scientific approach to photography.

Edwin Land was a young sophomore student from Harvard University, when he decided to study by himself at the New York library. The young student became inventor and businessman within a couple of years, introducing the first synthetic polarizing filter in 1937, the first sample of which was realised in his own condominium. Dr. Land – as he was usually called even if he never graduated – was the founder and the inspirational leader of a company -Polaroid- that would become one of the main success stories attached to photography. In his book, "*Land's Polaroid: A Company and the Man Who Invented It*" Wensberg who acted as Marketing Chief Officer at Polaroid Co. for almost two decades describes Land as follows.

"Polaroid as a company was for forty-five years virtually synonymous with Edwin Land. He was its founder. He invented its first products and indeed many of its products and processes throughout the five decades of the company history. His titles, during most of the period from 1937 to 1982, included Chairman of the Board, President, Chief Executive Officer, and Director of Research." (Wensberg 1987, 2).

b. Polaroid, two different systems.

Land invented the original concept of *one-step photography* when – as an amateur photographer – he became frustrated by the inevitable wait acquainted to photo films processing. Land was able to hire a team of engineers, chemists and marketers to finalise the product he had in mind with very few compromise. Land invented Polaroid instant photography – or *one step photography* as he liked to name it – a first time in the late 1950s, with the first Polaroid peel-apart system. For more than 15 years, Polaroid images were only in black and white, the first color Polaroid peel-apart films were introduced in 1963.

c. The first generation, peel-apart system.

Land personally presented the first prototype of the peel-apart system at the Optical Society of America dinner on February 21, 1947. At that time, the system was demonstrated with regular large format professional cameras, but Land insisted that Polaroid's goal was to offer an affordable system including easy-to-use and portable cameras, specifically designed for Polaroid instant photography. As reported by Wensberg, Land was highly preoccupied by the protection of the copyrights of his revolutionary invention, *"Land chose not to discuss the other chemicals contained in the pod."* (Wensberg 1987, 19).

As a result of Land's obsession on protecting its unique technology, Polaroid Co. filled suit against the U.S Environment Protection Agency (Polaroid Corp. v. Costle) when the agency asked the company to comply with the new federal legislation called the Toxic Substances Control Act and asked to collect information on the specific chemicals Polaroid was producing for its instant photography products. EPA lost the litigation, and a so-called "Polaroid exemption" was introduced in 1978 by EPA in its business and commercial product confidentiality regulations to keep the secrecy of Polaroid product away from potential competitors (Thanawalla 2002, 17).

Eventually, following the first appearance of the *one-step photography* system, Polaroid released more information about its enigmatic instant photography system. Wensberg describes in his book the official rhetoric that Polaroid Corp. published before the commercial debut of system in 1949. *"All the chemicals needed for the development process, the hydroquinone and the hyposulfite, plus some others, resided in a jelly the consistency of soft butter encapsulated in a sealed chamber Land called the pod. A pod was attached to each sheet of the positive print paper. After the camera exposed the photosensitive negative paper to the light of the scene, the two sheets were pulled together face to face, by the processing rollers and wring out like two towels going through a clothes wringer at once. As they passed through the steel rollers, the pod ruptured and the viscous chemicals extended between them over the entire common surface... When the chemicals touched the two sheets they began to work quickly. The hydroquinone turned the exposed silver halide crystals into silver on the negative. The hyposulfite gathered into solution the unexposed crystals which, rather than being washed away, transferred with elegant precision to the positive sheet, where the silver deposited the positive image."* (Wensberg 1987, 18).

The peel-apart Polacolor – a version allowing instant color photography with the same Polaroid cameras that were previously designed – was introduced to the public in 1963. It was an immediate commercial success, even the picky journalists of Popular Mechanics were impressed, *"Again, all of this may be irrelevant, All the scientific data in the world isn't going to make much difference to the proud mother and father who, with their Polaroid camera and first roll of Polacolor film, take a picture of the children around the birthday* *cake in their pretty, new party clothes, and just 50 seconds later peel off the first color print. How else on earth can you get a camera and film to do that?"* (Brown 1963, 207).

The only critic that was envisioned by market analysts and journalists at that time was the price of the Polaroid system: almost the double of regular color photography based on a Kodak process. *"Last the price. Polacolor, let's face it, is expensive – probably twice as expensive as conventional color prints"* (Brown 1963, 105)

The fact the camera was bulky with awkward design and that in cold temperature the results were unreliable, did not tarnish the fantastic commercial success of Polaroid for an impressive period of 30 years. Sales were growing steadily. According to the sales data released by Wensberg, during these three decades, 10 to 15 millions of film packs were sold annually, as well as 2 to 4 millions of new Polaroid cameras per year.

d. Problems with the peel-apart systems.

While the Polaroid film pack system was incredibly successful, Polaroid main product line began to face major difficulties. Two problems eventually forced Land to re-invent the concept of *one-step photography*, almost twenty years after its first presentation to the public.

The peel-apart system was based on the transfer of dyes from a negative film to a paper receptor. When Polacolor color prints were left in a dry environment a tension between the dye layer and the paper support occurred and the prints began to curl like a cigarette paper. The phenomenon was predictable and inevitable. All the Polacolor prints would eventually suffer from this, unless it was mounted on a board specifically designed in urgence by Polaroid engineers. To fix the commercial issue, Land decided to include a free pack of mounting board in each pack of Polacolor film. (Wensberg 1987, 145).

Another growing problem could not be fixed as easily. Polaroid was victim of the success of its system. The ever-growing number of amateur using Polaroid films became generating vast amount of waste, everywhere instant photographs were taken. *"In fifteen minutes a diligent photographer could finish a pack of Polacolor film with eight color pictures securely mounted on cards for his grandchildren to admire. Around him on the grass would be strewn a box, a foil bag, a sheet of instructions, a cover black sheet, eight negatives, eight tabs, the steel container, and eight was sheets: a total of twenty-nine disposable items, not including his eight hard-won pictures"* (Wensberg 1987, 147).

The number of waste pieces printed with the Polaroid name on it was a daily threat for the brand and its commercial success. *"Since pack film sales averaged about 15 million units per year in the sixties, some 435 million pieces of Polaroid debris hit the turf every year, each piece bearing Phyllis Robinson's admonition, 'Please don't liter the landscape, someone might want to take a picture of it' "* (Wensberg 1987, 147).

On top of the number of debris generated, the negative sheet, where the opened pod had been smashed to process the images, had hazardous proprieties, and could be dangerous for hours after an indelicate photographer had abandoned it on the floor. *"The main hazard of peel-apart* [Polaroid] *films result from potential exposure to small amount of the highly caustic processing jelly, which contains sodium hydroxide or potassium hydroxide. This jelly, which may appear along the edges of the film and remains at a high pH on the discarded portion for up to two hours is highly corrosive to skin, eyes, and mucous membranes."* (Shaw 1991, 222).

Due the incredible popular success of instant photography, and serious limitations of the peel-apart system, in the mid-1960s Land decided to create a specific task force within the company, to secretly invent a second generation of Polaroid, called integral film.

e. Polaroid integral film, an elegant solution.

Land personally created and managed the new secret research team in charge of the second generation of Polaroid *one-step photography* system. He worked exclusively on the project called SX-70, for almost a decade. The challenges were uncountable since Land had described the ultimate *one-step photography system* with no compromise. The print produced by the new Polaroid cameras had to generate no waste so that the public would never be in direct contact with the processing chemicals. *"This NEW film would have no chamber in which to develop, no sandwich, to be peeled. All the element of exposure and development – and the cessation of the development – must be self-contained. Gone in a stroke would be the 435 million pieces a year of what the industry analysts called garbage."* (Wensberg 1987, 149).

While the scientists and ingeneers were still asking for four to five years to achieve the challenging goal, Land abruptly decided to reveal the new Polaroid system to the company investors at the end of 1971. One year later, the SX70 system including the colour film and the first camera was introduce in Florida, a state chosen as real-time market test. The company that had built several new factories exclusively dedicated to SX70 was able to deliver the new line of product globally only in 1974.

Land had succeeded a second time, re-creating a one-step photography system that was easier and cleaner to use. He saved his company, making its main product-line compatible with the new environmental legislations that would protect the public from direct exposure to chemicals such as photo processing solutions.

Within the next decade, Polaroid doubled its sales averaging 9 millions Polaroid cameras a year every year for the next ten without reaching market saturation (Wensberg 1987, 178).

In 1991, EPA estimates 12% of the total number of film sold in the U.S was instant film. Given the fact that Polaroid film packs were on average four times more expensive that a regular film since the processing costs were embedded, Polaroid was cashing an estimated 30% of the global film sales (EPA 1991, 10). The commercial success would not fade until the mid-2000s. Polaroid produced 30 millions of film packs in 2007 (Dougherty 2009, B3).

The peel-apart Polaroid system did not retired; it was re-marketed toward commercial and professional applications like portrait ID photography or medical imagery. In 2001, faced with the rapid digitalization of photography, Polaroid Corp. filled bankruptcy. In 2005, the brand copyrights and company assets was acquired by Peter Group Worldwide, but the in early 2008 the group decided to stop the manufacturing of all instant photography products. Ironically, Fujifilm is currently producing the last instant photography film: color and black and white instant film packs that are compatible with Polaroid peel-apart cameras but based on Fujifilm proprietary technology.

Today, the ultimate one-step photography system based on the integral film, is not produced anymore. A community project called “The Impossible Project”, lead by Florian Kaps, managed to save from scrap the production equipments from a Polaroid factory that closed it door in Enschede, Netherland in 2007. Kaps’ goal is to re-invent Polaroid integral films and bring it back to market by the end of 2010. However, so far, it is estimated that 100 to 200 millions of workable Polaroid cameras are out of film-packs (Dougherty 2009, B3).

3. Kodak, a new vision of popular photography.

a. George Eastman, a marketing genius with a vision.

George Eastman started his company in 1878, supplying photographic dry-plates to local photographers. Modeled on other similar companies in Europe, Eastman's business plan was to produce ready-to-used (sensitized) glass photographic plates for the U.S market. Due to the relative isolation of the U.S at that time, lack of fast overseas transportation, and the relatively short lifetime of photo-sensitized product, Eastman was immediately successful.

The genius of Eastman genius relies expanding the activity of the company to the production of processing chemicals and equipments with – in parallel – the aim to create and support a new industry that would be in charge of processing films and plates exposed by a new generation of photographers: amateur photographers. Eastman founded Eastman Kodak company with a vision: offer user-friendly camera and film systems to amateur photographs who could have them locally processed by independent wholesale photo labs that would also use Kodak professional equipments.

In 1888, Eastman Kodak Co. introduced the first portable photo camera for amateur photography integrating a 20 feet long roll of film, that allowed to expose one hundred 2.5 inches diameter circular photographs. When the photographer was done with the 100 snapshots, he just had to send the camera to his local Kodak service shop to get the in return the processed film and photographs, and the camera re-loaded with a fresh pack of film (Eastman 1996, 202).

The business model worked well. Within his lifetime, George Eastman built one of the main American chemical companies. *"George Eastman was seventy-two in 1926. By 1926 he employed more then fifteen thousand people. Kodak, the name he coined, had become one of the three largest photographic companies in the world. 'You press the button, we do the rest' was translated into dozen languages. Genuinely committed to research, Eastman's laboratories had helped make the American chemical industry self-sufficient during the world war, and Kodak was moving toward world leadership in the manufacture of chemicals"* (Wensberg 1987, 96).

Constantly re-inventing and optimizing its photographic systems, Kodak was leading, in fact creating, the photo business in the U.S. Following the snapshot moments, family shots captured with a Kodak camera on Kodak films, were processed by Kodak's processing laboratories, and printed on Kodak photographic paper. Wensberg describes Jordan Marsh, Boston's oldest department store in 1948 as, *"Jordan's photo department did not carry a wide variety of merchandise. Eastman Kodak supplied most of what was offered. At the top of the line was the Kodak Reflex, a rather prosaic twin-lens reflex camera, There were folding Kodaks with collapsible bellows and prism viewfinders, and Baby Brownies which were sold for only $2.75 but took very acceptable black-and-white snapshots, The Brownie was the first aim-and-shoot camera.'You press the button, we do the rest,' reiterated Kodak"* (Wensberg 1987, 97).

Kodak's dominance on the American market, at that time one of the largest market for consumer goods, prepared the company to expand its dominance in the 1950s. The innovation capacity of its Japanese and German rivals was down by WWII, and Kodak used the window of opportunity to conquer the two other large markets, Europe and Asia. *"Before* *the war, Eastman Kodak had been overshadowed only by Agfa in Germany and Konishiroku* [Konica] *in Japan. Now* [1961] *it reigned supreme, its share of the American market is more than 90 percent"* (Wensberg, 1987).

Before 1954, Kodak color film technology was a monopoly. The first chromogenic color film, Kodacolor, that was sold with an advance charge for processing in a Kodak affiliated lab (Times 1955). An agreement between Kodak and the US Federal Governement signed in 1955 ended that commercial practice. Kodak was forced to open its technology to other players.

In a more recent anti-trust ruling *Berkeyphoto inc. v. Eastman Kodak,* judge Kaufman, recalls *"This film/processing "tied-in" attracted the attention of the Justice Department, and in 1954 a consent decree changed the structure of the color photofinishing market drastically. Kodak was forbidden to link photofinishing to film sales, and it agreed to make its processing technology, chemicals, and paper available to rivals at reasonable rates"* (Kaufman, 1979).

b. Kodacolor and Ektacolor technologies.

Eastman Kodak Co. opened-up the activity of taking photographs to everybody thanks to the processing services that it supported. However, Kodak business was mostly based on processing black and white films and prints. Until the mid 1950s, the only way to get color photographs was to shoot slide films such as Kodachrome, and use a projector to enjoy slides projected on a white screen in a dark room during family time.

Thanks to the invention of dye-forming couplers, or chomogenic development, it became possible to create the three primary colors necessary to obtain a color photographic image in a single processing step. Based on this unique technology, the first generation of Kodacolor film was introduced in 1942 and the Ektacolor print paper based on the same principle was presented in 1955.

Photographers were ecstatic about the new process, *"So it can certainly be said emphatically that a long awaited and highly satisfactory goal was attained with the introduction in 1955 of the color-print material, Ektacolor paper (originally designated Type C) and its team worker the Kodacolor films"* (Bagby 1961, 11).

Following the business model invented by Eastman, Kodak Co. was selling the films to amateurs and professional photographers, as well as the chemicals required to process them in the form of the new Kodak Process C22, the printing Ektacolor paper and the printing equipments to the processing labs.

c. Optimization of Kodacolor film process.

Kodacolor films were introduced in 1942 in sheets, followed by roll-films in the popular formats 120, 620 and 127, the camera standards of the time. In 1958, the format 135 (35mm) was added to the line. Almost all the cameras produced could benefit the new Kodacolor technology and led to Kodak color prints (Bagby 1961, 24).

Until 1955, Kodacolor films were exclusively processed through Kodak processing facilities. Several improvements were made to the process over the years, but very little is known today since they were not subject to publishing at the time.

Following the first anti-trust case of 1955, Kodak agreed on publishing its C22 process specifications and started to sell these photo chemicals for the process of Kodacolor films by other private labs, totally independent from Eastman Kodak Company. With the

Kodak process C-22, it took about 50 minutes to develop color negative films not including drying time.

Table 1

Kodak Process C22 for Kodacolor and Ektacolor films (1955)				
Step	Name	Time Min.: sec.	Temp.	Capacity
1	DEVELOPER	14:00	75 F	6 films / liter
2	STOP BATH	4:00	73-77 F	12 films / liter
3	HARDENER	4:00	73-77 F	12 films / liter
4	WASH 1	4:00	73-77 F	1 to 2 gallons / min.
5	BLEACH	6:00	-	12 films / liter
6	WASH 2	4:00	-	1 to 2 gallons / min.
7	FIXER	8:00	-	12 films / liter
8	WASH 3	8:00	-	1 to 2 gallons / min.
9	PHOTO FLOW	1:00	-	12 films / liter
TOTAL WET TIME		50:00		

Note. From Bagby 1961, 42

According to the C22 specifications, 7 liters of processing solution as well as 50 to 200 liters of warm wash water were necessary to process a batch of twelve 35mm 20 exposures rolls of Kodacolor films, averaging 16 liters of water consumption per film processed.

In the late 1950, the new Kodak C41 process replaced C22 with the introduction of the new film, Kodacolor II. It was designed to be used with continuous processing machines that would allow chemicals replenishment proportionally to the surface of films processed. In optimal normal conditions, a C41 processing machine needed a volume of 0.360 liters of processing solution as well as 6.5 to 7.5 liters of warm wash water were necessary in order to process each 35mm 20 exposures roll of Kodacolor film, averaging 7 liters of water consumption per film processed. The new generation process was not only three time shorter in term of processing duration, it allowed to conserve more than 50% of the water that was required only a few years before.

Table 2

Kodak Process C41 for Kodacolor II films (1962)				
Step	Name	Time min:sec	Temp.	Replenishment rate
1	DEVELOPER	3:15	100 F	100 ml / film
2	BLEACH	6:30	75-105 F	84 ml / film
3	WASH 1	3:15	-	1 to 2 gallons / min.
4	FIXER	6:30	-	84 ml / film
5	WASH 2	3:15	-	1 to 2 gallons / min.
6	STABILIZER	1:00	-	84 ml / film
TOTAL WET TIME		23:15		

Note. From Engdahl 1967, 49

The latest version of Kodak negative film process chemistry was introduced in 2006 and named Kodak Flexicolor C41-SM. It was designed to be used by small to medium capacity automated processing machines (10 to 200 rolls /day) that are generally used to process color films in one hour or less in locations like drugstores or photo stores. No running water was necessary as earlier version of the C41 process that appeared on the market in the mid-1980s. In optimal normal conditions, a C41-SM processing machine needs a volume of 0.100 liters of solution per 35mm roll of film, including a 10% increase to take into account the regular cleaning of the equipment. It represents only 1.5 % of the volume of water that was required to process the same roll of color photograph, when the original C41 appeared, 50 years previously.

Table 3

Kodak Process C41 SM for Kodak color negative films (2007)				
Step	Name	Time min:sec	Temp.	Replenishment rate
1	DEVELOPER	3:15	100 F	13 ml / film
2	BLEACH	1:00	95-105 F	3.5 ml / film
3	FIXER	2:00	-	15 ml / film
4	FINAL RINCE	1:00	-	27 ml / film
TOTAL WET TIME		7:15		

Note. From Kodak 2007, 2-1

When compared to the first version of Kodak negative film chromogenic process from 1955, the newest C41-SM is able not only to process negative film seven times faster, but it also uses 1,000 times less water to do so with a volume of effluent equal to 0.1 liter per film.

d. Optimization of Ektacolor printing paper process.

Before 1955, when Kodak processing facilities were the only industrial photo labs operating in the country and able to produce color photo prints with a high productivity output, none of the technology that Kodak used was published. Following the first Kodak anti-trust federal action from 1955, Kodak named its color print process P122 for Ektacolor paper. The wet process time was about 42 minutes (Bagby 1961, 76).

A very few operator used P122 for commercial printing due to its complexity and the average cost per print produced. After 1955, Kodak's commercial name for its color printing paper switched from Kodacolor to Kodak Ektacolor Type C. The name Type C print, is still commonly used to define a color chromogenic print. *"Kodacolor Types I, II and III were used exclusively by Kodak for making prints from amateurs' negatives until 1955 when 'type C' paper was made available to photographers using Ektacolor sheet film introduced in 1948. After 1959 Color Print Type C became known as Ektacolor paper in accordance with a* [new marketing] *ruling"* (Coote 1993, 163).

The first Kodak Ektacolor process that was widely used when the photo industry really took shape was named Kodak Ektaprint and appeared in the early 1960s with the introduction of the first Kodak resin coated color paper, Ektacolor 20 RC. With the new plastic-coated paper structure, Kodak color process entered the modern era of mass color photography. *"Wet processing time was reduced to 20 minutes and drying only added another minute or two"* (Coote 1993, 163).

With the perfection of resin-coated color print paper, Kodak Ektacolor 37 RC was designed with a new Ektaprint chemical process names EP-3. This particular process was designed to be used in automated continuous photo processors allowing a larger output than the previous systems that were only designed to be used manually in tanks. Wet processing time was a reasonable became 10 minutes (Engdahl 1967, 81), however the water consumption was still high compare to today's standards.

Table 4

Kodak Process EP-3 for Kodak Ektacolor 37 RC (1967)				
Step	Name	Time Min.: Sec.	Temp.	Replenishment rate
1	DEVELOPER	3:30	88 F	800 - 1000 ml / m^2
2	STOP BATH	1:00	86-90 F	800 ml / m^2
3	BLEACH-FIX	1 :30	-	800 ml / m^2
4	WASH	2:00	-	1 to 2 gallons / min.
5	STABILIZER	1:00	-	800 ml / m^2
TOTAL WET TIME		10 :00		

Note. From Engdahl 1967, 81

In a move to dominate the minilab market in 1986, Kodak totally redesigned its Ektaprint process with the introduction of the Rapid Access (RA) generation. It was possible to get a dry print from any negative film in less than 4 minutes, without running water, thanks to a new stabilization technology. The critical final wash was replaced by chemical stabilization without any compromise on the long time permanence of the prints. On top of these improvements, RA4 chomogenic developer was less concentrated and incorporated the last generation of color developer agent, CD4, that was known as less susceptible to cause skin allergies. Kodak color printing technology was ready to enter the photo consumer shops all around the world.

In an ultimate change, Kodak shortened the sequence of the original RA4 process to only 2 minutes of wet time, beating all digital printing system available at that time in term of productivity. The volume of water necessary to process a surface of one square meter was limited to less than 0.300 liter, or 0.1 liter to process the average 25 4x6' prints of a film.

Table 5

Kodak Process RA2 for Kodak Ektacolor Edge (2006)				
Step	Name	Time min:sec	Temp.	Replenishment rate
1	DEVELOPER	0:25	104 F	64.6 ml / m^2
2	BLEACH-FIX	0:25	104 F	26.4 ml / m^2
3	STABILIZER	1:30	95-104 F	193.7 ml / m^2
TOTAL WET TIME		10:00		

Note. From Kodak 2007, 2-3

e. Environmental impacts of standards Kodak process.

i. Size of the photo processing industry.

By late 1970s, all Kodak competitors (Agfa, Konica, Fuji) agreed on using the same color processes and the same chromogenic technology (C41 and EP2/RA4). In fact, the entire global photo industry started using the processes established by Kodak and alternative color photography technologies could not subsist.

In a recent study about the U.S photo processing industry, EPA estimates that 296 million square feet of color film and 4,130 million square feet of color paper were processed per year between 1994 and 1996 at the peak of production. An average 700 millions of color rolls were processed annually (EPA, 2006).

Mark DeSimone president of Qualex, Inc., Druham NC a subsidiary of Eastman Kodak that was the largest photo processing company in the world, estimates the 2008 US market at 50 millions rolls, less than a tenth that is was a decade before (Lansky, 2008).
In 2006, a majority of U.S amateur and professional photographers were using digital

camera. According to InfoTrends, 67% of the US households were equipped with a digital camera in 2006, while only 42% were in 2004.

ii. Water use.

Before the digital switch, these commercial photo-printing activities created wastewater discharged of 2,260 million gallons per year (MGY) in 1994. In 2003, the film market was already impacted by the rise of digital cameras, the photo processing wastewater discharge was down to 1,840 MGY (EPA 2006). It is estimated that during the last decade, new processing technologies as well as the downturn of the film market drastically reduced the need of fresh water from the photo industry.

iii. Toxicity and residual silver of photo effluents.

On top of intense use of fresh water, the photo industry effluents were problematic for their toxicity. The technological progress achieved on the formulation of chomogenic developers over the last 50 years made the release of this particular part of the process - while not harmless in case of human contact - almost innocuous for the environment thanks to very high level of biodegradability. *"The developing agent para-phenylenediamine and its diethyl and dimethyl derivatives* [CD2, CD3, CD4] *are highly toxic by every route of exposure and can cause severe skin allergies and asthma.* [However], *The newer color developing agents are designed to have reduced toxicity, but still may cause skin irritation and allergies"* (Shawn 1991, 198).

The EPA latest report about the photography industry titled "*Technical Support Document for the 2006 Effluent Guidelines Program Plan*" concludes that discharge of silver accounted for 99% of the toxic load discharged by the photofinishing industry (EPA 2006). This statement is a confirmation of early findings made by EPA about the photo processing industry in 1991.*"Photoprocessing laboratories primarily generate aqueous wastes from process operations. The most significant contaminant is silver, which may be present as silver thiosulfate complex. Some aqueous wastes also contain other chemicals. Technology exists to recover silver, as well as certain other chemicals. Solid wastes are primarily paper and fabricated items such as film cassettes, spools, and cartridges. »* (EPA 1991).

A study published in 1997 by Purcell and Peters estimated that in 1978, 25.5% of the total amount of silver release in the environment originated from the photographic industry. In modern color processes based on chromogenic developers (Kodak EP2/RA4 and C-41) silver is removed from the sensitized material during processing. All the silver based compounds go into the processing solutions overflow, mainly bleach, fixers and wash waters to charge it with silver thiosulfate, silver sulfide and silver chloride (Purcell and Peters 1998).

Starting in 1990, Publicly Owned Treatment Works (POTW) and private wastewater treatment facilities that have stringent limits in their NPDES permits started to monitor the level of silver in their incoming effluents and pointed the photo industry. By 2000, POTWs reported the benefits of the implementation of the silver recovery plan published in the Code of Management Practices for Silver Dischargers (CMP). In its 2006 report EPA notes "*Four POTWs documented loading reductions* *of 20 to 52% over historical baseline after the CMP implementation*" (EPA 2006, 19-23).

The photographic industry's response was organized in the form of a voluntary program summarized in a document titled "Code of Management Practices for Silver Dischargers" (CMP). In the introduction of the CMP published by the Silver Council in 1997, the photo industry makes it clear about its motivation to recover silver from all used processing solutions for three main reasons: *"1. Silver is a non-renewable resource 2. Some sewage treatment plants and states restrict the amount of silver that can be discharged 3. Silver has economic value. Depending of the size of the facility, 90% to 99% of the silver can be recovered either by investing in recovery systems or by collecting the processing solutions overflow and sending it to specialized treatment facilities*" (The Silver Council 1997).

The example of San Francisco Bay is of significance to evaluate the effect of silver recovery policy. Level of silver pollutants has been subject of study for decades, since the levels observed have always been considered as very high. A.R. Flegal, C.L. Brown, S. Squire, J.R.M. Ross, G.M. Scelfo, S. Hibdon, explain the historical problem this particular water basin had with silver accumulation. The authors critically review 20+ years of silver monitoring in the San Francisco Bay. They acknowledge a decline in silver over the years. However, the level of toxicity on marine life is still of importance. They conclude that the policies in place are efficient, but a long term monitoring program must be maintained to understand the evolution of silver pollution in the San Francisco Bay (Flegal, Brown, Squire, Ross, Scelfo, and Hibdon, 2007).

In 1985, East Bay Municipal Utility District (EBMUD) also started a program to monitor the level of silver collected at San Francisco-Oakland Bay Bridge wastewater facility (NPDES permit number CA 0037702). In 1991, EBMUD started issuing permits to local photo processing facilities with the goal to be in compliance with National Pollutant Discharge Elimination System permit limitations issued by EPA under Clean Water Act of 1977. This policy has been named Pretreatment and Pollution Prevention Program (PPPP). The sample NPDES routines collected from EBMUD main San Francisco-Oakland Bay Bridge WWTP following EPA Method 200.7 (EPA revised 2001), show a decline of silver concentration in wastewater incoming flow at EBMUD main wastewater treatment facility: "*Silver (Ag) declined from 6.5 kg/day in 1988 to 2.9 kg/day in 1991 when the first 79 photo processor permits (P2) were issued. This value further declined to 1.8 kg/day in 1994, following issuance of 160 printing shop permits. Currently, Ag level is 0.775 Kg/day, showing 88% overall reduction since 1988*" (EBMUD 2006).

The two last decades of silver release monitoring in San Francisco Bay, show that while the photo processing activity was accelerating, silver pollution was greatly reduced thanks to silver recovery practices that the photo labs had implemented.

4. Innovation theory and the photography industry.

In his study titled *"Burning with Desire: The conception of Photography"* Geoffrey Batchen defends the idea that photography was conceived by early users of the *camera obscura* before it could be invented back in 1700s and later.

Their idealistic approach of what could be an ultimate photography system was based on the notion of *photo-desire*, as defined by Batchen. *"Almost all the early photographers spoke of wanting to devise a means by which nature, especially those views of it found in the back of a camera obscura, could be made to represent itself automatically"* (Batchen 1999, 56)

According to Batchen's theory, *photo-desire* led photo scientists and inventors to constantly improve and optimize the photo technology of their time. Along the long history of innovation, ultimately the optimal level of photo practicality was achieved, at the same times lowering the environmental impacts of photography.

The process by which a *"natural"* reproduction of reality, as it was envisioned from the beginning, could not participate in the destruction of the same reality. Batchen argues that for many years, following the idealistic goal of reproduction of nature was at odd with the complexity of the chemistry and equipment that was necessary to practice photography, processes that was on top of their sophistication harmful to nature. Referring to the example mentioned in this paper – Daguerreotype – Batchen explains, *"To describe photography as spontaneous was to claim that it proceeded entirely from natural impulse, which seems at variance with the preponderance of chemical manipulation and equipment necessary to processes like the daguerreotype"* (Batchen 1999, 90).

In other words, the cumulative effort of the photo scientists, inventors, innovators and the entire photo industry – all of them inspired by the notion of the *photo-desire* – had as primary goal to eventually come-up with cleaner, simplified and user friendly photographic processes that could transform photography in an everyday practice for everybody. Daguerre, Land and Eastman personal stories support Batchen's vision of the evolution of photo technology toward an ideal cleaner, fast and cheap digital imaging process that ultimately is now dominating photography.

5. Conclusion.

Over the last two centuries, photography became part of everybody daily life. In modern life we are constantly exposed to photographic images to work, learn and communicate. Our lives are documented in almost every aspect with family pictures that are regularly taken as photography became a modern world social norm attached to friend, family and work gathering parties. Photography is embedded in our society as a systematic cohesive social tool.

The technological evidences discussed in this paper show that photography became an addictive social practice thanks to its constant technological improvement. The scientific community had to find simple and cost effective technologies under the pressure of the market forces willing to expand photography's role.

The environmental aspect of the simplification brought to photo users over the last two centuries is of significance. Photography became such a large scale industry that it became just impossible to use the early processes that were too water intensive, and based on chemicals that were too hazardous to be used on a commercial scale. These early processes were not sustainable.

The history of photography technology shows a path that should be studied for other widely adopted practices as well. When a practice becomes so embedded in human life that everybody use it on a daily basis, the market forces – helped with scientific knowledge and oversighted by environmental policies – have powerful incentives to re-invented the process in order to make the given practice sustainable in the long run.

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