Screenization

On the Diffusion of Digital Screens

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Introduction

Screens fascinate us. I recall an anecdote from some years ago when the supermarket where I used to do my grocery shopping upgraded its security system. Up until then they had huge mirrors hanging in the aisles of the shop to observe if somebody would be stealing something. A prominent mirror sphere right above the entrance would make you inevitably notice the mirror system when entering the market.

Once they upgraded to a CCTV video surveillance system, they replaced the mirror sphere with a large LCD screen, displaying the video signal of a camera filming the entrance of the store. During the next weeks, whenever I was standing in the queue at the cashier, I noticed little kids standing in front of the camera, waving and jumping, while looking at their images being displayed in real-time on the screen. Why did I never see any kids before, jumping in front of the mirror sphere and looking at their reflections?

Is there a difference between images perceived on a screen and from its surroundings? What is our relationship to screens, how do we influence them and how do they influence us? And at a fundamental level: What are screens and what do they do? And how did they became what they are today? These questions might sound trivial, but the more I thought about it, the more complex they became.

We use screens as well for working as for relaxation and leisure time. We use them to communicate with our friends and families but also to get in contact with people on the other end of the world we've never met before. We are touched and moved by the movies we watch and the games we play on them. They inform us what is happening around the world, when the bus is coming and if it will be raining tomorrow. We use them to write texts like this one, but also love letters or bookkeeping tables. They show us the things we want and the thing we think we want. They are with us from our most intimate, private moments to our most open and shared ones: People come together to watch cultural or sport events on big screens in a huge crowd but they can also consume Virtual Reality Pornography in the private solitude of their homes.

Nowadays screens increasingly structure and determine how we perceive and interact with our environments. They appear to us in different shapes, sizes, contexts, applications and circumstances. In most of our everyday encounters with screens the content is confined to a flat rectangle within the context of our regular field of vision. The images consist of many individual elements, but they are so small and indistinguishable that they appear to form a coherent image. We accept the patterns that are created by the modulation of light on the surface of a screen as equally valid as the visual impressions we perceive from the objects surrounding the screen. Today's screens mediate most of our interactions with the parallel digital world that is increasingly developing. They are the meeting point, where these two worlds become mutual understandable.

No matter where you look, you see screens, but you seldom notice them. This also reflects in media theory and scientific research in general: the screen is an undertheorized aspect. This might have to do with the fact that screens seem not very interesting by themselves. They have to be connected to something else to be able to show anything: *"[The screen] is not in and of itself a medium, format, or platform. Rather, it is often an in-between manifestation of all the three, one that materializes how we come to see and describe the differences and connections among television, film, computers, electronic signage, and digital spaces"* (ACLAND 2012: 24). On the other hand, none of these would function without screens, or at least we wouldn't be able to see their functionality. Screens can be seen as the unnoticed common denominator of most modern media. There are many perspectives and angles from many different disciplines through which you could think about the screen, but I will mainly focus on the role of the Screen in relation to Digital Media.

As this is such a complex, multi-layered topic, my approach relies on aspects of many more detailed observations that others conducted already. A great overview of the screen gives "The Screen Media Reader", edited by Stephen Monteiro. As far as I know, it is the first collection of texts dedicated to the screen in its material manifestation, crossing the borders of many disciplines.

The earliest conceptual predecessors of screens are described in great detail in Lucia Sehnbruchs dissertation "Eine Mediengeschichte des Bildschirms" from which I adopted the conceptualizing of the screen complex as a Dispositiv.[1] Sigfried Zielinksi's approach of Media Archeology and especially Erkki Huhtamos call for a new field of research called Screenology structured my interest to look into previous manifestations of screenic characteristics to learn more about recent and potential future developments. Lev Manovich's categorizations into three different stages of screenic development, and especially his thoughts on the real-time screen greatly influenced my view on electronic screens, and their separation from digital screens. The recent history of experimental screens such as Mixed Reality or Projection Mapping technologies is mostly based on a previous paper and interviews on the role of these technologies to shape our perception I conducted in 2016 for my studies.

In the beginning I will refrain from using the term screen in a strictly defined way and instead refer to something like a "common-sense" screen, something that seems obvious as a screen to most people. Throughout the text we will collect properties of screenic behaviors in its different stages of development, but not try to find an absolute definition.

After a short disambiguation of the term Screen, the first chapter aims to look at the current status of screens, to make an inventory of the global distribution of screens and the time and activities we engage with them. Later we will have a look into the material function and composition of modern screens, as well as some first thoughts about their more abstract characteristics.

The major part tries to understand how screens became what they are now by tracing their lineage of development. A wide range of concepts, ideas and technologies is covered in a more or less chronological order, interrupted by selective closer looks. This general history is extended by a specific part about digital screens, their contemporary transformations and experimental approaches. This part is concluded a description of screenic properties and an attempt for a definition of what constitutes a screen for the further usage.

The last part tries to describe the formation of these screenic properties and potential future developments as screenization and show its inherent interlinking with the general trend of digitalization.

1 Sehnbruch describes a Dispositiv after Foucault as *"a kind of heterogeneous ensemble that constitutes the structural components of a discursive field"* (SEHNBRUCH 2018: 6)

Etymology

A good starting point to think about the screen is to look at the etymology and meaning of the word itself. In most European languages you find similar terms, with a likewise meaning that describe a separating, yet connecting quality. The Proto-Indo-European *(s)ker- ("to cut, divide") is believed to have influenced many languages like the German Schranke ("barrier, gate") or the Old Dutch *skrank ("barrier") and also the French word écran (from Old French escren).

In the fourteenth and fifteenth century, the English word Screen came to use as a noun and a verb, describing "*any thing that affords shelter or concealment*" and *"to sift, to riddle"* (JOHNSON 1775, CITED IN HUHTAMO 2017: 82). The first time commonly usage of the word screen, came in the form of fire screens[2]. They protected the area around a fire from flying sparks and too much heat but sometimes also had some holes or were partly transparent to let the light pass through to enlighten the room[3]. Still nowadays the word screen is used outside the media domain for physical dividers of different sorts and for the process of checking or filtering.

Let us also have a brief look at some of the neighboring terms. The sometimes almost parallel used word display, derives from a meaning to "unfold" and is nowadays mostly used for the act of presenting something. A more withdrawn character is implied in the term Monitor and its usage to observe or supervise. The word projection again stems from a Latin origin that means "to throw forth" and is used in that sense in many cases, as in the emitting of light in the projector or the transformation from one system into another one in mathematics or psychology.

2 Erkki Huhtamo describes the early uses of fire screens as domestic furniture in great detail, but at some point concludes, that the variety of developments, *"[makes] it impossible to cover the topic in detail"* (HUHTAMO 2017: 82)

3 This usage bears some interesting notions towards the screens ability to modulate light, to which we will come back later in this text.

An overview of everyday screens

It is complicated to find research, articles or statistics about such a relevant, but also fast-changing topic as our relation to screens. Public discussions about the topic are often very emotional, which complicates it to distinguish between facts and assumptions. Almost all information you can find about the time people spend interacting with screens are related to the “screen-time” of teenagers or kids. Also the almost exclusive focus on Western countries make a global overview or even comparison a complicated undertaking.

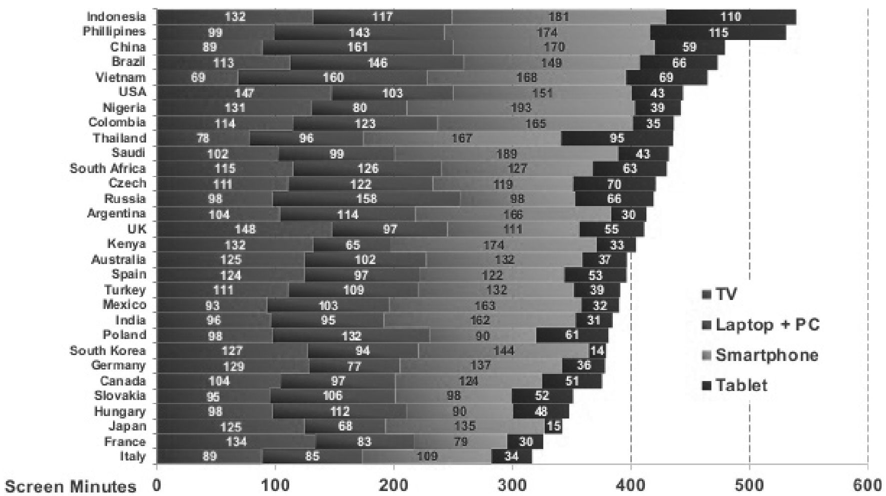

Fig. 1 Daily Distribution of Screen Minutes across different countries.

Nevertheless the collected information and different statistics, show a global average of 6-8 hours that people spend in front of a screen daily. In the changes of screen usage over the years we can see a correlation to the general ratio of existing screens. TVs were the primary interaction point with screens, until only recently, when the usage of computer screens and mobile screenic devices caught up.

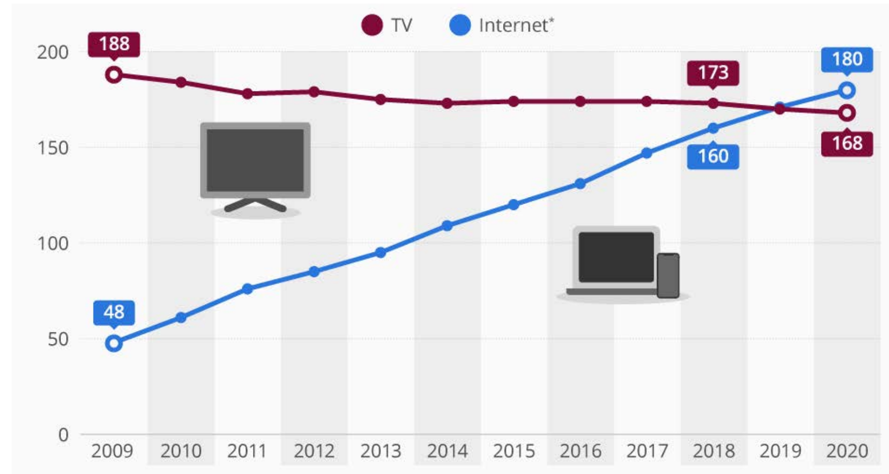

Fig. 2 Daily TV and Internet consumption worldwide (in minutes)

What might seem surprising is that screen time seems to be more or less similar distributed all over the world, but you can see from the statistics, that “more developed” countries engage with screens more through older technologies such as TVs and PCs, whereas “developing“ countries engage with screens much more through mobile screenic devices. This goes hand in hand with some previous research for a University course about the role of digital technologies in South Africa. In 2014 there were around 150 mobile phones per 100 people in South Africa, compared to 80-90 in most European countries. In the text I argue that South Africa, as many countries of the Global South leapfrogged a certain stage of development in digital technology, namely the phase of stationary PCs and fixed land line Internet access (POTTHAST 2015: 10).

For the seemingly simple question “How many screens are existing in the world?” is quite complicated to find satisfying answer. One problem is obviously the definition of a screen, the other one again the rapid changes and in this case specially the lifespan of the devices. After the comparison of multiple sources I assume there are around 9,5 billion common-sense screens that are currently in use worldwide. The number of screens that are not used anymore but have not been scrapped I estimate to be another half of that number.

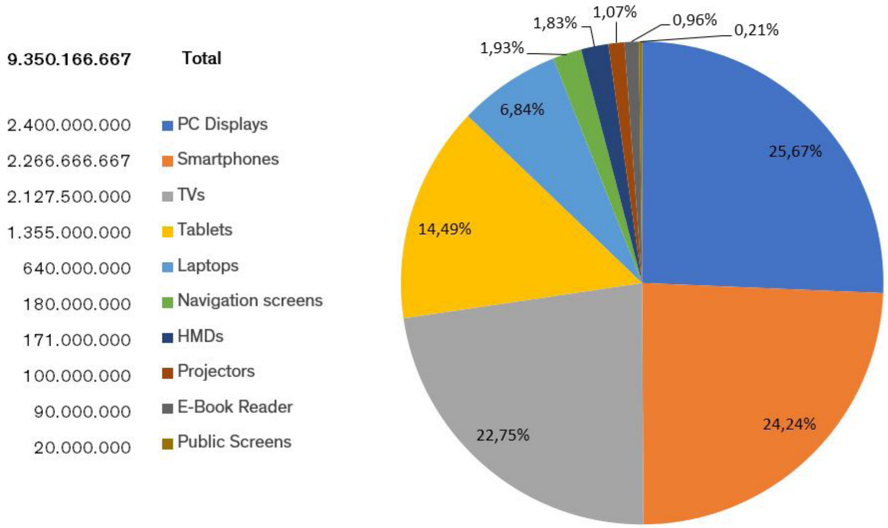

Fig. 3 Estimation by the author of the number of screens worldwide in 2018

Depending on the sources, until recently the most common screen was the TV set with around 2,1 billion devices, but in recent years the mobile screens such as smartphones or tablets overtook the TV and it is assumed there are now around 3,8 billion mobile screenic devices. PCs with external screens and laptops follow next with ca. 3 billion devices. After a huge gap follow navigation screens e.g. in cars, cinema, home and office projectors, Mixed Reality devices such as head mounted displays and screens in public space. A rough, curious calculation reveals that if all the screens where spread out next to each other, they would fill an area of 1.828 square kilometers. This might not sound too much, but at still it would be able to cover 2,5 million soccer fields or ca 3/4 of the country of Luxembourg with screens.

No matter how complicated it is to count the number of screens worldwide or to measure the time spent interacting with them, one thing is for sure: There is an immense number of screens worldwide that keeps on growing and they are used more and more.

What screens are made from

At this point it is worth looking into an aspect, that is often neglected outside of engineering circles: The actual physical composition and functionality of current screen technologies. This helps to problematize not only the normative qualities of the established grid-based screen, but also shows its very fragility and critical composition regarding sustainability.

Sean Cubitt lays out this aspect in his text "Current Screens" in great precision and I will mostly follow his argumentation. As mentioned earlier, the predominant technology for both television and computer screens were cathode ray tubes (CRTs) up until the 2000s. An electron beam is focused onto a layer of phosphor that keeps glowing for a short period. Through rapid line-by-line scanning of the screen the illusion of a consistent image appears for the human eye. One huge innovation that separated CRTs that were used for TVs or PCs from previous technologies used in oscilloscope and radar screens was the introduction of a raster, a Cartesian grid that separated the viewing area in small portions and allowed for brightness gradients and finally the representation of different colors.

The phosphors that are used to generate the different colors in a CRT screen and also the frequent use of barium in the electron gun are often toxic and almost impossible to extract. To withstand the extreme pressure of the tube, the glass in front of the screen has to be very thick and is often reinforced with additional metal. To decrease the risk of radiation of X-rays and ions generated by the electron beam also the glass is normally leaded. In addition, the power usage of CRTs is extremely high, as up to 32.000 volts are required in the screen anode (See CUBITT 2011: 39F.)

In 2004 CRT sales were overtaken by liquid crystal display (LCDs) for the first time, which follow a very different approach of image generation than CRTs. Instead of a very fast moving light beam, the light-modulating properties of specific liquid crystals are utilized to create a homogeneous image. The liquid crystals do not emit light themselves, but they can be used to control the brightness of a back light or a reflector. Broadly simplified, the amount of current applied to a liquid crystal determines how much light it lets through or reflects. LCD screens depend on a grid structure, in which each pixel consists of three liquid crystals with different color filters. Similar technologies are nowadays also used in many projectors and e-book readers.

LCD screens have a much lower power consumption than CRTs, but nevertheless some of their components are similarly dangerous to the environment. The back lights contain significant quantities of mercury and the per-fluorinated compounds used in the crystals are contributing to the greenhouse effect. In addition LCD screens require a range of scarce natural resources like rare earth minerals and metals. To produce the color red for example the element Europium is required, *"which is considered one of the scarcest elements in the universe"* (MONTEIRO 2017: 9). Even if these components can be extracted and recycled in theory, in practice they are often incinerated

A relatively new development are LCD screens back lit with light-emitting diodes (LEDs) or even fully consisting of individual LEDs. So far these are mostly utilized for large scale, low resolution displays, but in both applications they promise to be much more energy efficient than previous display technologies. Also many experimental screens rely on different technological approaches than the majority of contemporary screens

One main problems with all digital screens remains, that they are almost impossible to repair. The underlying grid structure is of such a delicate complexity, that it is mostly not possible to replace parts or repair individual pixels. Also quite often, even if only one pixel fails it affects the whole row or column surrounding it. Other problems can occur in the power supply, the back light or the video buffer. All the components are produced and assembled on such compressed space, that the only solution is normally to replace the whole screen.

Structure

This current grid-based structure of digital screens is incredibly powerful and it is a truly technical and conceptual masterpiece of engineering. They carry out an incomprehensible amount of microscopic electronic manipulations multiple times per second.

I conducted a small calculation about the number of possibilities of different images that can be displayed on a digital screen. Even with specialized Online large-number calculators I could only compute the number for a screen of 320 by 240 pixels, the other numbers were simply to big. If we assume that each pixel can display a standard color depth of 256 states for each of the Red, Green and Blue (RGB) colors, we already have 16,777,216 different color states that can be displayed with one pixel. Combined with the 76,800 pixels (of a 320×240 pixel screen) the number of possible constellations has more than 500,000 digits or fill over 200 Din A4 pages. And that all can change multiple times per second.

The grid of the screen works in many ways as a intermediary between the physical world and abstract systems or concepts. Light modulation becomes calculable, colors and shape can be described in a discrete form. The screen manifests the transitional layer between the world as we can perceive it sensually, and the mathematical descriptions that are understandable for the computer.

In the following chapters we will see, how the idea of separating given things into even smaller portions is inherent to the history of natural science and especially image producing technologies. Hannah Higgins even describes the grid as "*the most prominent visual structure in Western culture*" (HIGGINS 2009). From Dürer's drawing grid, to Babbage's usage of punched cards, to the partition of individual lines in CRT monitors the pixel emerges as the ultimate concept of the "picture element"[4].

4 This is also visible in the word pixel as a portmanteau of pix (from "pictures", shortened to "pics") and el (for "element").

Materiality

After looking into the technical functionality, material composition and grid structure of nowadays screens, let us think about more general tendencies, that associate all of appearances of screens: Their ambiguity and their self-effacement[5].

As demonstrated in our previous calculations, the pixels of a present day's screen can display an almost infinite combination of images. Therefore they can show nearly all pictures that can be imagined[6]. Independent of their meaning, a screen can show images, texts, movies, websites, a random noise or a combination of all of them. As long as the content is available in a digital form, it can be displayed on a digital screen. Coupled with the general trend for Digitalization[7] the screen becomes a flexible vessel for all sorts of digital visual media. *"[...] The computer screen has led the way in modeling itself as a container for anything (just as the computer models itself as a 'machine for anything')*. (WHITELAW 2011: 288)

The second tendency is to be found in this strong symbiosis of the screen with its content. It relies on an additional device to provide the images to be shown. *"The screen operates as a mediating substrate for its content – the screen itself recedes in favor of its hosted images"* (WHITELAW 2011: 287). This tendency can also be found in what seem to be desirable features of screens and how they are advertised today: They are supposed to be as slim as possible, ideally with no visible frame and of such high resolution that you cannot distinguish the individual pixels. The supporting framework and the structural elements of the apparatus should be invisible. And when the screen does show some content, the materiality of its surface steps in the background even more.

So in conclusion, the screens we surround ourselves with, are an ambiguous substrate for digital computing. They have the potential to make almost everything seen, while themselves staying unseen.

5 These observations are very precisely formulated in the beginning of Mitchel Whitelaw's text "After the Screen: Array Aesthetics and Transmateriality"
6 A great inspiration to think about the number of existing combinations of pixels was Jorge Borges short story "The Library of Babel" (1941)
7 Also used as Digitization: In the original meaning the word simply means the process of converting information in a digital format, that is computer-readable. By now it is often used as a synonym for the Digital Revolution. In the rest of the text I will use it in its duality for both meanings.

In 1957 the French philosopher, linguist and semiotic Roland Barthes wrote a series of observations in the form of little essays for his book "Mythologies". One of them is about the role of plastic as ubiquitous material in the 20th century. In 2012 the Canadian communication researcher Charles R. Acland drew an intriguing analogy to the role of the ambiguity of the screen as surface in the beginning of the 21st century.

From his perspective in the 1950s, Barthes' describes the characteristics of the fairly new material of plastic as a truly artificial one. It has no "natural appearance" and comes as a granulate, that can be shaped into any given form: *"It can become buckets as well as jewels."* (BARTHES 1957: 110). Looking at the ambiguity of screens which can show (almost) everything, but are nothing without their content, their dependent, artificial quality becomes evident as well. In the constitution of individual picture elements (pixels) as the substrate of screens, the granular, raw material of plastic is reflected that waits to be shaped. Barthes sentence "*[...] more than a substance, [it] is the very idea of its infinite transformation... [It] is ubiquity made visible"* (IBID: 110) could easily be applied to both, plastic and screens. In Barthes times, the ecological impact of plastic was not as obvious as today and maybe outshone by the potential new applications. Looking at the descriptions about the biological footprint of screens from above, we are in a similar situation today. Screens are as surfaces to the 21st century what plastic was as a material to the 20th century.

Finally, Barthes also describes how plastic is able to imitate a wide range of natural materials and how it substitutes their role bit by bit. *"The hierarchy of substances is abolished: a single one replaces them all: the whole world can be plasticized."* (IBID: 111). Here lies the equivalent to one of my main objectives of this text and the impulse for the following chapter: To look at the historic development of screens, the increasing diffusion of screenic properties and the substitution of other media as the process of screenization as diffusion. Also, let us keep the analogy to plastic in the back of our head, as a illustration of the screen's two tendencies for ambiguity and self-effacement.

History of the screen

Perhaps it would be possible to revisit the whole history of humanity along humans' relationship to light[8] and many of our modern behaviors through our interactions with screens. We won't be able to cover all these developments in great depth, but rather focus on those connected to the history and narrative of screens.

This history is not only a pure sequence of technical developments, but rather implies a whole history of cultural changes and epistemological paradigm shifts. The history of screens is found in a diffuse interplay of science and illusion and in constant exchange of visual perception, natural science, performative practices, media archeology, computer history and the duality of abstract concepts and concrete manifestations. Thereby we aim to trace the establishment of the cultural practices, that enable us to accept the light changes on a surface, mediated through a technical device, as part of our physical reality.

As everything else would go beyond the scope of this text, I also decided to focus mostly on the sequential history established in the Western discourse, even if many individual ideas or concepts were developed earlier or under different circumstances in different cultures. Also, for the first part of the text, I will focus on functional developments and usages of screens, rather than artistic ones. I will have to neglect the inherent forms of artistic expression, that take place within the individual screens (photography, video art, computer art, etc) and their experiments to explore the limits of the medium, as each of them includes a whole field of study for themselves.

Early times

Most texts dealing with the history of the screen begin around the 18th century. If we remember the etymology of the term screen, this is also the time, when things that resemble what we understand today as screens, were started to be called screens. I instead agree with Lucia Sehnbruchs approach, that one has to go back in time even further, to bring this line of linguistic developments

8 This ideas first came up in an discussion with Light Art curator Bettina Pelz, and is apparently also the basic concept of Sean Cubitt's book "The Practice of Light".

together with the conceptual precursors of what we understand as screen today.

One could argue, that the basic concept of screens goes back as far as the concept of perception and depiction in general. Even if we cannot verify how people were first inspired to start drawing, the earliest known form of drawings can be found in the form of cave paintings and date back around 40.000 years BC[9]. In different locations in Europe charcoal drawings of animals, humans and abstract shapes can be found. One theory about the origin of these first depictions of the environment suggests that the prehistoric artists where inspired by the flickering shadows of fires (see HERZOG 2010) or traced the shadows of small figurines onto the walls (see DAVID & LEFRÈRE 2014). Some even claim that small cracks in the caves or holes in tents acted as a kind of "accidental" Camera Obscura, that inspired early natural depictions (GATTON 2009).

If we think about the origin of drawings on a more abstract level, the concept to change the appearance of a surface as an act of communication can be seen as a very important phase in the development of mankind as a "*symbolic construction to make the invisible visible and to see the connections behind the obvious things"* (SEHNBRUCH 2018: 8). Also it marks the beginning of mankind's ability to externalize communication and pass on knowledge without direct interaction[10].

Now we will skip a long period of mankind's further developments, in which paintings, drawings and even writings have been cultivated in numerous cultures all over the world, and will come to the first recorded thoughts and theories about the concept of perception.

Shadow plays have been known in Central Asia, China and India for almost three thousand years. In the European culture we can find one of the earliest descriptions of a shadow play in Plato's allegory of the Cave around 400 BC. In ancient Greece existed two competing ideas about visual perception: The

9 These are at least the oldest still preserved drawings. There might have been early drawings on less stable materials like leaves or even much more transitory procedures like scratches in the ground or sand.

10 I investigated this quality of the origin of depiction as "Communication with the Future" in greater detail in my Bachelor Thesis.

"emission theory" and the "intro-mission" theory. The first one was represented by scholars like Plato, Euclid and Ptolemy and followed the idea that perception works through some kind of beams, that are emitted from the eye and would be intercepted by the objects surrounding it.

Around the same time Aristoteles expressed the idea, that "*what we can perceive is potentially such as the object of sense is actually*" (IBID 350) and introduced the idea that something travels from the object to the eye. This concept was refined by Lucretius, who claimed in his groundbreaking book "De rerum natura"[11] that "*objects continuously emit forms that are like ' membranae vel cortex' ['skins or bark)*" (AKBARI 2004: 17) and also expressed precursors of the idea that light is emanated as particles from external light sources. Around 1,000 AC the Arabic scholar Ibn al-Haytham[12] was the first one to describe how vision occurs when light is reflected from objects and then enters the eye.

Middle Ages

Influenced by theories from ancient Greece, the Arabic world and the school of Chartres, Robert Grosseteste defined the light as the source of insight, both spiritually and scientifically. In Grosseteste's key work for the Natural Science De luce seu de inchoatione formarum[13] he investigated the phenomena of optics and set the light and the vision in a cause-effect relationship. If you can see through light, you also should be able to measure through light. By assuming that seeing occurs through light and concluding that the human eye can be interpreted as an optical apparatus, a new dimension of symbolic and mechanical influences entered the traditional Christian relation between viewer and world. (See SEHNBRUCH 2018: 38FF)

Roger Bacon continued this research and emphasized the technical, experimental and mechanical aspects of natural sciences. In his main work "*Opus Maius*" he focused on the discipline of Optics (*Perspectiva*) and identified it as a key to knowledge of nature (See IBID: 59F). He conducted a series of experiments with lenses in the field of military applications, as reading helps and even for scientific experiments. Up until now they were – similarly to mirrors – disqualified from the common discourse as not being "*things of gods creation"* due to their deceptive characteristics.

11 The original Latin title is usually translated to English as "On the Nature of Things"
12 Also sometimes referred to in the latinized form of Alhazen
13 The original Latin title is usually translated to English as. "On the light; or the beginnings of the forms"

Renaissance

With the Renaissance, the Christian literal discourse transformed towards a more technical and naturalistic view of the world. In the course of these events, also an extension from the seeing-theory towards an image-theory was actively pursued by artist-scientists such as Fillippo Brunelleschi and Leon Battista Alberti (See SEHNBRUCH 2018: 81F). Sehnbruch describes the two as universal scholars that combine expertise in the fields of mathematics, architecture, crafts, painting and theory that established a new field of experimental culture in the visual art and science.

Arguably in 1425 Brunelleschi conducted two panel paintings and an experimental setup, that is considered as the first demonstration of the mathematically constructible perspective in Western cultural history. There have been perspectively correct paintings before[14], but Brunelleschi's experiment is important in so far, as it can be seen as the beginning of the experimentalization and thereby machinization of human perception (See IBID: 82).

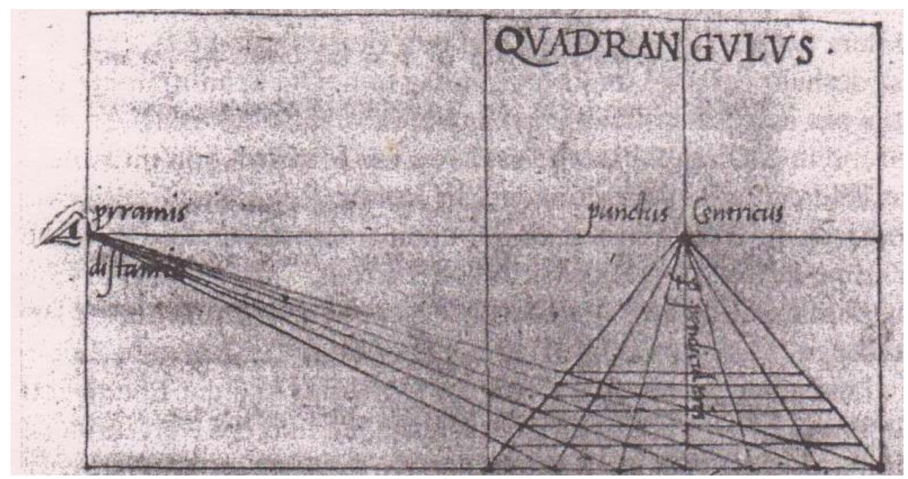

Fig. 4 Leon Battista Albertis drawing of perspective construction, around 1435

14 For example Ambrogio Lorenzetti's Presentation at the Temple in 1342

Leon Battista Alberti was the one, that turned Brunelleschi's experiments and thoughts into a perspective drawing matrix, that can be applied practically. Introducing the concept of planes intersecting the viewing pyramid and its projections, he described a method for perspective construction that became known as the Albertinian Window. One of the revolutionary aspects of this concept was the transfer of the three-dimensionality of the world into the two-dimensionality of the picture surface.

In opposition to Vilém Flusser, who sees the birth of "technical images" not before the upcoming of the photo camera (See FLUSSER 1990), Sehnbruch argues that the history of technical images already started with the mathematical description of perspective. The visual turn of the Renaissance was also a technical turn and an important step for the development of the screen.

Alberti's devices were soon followed by more advanced technologies that extended the construction of perspective towards an almost machinic production of images. The visual artists of the time created their paintings with great accuracy following detailed instructions and using specific tools for measurement and depiction, and insofar resembled our understanding of a machine.

As long as the rules of Perspective, Algebra, Geometry, Astronomy, and basically all natural sciences are followed, artist-inventors like Leonardo da Vinci and Albrecht Dürer saw the act of drawing as "*Divine Science*" that was able to create "*truly genuine depictions*"[15] (GIESECKE 2002, CITED IN SEHNBRUCH 2018: 120). Albrecht Dürer's textbook Underweysung der Messung mit dem Zirckel und Richtscheyt[16] from 1525 contains two drawings with huge importance for the development of the screen in general and the digital screen more specifically. The first drawing "Der Zeichner der Laute" shows a quite complicated procedure to create a perspectively correct two-dimensional image of a three-dimensional scene[17] that can be seen as a direct predecessor of the Ray-tracing procedure, used for 3D rendering today.

15 [Translated by Author]: *"Wahre Abbildungen"*
16 In English: "Instruction of the measurement with the compass and straightedge"
17 A cord is pinned to a point in space which signifies the origin of perception (or the observers eye). From here the cord is moved to different points on the object, it's location within a frame is marked and than transfered to the foldable screen. This process is repeated with several important points on the object, which can than be used to interpolate the connecting lines. For a more detailed explanation see: https://www.martin-missfeldt.de/perspektive-zeichnen-tutorial/perspektive-albrecht-duerer.php

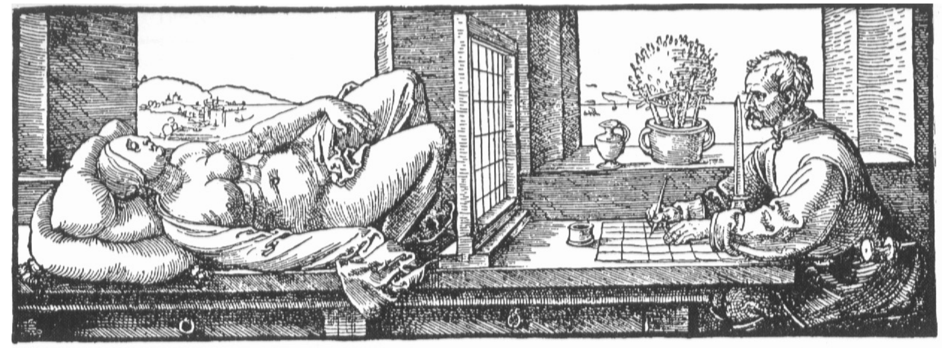

Fig. 5 "Der Zeichner des liegenden Weibes" Albrecht Dürer: 1512–1525

The second image "Der Zeichner des liegenden Weibes[18]" shows the painter using a grid structure through which he is looking at the scene, and a corresponding grid overlaying his canvas[19]. This can be seen as an early example to subdivide a given image into a Cartesian coordinate grid, and thereby make it mathematically describable and reproducible.

Modern Era

Already in the 4th century BC the functionality of the Camera Obscura was described by Chinese writings and questions about its principle were asked in one of Aristoteles books. Also Da Vinci examined the light path of the Camera Obscura, realized that the same principle is to be found in the vision of the human eye and introduced the idea of using lenses. Based on this[20] and many more previous thoughts, Giovani Baptista della Porta popularized the functionality of the Camera Obscura for scientific research but was also the first one to use it for entertainment purposes (see BRAUCHITSCH 2002: 19FF). Apparently no specific screen was used, just any given surface was utilized to cast the light onto. In opposition to the "conceptual" screens – e.g. the projection plane in the mathematical construction of perspective – a concrete manifestation enters on which images can be perceived directly.

Through his interest in Anatomy and Astronomy Johannes Kepler was able

18 In English: "The Draftsman of the lying woman"
19 The image has been used by Postmodern criticism to illustrate the patriarchal gender roles in early modern culture, which is also evident in the previously mentioned established Western discourse. (See FARBER)
20 Da Vinci wrote his findings in a kind of mirror writing, so that is was only deciphered and published in 1797 by Giovanni Battista Ventur

to directly prove the optical function of the lens in image acquisition, equally on the retina and the projection surface of the Camera Obscura and *"as first one [explained] the human vision as a physical process."*[21] (WOLLGAST/MARX 1977: 44, CITED IN SEHNBRUCH 2018: 178). Directly following Kepler's findings René Descartes continued the experimentation of perception and was the first one to develop a purely mechanical theory of light, that is commonly seen as the birth of modern physical optics. Thereby, the two laid the conceptual foundation for the acceptance of surfaces, whose appearance is artificially modified[22] as equally valid by the human eye as everything else it perceives.

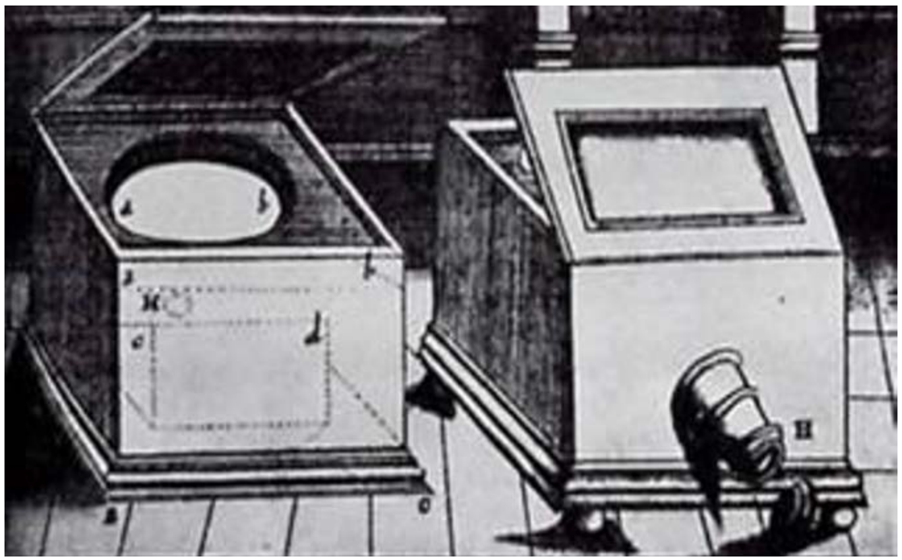

Fig. 6 Johann Zahn's "Artificial Eye" in a drawing from 1685

Only shortly afterwards, Johann Zahn turned Descartes' research in a mechanized replica of the human eye, his "Artificial Eye" (Oculus artificialis telediοptricus) in 1685. Looking at the drawing of this machines, one can find an astonishing resemblance to what we would today describe as an archetype of a screen: an apparatus that creates images on a surface.

21 [Translated by Author]: "[...] erklärt als erster das menschliche Sehen als einen physikalischen Vorgang"

22 Or even more accurate: whose physical interplay with light is purposefully manipulated

Photography

Even if the Camera Obscura became widely used in the following decades, the image stayed ephemeral. It was used as a support for painters, but the process of capturing it into a more stable form stayed an manual one.

In chemical experiments in 1674 the alchemist Christoph Adolph Balduin stumbled upon the light capturing properties of a mixture of chalk and nitric acid and called them Phosphorus ("= light carrier"). In the 1820s Joseph Nicéphore Niecpe began similar experiments and soon also combined them with the principle of the Camera Obscura. In 1826 or 1827 he created what would become known as the world's first photography. After his sudden death in 1833 his collaborator Louis Daguerre continued to work on the process. Also the British allround talent William Henry Fox Talbot perfected his process and introduced the concept of a negative-positive procedure, which allowed multiple prints of one motif.[23] In the following years a lively competition for the different photographical procedures flared up, with many companies and individuals inventing and claiming ownership of certain procedures or technologies. Through his previous work with Dioramas, also Daguerre was mostly interested in the commercial applications of photography and recognized the value of shorter exposure times. Talbot's concept of negatives, that allowed a reproducibility of images, was not so relevant in the early times of photography and should only unfold its potential later to pave the way for photography as a mass medium and predominant form of visual communication in the next decades.

At this time photographs were vaunted for their objectivity and ability to reproduce reality. The extinction of the need for a human painter to capture a perspectively correct image was an important step towards the screen. "*The photo camera is a memory or storage medium. Its materiality is the embodiment of the change from technique to technology."* [24] (SEHNBRUCH 2018: 286).

23 It is a not very well know fact, that Talbot also used to write poetry. Before he even started working on his experiments with photography, in 1830 he wrote a poem seeming almost prophetic, called "The Magic Mirror". In this romantic ballad he describes the story of the daughter of a wizard who looks into a veiled mirror. The mirror is able to show images of a artificial world and its description reads like a blueprint for what would later become screens.

24 [Translated by the Author]: "Die Fotokamera ist ein Gedächtnis- bzw. Speichermedium. Ihre Materialität ist der Inbegriff des Wechsels von der Technik zur Technologie."

Also in other disciplines inventors and engineers aimed to apply results of natural scientific research in practical applications like the steam engine by James Watt or the Difference Engine Nr. 1 by Charles Babbage.

The new fascination for electricity, machines and automates led to the beginning of the industrial revolution in Europe. We will skip this developments for now, and come back to them later in detail, when we look at the specific history of the digital screen.

Film

Much earlier, in 1420 the Venetian engineer and scholar Giovanni Fontana included a drawing of a demon projected by a lamp in a book about mechanical instruments (FONTANA 1420: 144). At the beginning of the 17th century the principle of the Camera Obscura was inverted and resulted in the Laterna Magica. These device used a bright light source and a lens system to project images from a painted glass panel onto a surface. Scenes drawn on glass were projected onto walls, improvised fabrics or other flat, bright surface. Through movement of the projector it was also possible to set the images in motion and in some devices even sequences of images could be displayed. (See HUHTAMO 2017: 85F.)

The Laterna Magica expanded the principle of previous shadow plays by the progressions in the field of optics and applied the knowledge gained by observing and experimenting with lenses in the Camera Obscura and similar apparatuses. Instead of using the sun as an external light source, that carries reflected light into the system, an artificial light source within the system was used to carry images to the outside: *"One pushes the image of something, its idea, into the black box, sends light through it and throws an idea of this idea, a picture of this picture, on the wall"*[25] (KITTLER 2002: 91) In the usage of the projector, also a circle closed between the Camera Obscura and the Laterna Magica, as apparatuses for image creation and image representation based on the same principle.

The projection of images was later developed into the PHANTASMAGORIA, a show combining multiple projections with various other effects for entertainment purposes. A main distinction to previous Magic Lantern shows was the conscious use of the screen. For example rear projections on translucent materials that concealed the apparatus and the "Lanternist" were used or even more experimental projection materials like smoke, that created a ghost like effect (See CHRISTIE 2016: 71). After Magic Lantern and Phantasmagoria shows had been a spectacle for special occasions, in the 19th century the concept diffused into everyday live and the domestic space – at least in the homes of the bourgeoisie – and developed into a series of related devices, that also aimed at non-professional users or even children (see HUHTAMO 2017: 91F.)

With the wide-spread usage of photography also the interest to set photographic images in motion was sparked. One of the pioneers in this field was Eadweard Muybridge[26], who perfected his CHRONOPHOTOGRAPHY in 1872, which allowed a very short exposure time. An arrangement of multiple cameras next to each other allowed to capture movements in rapid succession in a series of photos. In the tradition of previous motion studies this technology was first seen as a tool for scientific research[27]. It also served as proof in the famous legend about the dispute of two US-American race-horse owner whether a horse has all its legs in the air at some point while trotting.

Fig. 7 Model of the first Zoopraxiscope by Eadweard Muybridge

25 [Translated by Author]: *"Man schiebt das Bild von etwas, also seine Vorstellung, in den schwarzen Kasten, schickt Licht hindurch und wirft eine Vorstellung dieser Vorstellung, ein Bild dieses Bildes, an die Wand"*

26 When he moved to the United States from Great Britain, he changed his previous name Edward Muggeridge (BRAUCHITSCH 2002: 72)

27 Also others like Étienne-Jules Marey, Thomas Eakins, Ernst Mach and Ottomar Anschütz worked on the relation of photography and movement around that time.

Nevertheless Muybridge always saw himself primarily as an artist and kept on experimenting with different applications. Of crucial importance for the development of moving images was the research of the physician Peter Mark Roget on the persistence of vision, and the realization that images reverberate on the Retina. Muybridge developed a device called Zoopraxiscope, a viewing device for a series of images drawn after photos. The images were projected from a rotating glass disk in rapid succession to give the impression of motion. Some contemporary writers foresaw, that: "*Mr. Muybridge laid the foundation for a new method of entertainment for humanity and we predict, that his current photographic laterna magica Zoetrope will make the rounds in the civilized world.*" [28]

Inspired by Thomas Edisons Kinetoscope the brothers Auguste and Louis Jean Lumiere develop the Kinematographie in 1895. They were also among the first to organize public screenings of films and laid the foundation for the birth of the cinema as an institution for movies to be watched. One of the birth myths about cinema tells the story, that when the brothers Lumiere showed their movie *"L'Arrivée d'un train en gare de La Ciotat"* in 1896, people were screaming and running out of the cinema, when they saw a train on the screen approaching towards them. This story might have been exaggerated[29], nevertheless the famous anecdote gives us an idea, of how unusual the concept of a moving surface must have been to people watching a film on a screen for the first time. *"What the Lumière's audience experienced, wasn't the fear of a real train, but the horror in the face of an apparently unreal and at the same time surprisingly realistic image."* (BINOTTO 2010: 33) [30]

Similar to the developments in the early times of photography a vivid competition arose about the newest technologies and patents to turn the principle of film into a lucrative business. Together with advances like the intermittent film transport mechanism, sound film and color film also a language of editing and montage emerged. The cinema goers became accustomed to certain codes, standards and habits of perceiving what was happening on screen. A sort of "filmic language" emerged and the idea of the screen changing its appearance became something normal.

For our purpose it is also interesting to look at the transformation that the materiality of the screen underwent in this time. First cinema theaters were – as the name suggests – modeled after classical theaters, with the screen in the center of attention where previously the stage had been. A trade journal from 1909 advises to design the "moving picture stage" in a way that "*the audience [has] the impression they are looking at the enactment of a scene set a little way back on the stage. They look at it, as it were, through an aperture or tunnel [...]" (*CHRISTIE 2010: 74).

The screens used in cinema theaters of the time were usually framed, mostly for reinforcement, but also for decorative purposes complementing the pictures on screen. It became usual to hide the screen behind a curtain when it was not in use. This might have some origins in the tradition of the theatre, but it was also "*believed to enhance the sense of occasion surrounding a film show, and also perhaps to counter any sense of 'flatness' or non-transparency associated with a 'blank' screen*." (See CHRISTIE 2010: 71) The screens themselves normally consisted of cotton muslin and only for a short period of actual silver-coated materials. Nevertheless the term "*silver-screen"* became a synonym for the whole cinematic complex in the 1920s, together with terms like "t*he big screen", "screenplays"* and cinema magazines with titles such as "*Modern Screen*" or "*Screen Guide*". (IBIB: 71F.)

This is also the time, where the concept of the screen as the *"window to the world"* was introduced, in recollection of the Albertinian Window. The movie screen was the beginning of what Lev Manovich calls the "*Dynamic Screen"*, whose images can change over time. He describes how this emphasized a certain *"viewing regime"* that was already implicit in *"classical screens"* of paintings and drawings, but now gains a new intensity: "*The viewer is expected to concentrate completely on what he sees in this window, focusing her attention on the representation and disregarding the physical space outside"* (MANOVICH 2001: 126).

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28 [Translated by the Author]: "*Herr Muybridge hat das Fundament einer neuen Unterhaltungsmethode für die Menschheit gelegt und wir sagen voraus, daß sein momentanes, fotographisches laterna magica Zoetrope die Runden in der zivilisierten Welt machen wird*": Alta California, 5. May 1880, Cited after: Robert barlett Haas, in: Eadward Muybridge, Stuttgart 1976, P. 24)

29 Binotto notes that the movie wasn't even shown on the program notice of the Grand Cafe, where the screening happened on the 28th December 1895.

30 [Translated by Author] „Was das Publikum der Lumières erlebte, war nicht die Furcht vor einem realen Zug, sondern der Schrecken angesichts eines offensichtlich irrealen und zugleich doch erstaunlich realistischen Abbilds"

Together with this property of the screen as being perceived as a "window to the world" also their framing for (mostly) technical reasons and the unease to let a blank screen stand for itself are qualities of our perceptions of screens that, which were established around this time and are still relevant today.

Electric images

At the end of the 19th century optical extensions such as the telescope or marine communications were already quite common, but the idea of "*seeing at a distance*" gathered new momentum through the concept of applying electricity to it. Inspired by the electrical telegraph or the telephone many researchers were fascinated by the idea to transmit visual signals in a similar way. In contemporary fictional literature and illustrations about the future you can find the reoccurring motif of picture-phones, that connects two remote locations in real-time. Also the prototype of screens outside the cinema keeps on appearing in various shapes and forms, as Huhtamo vividly demonstrates in an own chapter called "Round or square" (See HUHTAMO 2016: 99F. , 104)

In one of the masterpieces of early cinema, Fritz Lang's "Metropolis" from 1927, early visualizations of an electronic, maybe even digital screen, can be found. In the office of Joh Fredersen, the city's master, one can see workers quickly changing between taking notes of Fredersen talking and comparing them with some screen like devices on the wall on which numbers, symbols and equations are rolling down. In a later scene one can see him interacting with a sort of video telephone, that features some characters, numbers and also a face -to-face transmission with a remote worker.

Fig. 8 Stillframe from the movie "Metropolis"

These creative visions and technological developments laid the foundation for various steps toward the Television[31]. Paul Nipkow invented the principle of linear scanning for his "electrical telescope" in 1884. The revolutionary procedure allowed the deconstruction of a homogeneous image into a series of light, or electrical impulses. The idea of the Oscillograph of the "Braun tube" was extended into the functionality of the ray cathode tube in which electrical signals were turned into visually perceivable light intensities. The last step towards television was formed by the real-time electrification of the recording, which was completed by Vladimir Zworykin and his research group in 1931 in form of the Ikonoscope, the first electronic camera.

When these three components are combined, the images on TV *"are not optics anymore. You can hold a film roll against the sun and see, what each single frame shows. You can intercept a TV-signal, but you cannot look at it anymore, because they only exist as electronic signals. Only at the beginning and the end of the transmission chain, in the studio and on the screen, do the eyes have a possibility for perception."*[32] (KITTLER 2002: 316). The transformation of images into sequences allowed for their electronic transmission and ushered a whole new

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31 The word is coined on the 1st International Congress of Electricity in Paris by the Russian physicist Constantin Perskyi and consists of the Ancient Greek words tèle (far) and Latin visio (sight)

32 [Translated by Author]: *„ [...] schon keine Optik mehr. Man kann eine Filmrolle gegen die Sonne halten und sehen, was jedes Einzelbild zeigt. Man kann Fernsehsignale zwar abfangen, aber nicht mehr ansehen, weil es sie nur als elektronische Signale gibt. Nur am Eingang und Ende der Übertragungskette, im Studio und auf dem Bildschirm, haben die Augen eine mögliche Weide"*

chapter for the functionality of the screen. Not merely as a surface for reception anymore, but an apparatus for conversion from invisible to visible signals.

After World War II the TV slowly started spreading and new stations, content and formats developed driven by commercial interests. Already in the 1950s the TV had become the epitome for mass media and in the 60s it became the "*dominant access point to social reality, information transfer and entertainment."*[33] (SEHNBRUCH 2018: 356) for a majority of the Western population.

With the Television set, the screens moved into the domestic space and were perceived within everyday context. The screen of the TV – the part on which the images are visible – consisted of glass but was mostly covered in a decorative box, whose material changed over the times. It aimed to fit in with the furniture and hide away the underlaying apparatus. The new spatial arrangement of the screen made the screenic engagement much more casual and even allowed the viewers to pursue other daily activities while watching TV. In opposition to the cinema, the mode of reception could be both, much more individual and much more public: When watching TV alone, the viewer has full control what and how they want to watch and in addition, if watching TV in a group it is commonly accepted to converse with each other.

Edmond Couchot describes as "*effect of embeddedness"* how people went to the cinema, to *"plunge"* into the worlds behind the *"image-window of the cinema"*, whereas in case of the Television those worlds were brought directly to the viewer's living room (see COUCHOT 1988: 135F)

Screen Theories

The commonly agreed practices of editing and montage also led to the emergence of theoretical thoughts about the nature of film by Sergei Eisenstein, Siegfried Kracauer and others. Later the field of film theory was established as an academic discipline. Influenced by earlier ideas of Marxist Film theory and Pyschoanalysis, the idea of seeing the whole cinematic complex as a unity, developed into the influential concept of the "*cinematic apparatus theory*" in the 1970s, most prominently advocated by Jean-Louis Baudry: "[*It] considered the dispositif*[34] *as a kind of psycho-physical machinery that consisted of the technological and environmental elements of the viewing situation (the auditorium, the screen, the projection booth, the light beam of the projector, etc), but also of the meta-psychological operations taking place within the spectator's mind"* (HUHTAMO 2017: 79). It saw the cinema as a coherent apparatus that is ideological by default and acts as a representation of nature. The screen's role was restricted to that of a "cinematic mirror-screen", an abstract concept on which the audience would identify with the characters on screen (See BAUDRY 1974-75: 239F.)[35] The "*Apparatus Theory*" which eclipsed in the 1980s broadened the exclusive focus on the movie theater and was liberated from the psychoanalytical emphasis (See HUHTAMO 2016: 79F.)

The field of film studies only took partly interest in the ability to watch films on TVs. So the domain of emerging TV studies became more of a branch of popular culture studies, combining elements of social science, dramatic criticism and journalism. So it wasn't the characteristics of the TV screen itself, that were in the focus of interest, but mostly the influence of its content on the audience, or in specific cases also the (spatial) relation of the TV set to its audience.

There have been and still are whole study courses called "*Screen Studies*", but as Stephen Monteiro points out, they tend to "*reiterat[e] the screen's connotation as a passive, immediate, practically invisible entity through which events and sensations may flow unimpeded*" (MONTEIRO 2017: 4). It is only in recent years, that "screen studies" started to look into what constitutes the screens: Their historical developments, physical materiality and technical implications. (See IBID: 4)

33 [Translated by Author] = "dominanter Zugang der gesellschaftlichen Wirklichkeit, Informationsvermittlung und Unterhaltung"

34 "Dispositif" was the original French word used by Baudry and others, which was translated to "cinematic apparatus"

35 It is interesting here to note the resemblance of the projection in Plato's cave allegory, that influenced both Freud and Baudry..

Digital Screens

Let us go a step back in history now and look into the development of the digital screen more specifically. The history of computers alone can fill books, so I will focus on the role that screens played in the development of computers and the relation between calculation and image.

A good point to jump in, is the beginning of industrialization in the 17th century. One of the first applications for automation was found in the use of power looms that were firstly deployed in England. We want to focus on a particular type of loom, that wasn't aiming to improve the speed of production but to weave images. Building on innovations of previous inventors Joseph Marie Jacquard presented his automatized drawing loom in 1804. The Jacqard Machine could weave images or patterns based on a series of punched cards[36]. The cards didn't show the image itself, but the instructions for its production. Therefore the Jacqard loom can be considered as the first forerunner of a programmable machine. It picked up conceptually on Dürer's principle of breaking down an image into a grid[37], and combined it with one of the core concepts of automation: The decomposition of a task or process into individual operations that would later become emblematic in the assembly line.

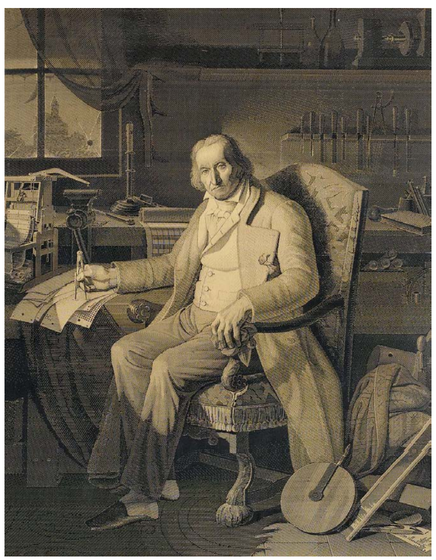


Fig. 9 A portrait of Jacqard woven by a Jacqard loom from 1839 that required 24,000 punched cards.

Apparently the English polymath Charles Babbage owned one of the self-portraits of Jaquard woven on his machines and when he set out to extend his Difference Engine Nr. 1, he got inspired by the use of punched cards.

36 Amongst others, thereby it conceptually anticipated the sequential image transmission, as it was technically utilized in television around 130 years later..
37 Similar principles can be found earlier already in the mosaic or the process of manual weaving.

Together with Ada Augusta Lovelace he started planning a mechanical, automatized calculation machine, which they called the Analytical Engine in 1837. In their concept, the material body of the machine and the program existed independently. Also it should be possible to use the same material – the punch cards – for inputs and outputs, to enable a first rudimentary concept of feedback. Even if the Analytical Engine wasn't finished during Babbage's lifetime, it paved the way for modern computing in many ways, both theoretical and practical.

The concept of a computer as a universal calculation machine was further developed by many mathematicians and scientist, amongst others Alan Turing. In 1936 the mathematician described an abstract mathematical model of a machine that doesn't differentiate between data and instructions. In 1945, the concept of a computer architecture by John von Neumann realized all the components of the Turing Machine and can be seen as a reference model for modern computers. Programs and data are stored on the same memory, but interpreted differently by the hardware through a compiler (see SEHNBRUCH 2018: 364 F). The first practically functioning computers were built in 1939 by Howard Hathaway Aiken at IBM and around the same time by Konrad Zuse in Germany. Zuse's Z3 was also the first computer ever, that had something like a screen to show the results of a calculation: an *"output via display of results on a lamp strip, including the placement of the point"* (ZUSE 2013: 63)

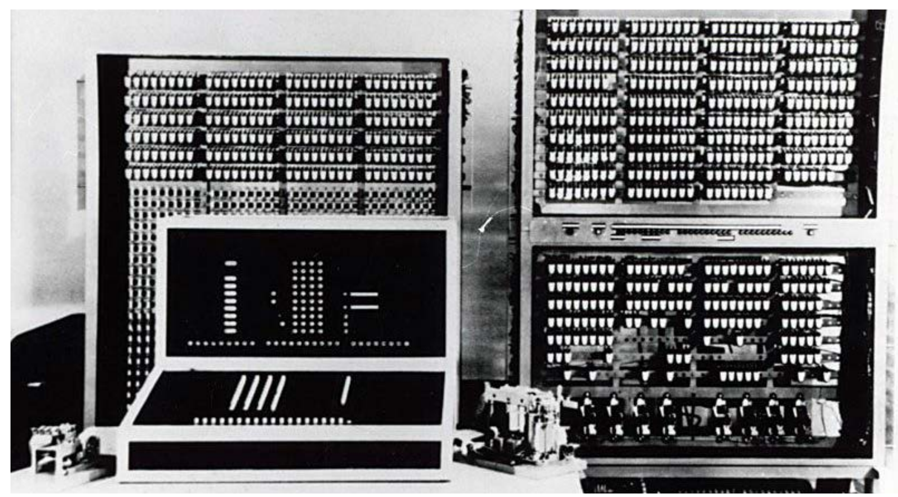


Fig. 10 Image of the Z3 with the output unit in the front

Radar and video screens

It is no coincidence, that we find the merging of devices with screenic qualities and the rising power of computer technology happening during the troubled years of the World Wars. Photography had been used for aerial surveillance for a long time and the radar became the next major surveillance technology during WW2. The radar screen emerged from the same early experiments as the TV. In opposition to film and photography the inputs of the radar were electronic, they were not directly perceivable by the human eye and a screenic device was needed to turn the electric impulses into light intensities. (See MANOVICH 2001: 127-128).

Previous image producing technologies were literately a "snapshot" of a specific moment in time and had to be developed afterwards – they could only show events from the past. The quality of immediacy was therefore another fundamental and new aspect radar brought into the world of depiction. Lev Manovich calls this new type of screen that entered with radar, television and later video technology THE SCREEN OF REAL TIME (IBID: 129). With the speed of electricity it was now possible to visualize what happened at a distant location in (almost) real-time. But this came at the price of fragmenting the images, through a circular scanning in the case of the radar, or horizontal scanning in case of the TV. Only trough rapid repetition – and under conscious utilization of the persistence of vision – the impression of continuous images or movement could be maintained.

Even after the end of the war the biggest inventions towards screens were developed under the influence of military interests. They were the first to realize the immense potential of automatized computations in combination with new screen technologies. The surveillance of airspace and prediction of trajectories required many calculations as fast as possible and in a form that could easily be perceived and acted upon by the human operators.

In 1951 scientist of the Massachusetts Institute of Technology (MIT) developed the Whirlwind Computer as part of the SAGE (Semi Automatic Ground Environment) program that should connect all radar systems of the USA. The Whirlwind showed graphical symbols on a tube screen that corresponded to actual objects that were in the air at the same time. Through a "light pen"[38] it was possible to mark these symbols on the screen and carry out further actions. So the Whirlwind was the first computer with a graphical interface, through which the user could interact in real-time and influence the computations. Through the interactivity, the screen became more than only a display of reality, it became the actual "interface" for directly affecting reality (See MANOVICH 2001: 130F).

This interactivity continued to become an integral part of digital screens, that separates it from all previous forms of screens. The field of Human-Computer-Interactions (HCI) is a whole area of research in itself, so we will only occasionally refer to it in the following,

Fig. 11 Operators of the SAGE program interacting with screens

The idea of graphical computing was refined by Ivan Sutherland's Sketchpad system in 1965, a software for drawings that existentially relied on the screen as input and output device. Sutherland also invented the first "Head Mounted Display" (HMD) and emphasized the potential of computer based design, navigation and experience of virtual worlds in his short but very influential paper "The Ultimate Display" (DÖRNER ET AL. 2013: 19).

38 The light pen was a input device, that makes use of the electron beam of a CRT monitor

Terminal screens

Still, most computers that were produced at that time were used in their primary function as calculation machines and only very rarely equipped with screens. The few existing graphical screens for computers were vector screens, in which the cathode ray directly drew points and lines onto an after-glowing surface. Often teleprinters, plotters and other printers were used to manifest the results of calculations on paper, rather than a screen. Over time, buttons and keyboards started to replace the input via punched cards and in the 1970s computer terminals that combined screen, keyboard and sometimes a printer started to appear for professional users, and were often connected to mainframe computers. The existing vector display technology was not suitable for displaying too many characters [39], so the computer screens of the time adopted the principle of linear scanning and rasterization from Television. The mathematical grid of the Cartesian system proved to be a perfectly fitting counterpart for the mathematical functionality of computers. Instead of drawing continuous lines and shapes, the electron ray scanned the screen line by line and pixel by pixel. Still the tube screens could only display a defined amount of text rows[40] and were mostly monochrome. The broad public came in contact to graphical screens first through the growing arcade video games, with custom per-game hardware and the latest computer graphic technology with which also shapes could be displayed.

The paradigm shift from programming on paper and punched cards to writing text on the command line of a terminal marked a huge transformation of the computer becoming a medium, rather than a machine (See NAKE 2008: 104). It is now the machine itself, that "mediates" the process of translating between the forms understandable for humans and computers. Over different layers of complexity the keyboard input of the user is broken down to a level of binary operations upon which the computer can act. *"Between the signs that the system uses for computation and the semiotic signs the observer interprets lies the*

39 The characters had to be drawn from individual lines. When there were to many lines that had to be drawn, the electric ray couldn't move fast enough and the image started to flicker.
40 Many model were inspired by punch cards and could for example display 24 lines of 80 characters of text, the equivalent of a popular IBM punch card.

transformation through the interface"[41] (TROGEMANN & VIEHOFF, 2005, 107) And it is the screen by which the role of the interface was realized from early on.

At this point in time, let us take a little excursion into the usage of the term INTERFACE. During my research I found many of my thoughts on the screen as mediator between computer and human reflected in a text by Frieder Nake called "*Surface, Interface, Subface"* (2008). The text describes the idea of a semiotic concept - of an algorithmic sign – that exists in every of our interactions with a computer and is always of a twofold nature. The side that faces towards us, the changing light intensities on the screen that form letters, shapes and much more, comes in a visible appearance for humans; the other side comes in a computable appearance for the program and consists of a sequence of mathematical instructions. *"The screen is the* SURFACE*, the display buffer is the* SUBFACE *of the algorithmic thing that the two of us – we ourselves and the program – are engaged in.*" (NAKE 2008: 105).

Nake continues to explain the algorithmic sign as an extension of Charles Peirce's definition of a Sign as a triadic relation between an Object, Representamen and Interpretant. Whereas the user interprets the output on the screen intentionally and based on its context, the computer always has exactly one way – a determined or causal way[42] – to interpret the users input: "*The surface of any object on the computer corresponds to the intentional interpretant of the computer sign. The subface corresponds to the causal interpretant*. [...] *What is usually called the interface between human and machine, appears as the coupling of surface and subface."* (IBID: 107) The screen – in combination with the feedback of the input devices – is, what makes the algorithmic sign abstract and material at the same time. The interface, as the combination of surface and subface, can be seen as the transition between the mathematically describable (determinable) world and the sensually perceivable (interpretable) world.

Here we find an interesting analogy, almost a recursion to the first usage of the term screen to describe the separating yet permeable surface that divided

41 [Translated by Author]: "*Zwischen den Zeichen, mit denen das Systems rechnet und den semiotisch interpretierten Zeichen des Betrachters liegt die Transformation durch das Interface.*"
42 As Nake notes: "*The computer performs an act that formally is of an interpretive nature even if the computer is not capable of any interpretation. It is programmed in a definite, and precise way." (Nake, 2008, 106-107)*

the fireplace from the domestic area (See P. 9). Extending Huhtamos assumption of the screens ability to "*conceal as they reveal*" they could be seen as filtering instances, that translate between the human and the computer and filter only the understandable information for both sides.

Personal screens

The next important historical step was the diffusion of digital screens into everyday life in the slipstream of the Personal Computer (PC). Already in 1968 Douglas Engelbart presented what would later become known as The Mother of all Demos, based on his previous research. He demonstrated almost all features of modern personal computers, including the use of graphics, windows, video conferencing, hypertext and also introduced the concept of the computer mouse. It is interesting to note, that all of these innovations heavily depend on a operating system that supports a Graphical User Interface (GUI), but even more fundamental on a screen to display it. Similar to Sutherland's concepts, it had to do with the restrictions of the screens capabilities that Engelbart's visions could only unfold its true potential long after its first demonstration.

In the 1970s CRT screens had evolved so much that they were able to display more than a defined set of characters. But it should take until the 1980s for computers to really find their way into people's households, when frame-buffers became cheaper and more accessible. As screens themselves were still quite expensive, home computers were often equipped with an RF modulator, which would enable them to use an already existing TV set as both video display and sound system (see STENGEL). Also the first generation of domestic video gaming consoles utilized the screen of the Television for their output.

With the sudden availability of screens, the ideas of Engelbart were popularized as Graphical User Interfaces (GUIs) in the 1980s. Commercial systems like the Xerox Star, Apple Lisa and Microsoft Windows replaced the interaction with the computer via command line by graphical interfaces.

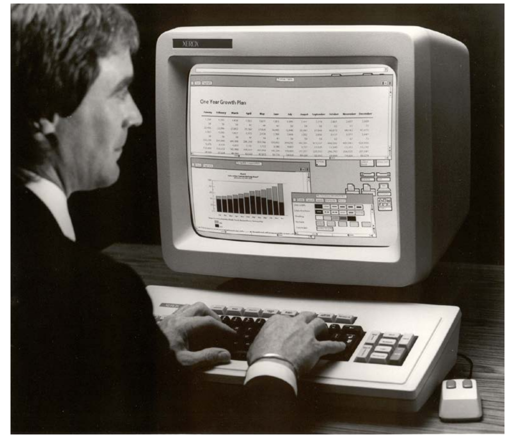


Fig. 12 Graphical User Interface of the Xerox Star 8010

With the ability to show graphics on a computer screen the question emerged, how those interfaces should be designed and the discipline of screen design developed. The idea of the desktop metaphor became widely established and introduced the representation of the inner workings of the computer through icons, pictograms and menus. Also the concept of the "window" became of crucial importance. It was the first time, a screen was divided into "sub-screens" – into areas which would show content independently from each other[43]. Here, the long established metaphor of the screen as extension of the Albertian window started to dissolve. On a digital screen you can view "into" many windows at the same time, instead of looking "through" one window. Or, as Anne Friedberg calls it: "*The 'windows' trope is emblematic of the collapse of the single viewpoint; it relies on the model of a window that we don't see through, windows that instead overlap and obscure, and are resizeable and movable.*" (FRIEDBERG 2006: 56)

On a more general level, the change from interacting with the computer by writing text into the command line to using a mouse to click, scroll and drag is the second important shift in the role that the screen plays in our relation to digital computers. Instead of typing formal, language-based instructions that result in a determined reaction of the computer, the act of moving the mouse on the screen is a much more diffuse way of interaction[44]. The combination of widespread distribution of digital screens and the new graphical interfaces enabled a new way of interaction with machines: „*The evolution of computer technology*

43 The concept of the Split Screen had been existing in films since the 1920s, but the multiple angles were always related.

44 Referring to our established concept of the semiotic sign, of course the clicks on symbols and icons are interpreted by the computer in a determined way (See P. ???), but the mental mode of interaction for the user is fundamentally different.

from the 1970s to the 1990s is captured by a paradigm shift from algorithms to interaction. (WEGNER 1996: 1).

The GUI "*introduced a new semiotic layer*", that shifted the communication between humans and computers from a formally articulated interaction based on language to a more natural, diverse one, based on the concept of the computer as a visual medium. (See STEPHENSON 1999: 64)

Modern screens

By the end of the 1980s color CRT monitors that could clearly display XGA and higher resolutions were widely available, increasingly affordable and became the standard equipment for desktop computers. From a technical point of view, nothing much changed in the next decades, apart from screens becoming even more high-resolution, more accessible and more widespread. The biggest transformation for computer displays should come in the technology of LCD displays. The functionality had been discovered already in the 1960s and in the following was used for simple bar graph and multi-segment displays in devices like pocket calculators and wristwatches. The first mobile calculators and prototypes of portable computers utilized monochrome LCD displays in the 80s (see EDWARDS & FINNEGAN 2015) and the trend towards laptops in the 90s was only possible due to the advances in of LCD screens over CRTs, that enabled them to become light enough to be movable. Nevertheless the use of Laptops was restricted to certain circumstances and they are only semi-mobile, meaning they are only supposed to be moved when they are not in use. While the user is actively in motion laptops are usually turned off, and intended to be used only stationary, on a desk or on the eponymous lap.

Contemporary screens

In the last years the biggest shift has not been how screens function on a basic technical level, the changes lay in the way we interact with them and in which contexts we use them. However these changes in behavior can be traced back to some technological developments like the LCD screens or mobile networks, that extended the functionality of the screen just a little bit, but with huge consequences.

Even if it had predecessors in hand-held video game consoles, pocket calculators, PDAs and mobile phones the recent revolution in our everyday usage of screens came to in the form of smartphones. The uprising of the new paradigm of smartphones began with a shift of the form factor toward multi-touch, screen-only devices around 2007.

Fig. 13 *A collection of smartphones with an only-screen form factor*

After the first LG Prada this new form-factor was popularized by the iPhone and Google's Android operating system. Smartphones are basically phones reduced to screens[45] that were in a new way connected, mobile and interactive. The impulses of smartphones can now be seen in many of our expectations and assumptions towards Digital Screens in general.

45 Maybe a more suiting name actually would be "Screenphone"

Connectivity

In opposition to earlier mobile communication devices that were also equipped with screens, a smartphone is connected to not only one, but to multiple communication networks. It becomes the center point for telecommunications with other people through calls or SMS, for communications with other devices such as Bluetooth or Near Field Communication (NFC) and of course for communications with other people and other devices through the Internet via WiFi of mobile data connections. All this connectedness made the screen (and to different degrees also the other outputs such as the speaker) of the smartphone our permanent companion[46] and the most important mediator for communication in many life situations. Together with the factor of mobility, the Smartphone screen became our main connection point to the all surrounding digital networks, independent of our own position within them. Stephen Monteiro explains how screen media has incredibly intensified the process of *"diffusion of knowledge on a mass scale"* set in motion by movable-type printing and concludes that screens are our *"privileged point of access to a large portion of the sum of human knowledge*" (MONTEIRO 2017: 6).

Mobility

Previous screens let you be mobile at most "virtually" by extending your audio-visual perception into other places or situations[47], but they themselves would stay stationary most of the time. Even if you could move your position in relation to the screen in theory, this rarely happened, as the established "*viewing regime*" expected you to stay in a certain distance and position in relation to the screen (See MANOVICH 2001: 2016).

When the interaction with screens became truly mobile – not only movable as with laptops – they set into motion even more than the screen as an object. Now all the three participants involved in the screenic engagement can be moving on different levels: The content on the screen can move; the screen itself can be moved to a different location in space while in use; and finally even the user's position in relation to the screen can shift from being hand held, fixed

46 This description was even used as a promotional slogan by one of the biggest Smartphone producers for their Samsung Galaxy S4.
47 As we've seen in the previous chapters the idea of the "window in another world" in cinema or even the etymology of the Television ("To see in the distance") pay tribute to this fact.

on a mount or even passed around amongst different people. And even more: Anticipating this different modes of movement, the screens functionality will adapt to its current orientation, context and location.

With digital screens becoming truly mobile, their usage extended to places, situations and contexts that were out of reach for previous screens. People started using their screens literally in everyday life: while walking from one place to another, while waiting for the bus and even on the toilet[48]. Even if there is no direct necessity to use a screen in any of these situations, the sheer possibility seems to motivate the usage. In other situations, like for navigation purposes, the moving screen become a quite fascinating concept in itself: The screens instructions determine where it is moved by the user, so basically the screen moves itself based on input from the various networks and its current contextual location (See VERHOFF 2012: 149).

Sherry Turkle describes the concept of the window as *"a way for a computer to place you in several contexts at the same time [...] your identity on the computer is the sum of your distributed presence"* (Turkle, 1995, 13, and I think this suits even more for the smartphone screen. Extending Anne Friedberg's idea of the fragmentation of the screen through windows and the "*collapse of the single viewpoint*", Heidi Rae Cooley describes a *"shift from windowed seeing to screenic seeing [that] reconfigures one's relationship to that which is seen."* (COOLEY 2004: 320).

Touch interaction

Even if early predecessors of smartphones often had resistive touch-screens, the main part of interaction with these devices still depended on particular inputs such as numeric or QWERTY keyboards or a stylus pen. The screen-only smartphone made touchscreen interactions widely accessible and usable. Thereby the screen took over and substituted the functionality of these former physical input devices. The ambiguity of the screen enabled a context depended offering of interactions: The QWERTY keyboard only appears when it is needed and the buttons on the screen can appear and disappear in a similar way. The screen became the source of output and input at the same time. Instead of

48 Depending on which surveys you look, between 38% and 75% of people use their smartphones on the toilet (RIVERS 2016)

moving the mouse that is represented by an abstract pointer on the screen, the touch interaction happens on the same surface where also the reaction occur. The spatial dimension of interaction is reduced to a flat, two dimensional one – touching instead of pressing a button or movement of the finger instead of the turning of a wheel. But this also led the way to a whole new repertoire of tactile interactions, like swiping or pinching. Many of the shortcomings of the missing haptic feedback were replaced by indirect, semi-haptic feedback (like vibration as confirmation of an input) or through advances on the Software side (like the auto-correct function to overcome the much more common spelling mistakes when typing on a touch screen).

Another shift was, that touch-screens broke a boundary that screens were something that should not be touched. Looking back at the history of how people interacted with paintings and photography, later followed by the film screen or even TVs and Computers, direct physical interaction between the viewer and the materiality of the screen surface was not required or even strongly discouraged.

Alexandra Schneider points out that this relationship can be seen even on a much more abstract level on how the relationship between humans, their senses and the environment developed over three stages in the last 200 years. In the eighteenth century touch was still regarded as a legitimate sensory input to gain knowledge about a certain object or situation (See SCHNEIDER 2012: 328F). In this first stage the material object was aligned with the knowledge one could gain about it through touch and vision [49].

In the second stage, arguably strongly influenced by the object-viewer relation imposed by the upcoming cinema and art museums[50], the senses of touch and vision became separated. Individually experienced knowledge was replaced by generalized scientific knowledge about both material and immaterial characteristics of an object, that was gained through distant observation and measurement.

49 See the origin of the English word "to grasp something" or the German equivalent "etwas erfassen
50 Also Giluiana Bruno describes the cinema as analogy to the museum that developed at the time of "*emergence of public consumption*" (See BRUNO, 2014: 143F.)

As a third step, through digital screens in general and touch screens in particular, we experience a re-alignment of vision and touch, but not to gain knowledge about the immediate material object we are interacting with through touching, but rather of distant immaterial ones. The digital screen is where this relationship manifests in a material, yet ambiguous object (see SCHNEIDER 2012: 330).

Experimental screens

Now we are back where we started in the first chapter - the overview of the distribution and materiality of screens in todays world. So far we have been looking mostly at manifestations of screen that everybody would immediately describe as screen – common sense screen – like they occur to us on an almost daily basis. But there is also a long tradition of more experimental screens, that have not gained such a broad public acceptance or usage. In addition to multiple re-configurations of everyday-screens there are numerous approaches that try to blur the boundaries and try to get the visual paradigm of the screenic perception out of the flat rectangle that normally contains our expectation of the screen.

The following part of the text is largely based on a previous paper I wrote during my studies on experiments of Spatial Displays and specifically on the technologies of HMD-based Augmented Reality and Projection Mapping[51]. Both utilize the concept of pixels aligned in a grid, but aim to apply it outside a flat rectangle.

Mixed Reality

Ever since Even Sutherland's text about the "Ultimate Display" in 1965, the idea of perception being created or simulated in a computer influenced the imagination of scientists. The visions of virtual environments, simulations and networks found it's way into the mainstream media with books like "Simulacron-3" by Daniel F. Galouye (1964) or the movie "TRON" in 1982. Shortly afterwards, Thomas Zimmerman together with Jaron Lanier founded VPL Research, the first company to sell Virtual Reality goggles and gloves. Lanier is also credited with being the first scientist to use the term Virtual Reality (VR) (DÖRNER ET AL. 2013: 20). Constant references in literature, TV and film such as the concept of cyberspace in the book "Neuromancer" by William Gibson (1984), the Holodeck in Star Trek (first appearance in 1987), or the movie "The Lawnmower Man" by Brett Leonard (1992) publicized the concept of Cyberspace, Virtual

51 In the text I also first used the word Screenization, but in a different sense.

and Augmented Realities for the broader public. Even with new businesses in the VR industry growing rapidly after 1990, nevertheless the first generation of VR applications and hardware could not keep up with the expectations. After the first VR-hype and the dot-com collapse around the millennium, the topic of AR and VR in the public sphere became relatively quite, while the academic research continued as before.

In 2011 the young VR enthusiast Palmer Lucky designed the first prototype of the Oculus Rift, an inexpensive Virtual Reality headset with an unusually large Field-Of-View (FOV), that drew new attention of the broader public to the field of Virtual Reality by the broader public. Since then many other major technology companies partnered or announced their own VR or AR glasses, such as the Playstation VR by Sony, Vive by Valve and HTC, the Samsung Gear VR, Google Cardboard or Google Glass

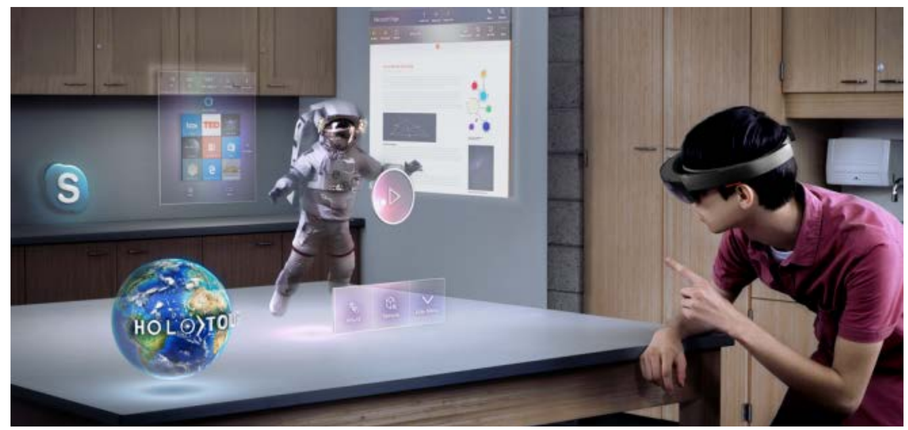


Fig. 14 Promotional image of the HoloLens by Microsoft

The basic functionality of HMD-based Mixed Reality approaches has been the same since its invention: Two small screens are mounted just before the user's eyes, and through the usage of lenses they fill out the viewer's field-of-view.

Huhtamo draws a connection between Virtual Reality technologies and a long tradition of what he calls PEEP-PRACTICE (See HUHTAMO 2017: 91F.). The ideas of the Panorama, the Stereoscope and others followed the same concepts of placing the viewer *"inside"* the screen, by blending out the surroundings, but therefore *"emphasized individual viewing and isolation – the peeper was, at least in theory, alone with the scene inside the box"* (HUHTAMO 2017:

92). The same can be said about todays Virtual Reality or 360° film applications which always have an isolating aspect. The consistent longing of Virtual Reality for immersion – for the idealized state of feeling present in the virtual world – aims for the screen to disappear. The use of lenses eliminates the distance between the user and the screen, and thereby effectively also the borders of the screen. (See MANOVICH 2011: 126).

The concept behind Augmented Reality (AR) takes a different angle, and also can come in more diverse forms apart from HMDs, such as smartphone Apps or specialized semi-transparent screens. It aims to extend the visual perception with computer generated imagery[52], that changes depending on orientation and context. As described above, many screens – especially mobile ones – already contain many of the qualities of AR on different levels of abstraction.

Projection Mapping

Also the idea to use projectors on non-flat surfaces has been around for a while. In the lineage of the Phantasmagoria, first experiments in projected stage designs for theatre productions were conducted by Erwin Piscator in the 1920s and together with Bauhaus founder Walter Gropius he dreamed of the "Total Theatre", where the visitors would be completely surrounded by projections. The concept of using projections in stage design and scenography was further developed by the Czech artist Josef Svoboda. Together with Alfred Radok he initiated the world's first multimedia theatre "Laterna Magika" for the World Expo 1958 in Brussels. It used multiple film and slide projectors, movable screens and a stereophonic sound system. The first known example of custom fitting projections on an irregular surface was created for the opening of the Hunted Mansion Ride at Disneyland in 1969. Prerecorded 16mm film material of five singers was projected onto five "Grim Grinning Ghosts" busts.

52 For a more detailed classification based on the Reality-Virtuality Continuum by Paul Milgram and Fumio Kishino, refer to POTTHAST 2016: 11-14

Fig. 15 The five "Grim Grinning Ghosts" brought to live by projections at Disneyland

Around the same time, Gene Youngblood's book Expanded Cinema described how to use aspects of the cinema outside the cinema theatre. The usage of multiple projectors, uneven projection surfaces, computer generated images and performative aspects also paved the way for what would later become known as Video Art.

In the 1980s a small scene of so called VJs (Video-Jockeys) started augmenting music performances or (mostly) electronic dance events with real-time generated visual imagery. The upcoming of first household-consumer orientated projectors in the middle of the 1990s gave this community whole new possibilities of expression in addition to lights and CRT displays.

Patents by Disney and General Electrics for projecting on three-dimensional objects sparked great interest in the academic world. Their previous research and experiments about "*The Office of the Future*" led a group of researchers around Ramesh Raskar and Henry Fuchs to the term Spatially Augmented Reality in 1998. They also developed the concept of Shader Lamps, a combined system of projector and tracking that allowed the real-time manipulation of lighting and material properties of physical objects through a projected digital texture.

Around 2000 the first large scale projectors where getting more affordable and opened a whole new field of creative and artistic uses in public space. The tools previously used for VJing evolved into Media Servers that could play and distort multiple videos synchronously and generate images in real-time. The new possibilities for large-scale architectural projections were popularized under the name Projection Mapping and established as an art form in public space, often commissioned by cultural institutions or museums, and at the same time as an effective tool for marketing and advertisement. Since then other projection surfaces like sculptures, stage designs, the human body or other organic shapes were explored and experiments with moving projectors and combinations with other technologies or interactive installations were conducted.

Fig. 16 The projection sculpture RADIX by Xenorama - Collective for audio-visual art

In its conceptual approach, the technology of Projection Mapping has similar ambitions as Augmented Reality: It aims at the amalgamation of computer generated images with the physically perceivable environment. But the principle of distribution, of overlay is fundamentally different: In the case of AR a technical system (namely the HMD or screen) is used to bring the perception of the physical reality close towards the viewer to be overlaid with virtual content, whereas in the case of Projection Mapping a technical system (namely the projector) is used to send a virtual overlay out into the physical reality. This enables Projection Mapping to be perceived by multiple viewers at the same time and allows for a collective and public experience.

Attempt for a definition

But what is a screen now? Even after so many pages about the history and usage of screens, the answer to this question is not evident at all. Nevertheless I will try to formulate my understanding of the screen, with regards to the following usage in this text.

The English word SCREEN comprises both, a surface onto which something can be displayed or a surface which displays something by itself. With this realization, Marshal McLuhan (1964: 313) seems *"to have captured a fundamental aspect organizing screen technologies, namely projection versus emission."* (ACLAND 2012: 23). Even if these two approaches might seem quite different at first glance, the underlying functionality is the same: The primary property of the screen is to manipulate light to be perceived by the human eye. Let us specify those modulations of light by noting that we are not talking about any random changes of light, but a deliberate, purposeful modulation of light that aims to represent something[53]. Let's add, that this manipulation is a dynamic process whose function is to change and to be reconfigured multiple times.

A secondary property which we can define, is that a screen is normally confined by an edge or border, that distinguishes it from its surroundings[54]. The transition that happens at this border brings us back to the etymology of the word screen as something separating, yet connecting. It enables an exchange between the "mediated world" on the screen and the "immediate world" surrounding it[55].

So, even at the risk of contradicting myself about the description of a screen in terms of properties instead of an absolute specification, I propose the following definition of a screen for the further usage in this text: A screen is a defined area, in which light is purposefully and repeatedly modulated to represent

53 Here one could go deeper into the screens function of representation and its semiotic relationship, but that is not the focus of this text.
54 In the previous discussions on experimental screen developments we saw that this property is already broadening.
55 Even if the ideal-type of the cinema as a place where you forget about your surroundings or the promise of VR to be fully immersed in a virtual world seem to be contradictory, from a technical point of view their screens still work within a defined area.

something. Or in shorter words: An area, in which visual appearance can be changed for representation.

This is a deliberately very broad definition, taking into account many of the influences of the long and rich historical predecessors of the screen and might go beyond the way we spoke about common-sense screens in the previous chapters. But as we are looking at potential future developments of screens in the following, this description is open enough to also include experimental screens and so far unknown tendencies of what we will describe as screenization.

Following this definition one could ask if a sheet of paper and a pen could be named as a screen? It contains some screenic properties and light is changed to represent something. This applies even more so for a blackboard and charcoal, whose purpose it is to be repeatedly changed. I would argue, the question of what a screen is, stays always situational and context dependent. It cannot be determined if something is a screen or not, only if it contains more or less screenic properties in its embedded situation and usage. Is the blackboard a screen, even without the chalk? Can a traffic light be seen as a screen? Is a TV still a screen when it is turned off? . What constitutes a screen in our perception is always at the same time process and product.

Digital Screens

To narrow my focus I want to work out a specific case of what I described above: the digital screen. A digital screen is strongly based on the definition of a screen in general, but it adds the "digital" to it, a big word with lots of connotations. Often it is described in opposite to its supposed counterpart analog[56].

How I use the term digital in relation to screens, is that the modulation of light as described above is based on digits. Discrete numerical values are converted into light intensities that are perceivable for the eye[57]. *"Numerical values and light intensities are two sides of the same medal."* (TROGEMANN&VIEHOFF 2005: 268)[58]. The transformation between the two is automatized, it is carried

56 Strictly speaking, both are abstract concepts of how we categorize things, even if finally they exist in the same physical world.
57 In that sense also the popular children's game paint-by-numbers or the work of several conceptual artists like Vera Molnar that created systematically determined paintings could be considered to have properties of a digital screen.
58 [Translated by Author]: *"Zahlenwerte und Lichtintensitäten sind zwei Seiten derselben Medaille"*

out by a machine and based on mathematical calculations. Through the enormous calculation capabilities of the computer, this conversion happens at a speed that is so fast, it *"[...] not only undermines the time of our perception (like all analog media), but also the time of the so-called thinking."* (KITTLER 2002: 317)[59]. This enables an immediate feedback for the user and thereby facilitates a new form of interaction, that could not be accomplished by previous forms of screens. *"This relationship is [...] based on a mode of switching (commutation), [...] where it develops during the exchange through direct and immediate contact, through reciprocal contamination between viewer and image"* (COUCHOT 1988: 138).

In summary, it can be said, that a digital screen is based on calculations that converse discrete, mathematical values into visually perceivable light intensities and enables a seemingly instantaneous interaction with its environment. Or: It is an apparatus, that can change visual appearance based on calculations to allow interactivity.

Screenization

In the following I want to work out some aspects of what I understand as screenization. My first and most basic motivation is to broaden and generalize the understanding of screenic properties as traced out in the previous passages. Following my attempt for a definition, the common denominator under which all previous, contemporary and future screens can be summarized is the core attribute of changing visual appearance to represent something and to be change over time.

In current discussions screens are mostly looked at from only one particular context, let it be a scientific discipline, cultural practice or particular technology. As we've seen previously, the diverse range of screens is increasingly fusing in the principle of the digital screen, which creates the necessity to also diffuse the division between different perspectives on the screen to be able to talk about potential future developments.

59 [Translated by Author]: "[...] *der nicht mehr nur (wie alle Analogmedien) unsere Wahrnehmungszeit unterläuft, sondern auch die Zeit des sogenannten Denkens*"

When remembering the history of screens, we can see a trend from specific use to unspecific use. Many previous screenic developments enabled a unique mode of image production or reception and it is the same for digital screens: Websites, Computer Games or Apps would be unthinkable without digital screens. But further developed screenic technologies could also always "emulate" previous ones: *"The early screen constructs return again and again to any further determination of screens in the history of technology, are included in it, and even play a constructive role during technical revolutions."*[60] (SEHNBRUCH, 2018: 5). Picking up on the statement of the digital screen as a vessel for all kinds of digital visual media[61] we can clearly see that the ability to substitute previous screenic appearances applies especially to digital screens. *"As a universal form, the screen is in a way the possibility of all images."*[62] (TROGEMANN & VIEHOFF 2004: 268). Contemporary digital screens can be used to read texts, look at photos, watch movies or TV shows, display information in public space and much more. This variety of previous media that can be perceived via the means of the digital screen all come with their own established habits and codes of perception and their "emulation" and adjacent existence on a digital screen requires a constant mode switching for the percipient.

Since its inception the Internet has been described as a kind of Hypermedia[63], that can contain many previous forms of media and in which different contents like texts, images, audio and video can converge. In a similar sense, the digital screen can be seen as a "Hyperscreen", that connects aspects of previous screen usages, concepts and behaviors. It can be used to emulate older screen-based content, allowed the emergence of totally new ones, but even more to make all of them visible and set them in context through the same principle. *"The entrance of the digital has made it possible to articulate the potential of the screen to hold different planes, to host simultaneity, and to enhance combinations and connectivity."* (BRUNO 2014: 113).

60 [Translated by Author] = *"Die frühen Bildschirmkonstrukte kehren immer wieder in jede weitere Bestimmung von Bildschirmen in der Technikgeschichte zurück, werden in ihr aufgehoben und spielen selbst bei technischen Revolutionen noch eine mitkonstruierende Rolle."*

61 See P. 16

62 [Translated by Author]: = *"Als universelle Form ist das Display gewissermaßen die Möglichkeit aller Bilder."*

63 The term was used first by Ted Nelson in 1965 to refer to features of a system in which computerized information are "linked" with each other. .

Nowadays digital screens become more and more used for tasks that were previously the domain of specialized processes or devices. The digital screens in contemporary devices are closely connected with the general trend of digitalization. They tend to not only substitute earlier screenic properties, or previous media but whole functionalities of previous apparatuses. Terminal computers took over the role of printers as necessary tools to output text, the screens in digital cameras took over the function of the optical viewfinder, nowadays touch screens take over the role of the mouse and keyboard as input devices. These are just a few examples, of how digital screens let their surrounding apparatuses come closer and closer until they eventually substitute their functionality.

Extending those thoughts, recent screenic devices like the smartphone can be seen as a fusion of the Hypermedia of the Internet with the "Hyper-Surface" of the digital screen: They become the "Hyperdevices" of our time.

Digital screens are rarely blank anymore, due to their multi-purpose, ambiguous use and the close interlinking (or even merging) with the actual computing units and input devices. The relationship between computers and screens seems perfectly fitting: The "power-duo" of digital devices and digital screens is increasingly intrinsically connected.

The first shift in this fusion came through the replacement of the punch cards by the keyboard, and was significantly promoted by the new possibilities of vector screens. With pixel based screens, graphical user interfaces took over and introduced the visual metaphor of the pointer of the mouse which can bee seen as the second big shift. Recently the touchscreen eliminated the need for any external devices for interaction between the computer and the human, similar to the "immersive" interaction many experimental screen technologies.

Digital screens also led to a fluidization of screenic borders. As described before, the introduction of the GUI brought the conceptual new paradigm of a screen that could be separated in several sub-screens, called "windows". New screens appearing in multiple formats now even enable the opposite: to combine multiple screens to something like a "meta-screen"[64]. New networks and

64 I chose this term in missing of a better opposite of the word "sub".

platforms enable automatic synchronization of content, files and settings between different devices (see CASETTI 2013: 29). Browsers can already automatically synchronize your tabs between your computer and your Smartphone and many Online video portals have functionalities to continue watching a film or video exactly where you paused it on a previous device. The famously evoked "SECOND SCREEN"[65] to make watching TV interactive, or Nintendo's new "hybrid" gaming console "Switch"[66] make the combination of multiple screens their core principle. The ability to seamlessly switch from one device to another, makes the borders between individual screens almost irrelevant.

Looking at the recent technological developments, one can assume that screens in the future will become even more powerful and cheaper at the same time. As they are already increasingly built into most digital devices, we can assume that devices with screenic attributes will spread all around us, especially together with concepts of "ubiquitous computing" and trends like the "Internet of Things". Through this connectedness they will eventually become part of connected "meta-screens", through which different content can flow unimpeded: The boundaries between individual screenic devices will increasingly diffuse.

Another tendency for diffusion can already be found in experimental screens, which aim not only to blur the borders between screenic devices, but to also traverse the spatial separation with its environment. Mitchel Whitelaw describes Spatial Displays[67] and Projection Mapping as *"two distinct but parallel strains of 'post-screen' practice in the media arts and design."* (WHITELAW 2011: 293). Drawing on the previous chapter on experimental screens, I also think it is suitable to add the whole range of Mixed Reality as another strain of these practices.

Through the tendencies for ambiguity and self-effacement our screens are always already latently local and specific depending on their content and usage. Instead of being perceived on a flat surface – clearly separated from its

65 A term that evolved around 2010 to describe the usage of a second screen, usually of a mobile device like a Smartphone or Tablet, to access additional information or interact with others while watching TV.
66 The console unveiled in 2016 consists of a main unit, that can be connected to a TV or used as a hand-held device, depending on the game or situation.
67 He mostly refers to installations in which pixels or screen elements are distributed in a three dimensional space-

spatial surroundings – the screenic properties of post-screens are increasingly embedded in their context and contain site-specific or even performative aspects. They continue *"bending [the screen] to the local, present and specific"* (WHITELAW 2011: 294). This bending can be described in other words, as the screen's tendency to diffuse the boundaries of the flat rectangle they are currently bound to and to merge with their context.

More generally speaking, the diffusion of digital screens can be described as their tendency to blur the boundaries to other devices, to other screens and to their surroundings in general.

In the last chapter of his book "Optical Media", Friedrich Kittler (2002) summarizes Vilém Flusser's thoughts regarding the computer, as a consequent reduction of dimensions while at the same time increasing the possibilities for manipulation: *"The first symbolic act, [...] to extract from the four dimensional continuum of space and time a three dimensional sign, that stands for the continuum, but was manipulatable due to its reduction of dimensions." (*IBID: 317*)* Those again were reduced to two dimensional symbols and images and later transfered to the linear one-dimensionality of the text. Following Flusser, at the end lays *"the replacement of one dimensional texts by zero dimensional numbers, or bits"* (IBID: 317), which allows for their almost infinite manipulation.

After the computers conceptual birth as the "[...] *accomplishment of the reduction of all dimensions to zero*" (IBID: 318)[68], Kittler describes the inversion of these transformations that the computer went trough ever since: the one dimensional command lines were extended by two dimensional GUIs, and with the experimental screens of Mixed Reality or Projection Mapping they now even reach for the third dimension.

At this point I want to emphasize the role that the screen played in the return of the computer into the world of dimensions. Over all, a tendency can be witnessed, in which the abstract inner workings of the computers are covered under layers of computation that appear as reduction of complexity to us as humans. But these reductions are realized through more and more complicated software on the inside of the computer – the subface – and advances in screen technologies on the outside – the surface. Future developments will continue to go in the direction of our interactions with computers becoming even more intuitive and natural to use and perceive for us as humans, with their complexity being hidden away under the power of computation.

68 [Translated by Author]: "[...] *vollbrachte Reduktion aller Dimensionen auf Null"*

Conclusion

Only very few of the theoretical texts by scholars from various fields I consulted for my research dared any assumptions about future developments of the screen. In addition to some science fiction stories or movies, the predominant forecasts to be found are the ones by big tech companies, most of them of technical nature and motivated by marketing considerations. I completely agree with Mirjam Struppek, when she says: "*Forces other than commercial interests need to urgently lay claim to shaping the future development of the emergent 'screen world' in which complex display systems are currently detecting our behavior and adjusting to our consumer preferences*" (STRUPPEK 2006: 14). Some authors went even further and drew a more extreme picture, like the US-American psychologist Timothy Leary: *"In the twenty-first century, whoever controls the screen controls consciousness, information and thought."* (LEARY 1987: 131) Even if Leary issued this statement at a different time, aiming at very different screens than we are facing now, it cannot be argued, that what we see on screens is increasingly shaping our perception of the world. It allows us to perceive things that were out of our reach before and do things that we couldn't do before. But it also always subjects and determines this perceptions and possibilities under its inherent connecting yet separating structure: *"As a symbolic meshwork (refractive index, orientation grid, image wall), the screen slides into the gap between observer and observation."*[69] (SEHNBRUCH 2018: 384)

Due to its intrinsic link with digital technologies, our interaction with screens not only determines how we perceive the world, but even more how we actively influence it, with real, physical consequences. Most of what we think to know about the world we learned through screens, many of our relationships are deeply dependent on communication via screens and drone operators even decide on life or death based on the images they perceive via screens. *"The [screen] medium opens windows to the world, is the operational center of industrialization, planning, production, politics and warfare as well as world observation, the media world, physics, medicine, research etc. And it is also our socialization instance."*[70] (SEHNBRUCH 2018: 378) In opposition to many other technological developments, screens are not only available in the industrialized, Western world. Screens are used all over the world, in different ways and circumstances, but they are a truly global phenomena.

Let me now try to summarize some aspects of what I described as screenization: Screenization can be seen as a long term paradigm shift of the diffusion of screenic properties, based on observations and extrapolations of previous and current developments of screens and the perceptional and communicative aspects of our relationship with them. The long and broad history of screenic devices testifies of the immense spreading of screens all over the world and its role as most prominent visual media of the present. In their contemporary manifestation as digital screens, they are able emulate or substitute most previous visual media and even neighboring concepts. The simultaneity of contents on digital screens leads toward a fluidization of the screens border. The close interconnectedness with computation and networks diffuse the boundaries to other devices and the environment. Screens are the main point of interaction between the abstract concepts of digital computing and the multi-dimensional and sensory perceivable world of humans.

We can no longer exist without computers, and we can barely interact with those computers without screens anymore. *"The language of the screen has turned into an actual material condition of our existence"* (BRUNO 2014: 113) The screen became "Digital Media" in the truest sense of the word: It mediates between us and a world increasingly influenced by digital technology.

And this digitalization will continue – in the small scale as the conversion of information into a digital form, and in the large scale as technological, economical and social transformation. And what we will perceive of these changes, we will perceive mostly through screens: Therefore Screenization can be seen as the visible side of Digitalization.

69 [Translated by Author]: "*Als symbolisches Maschenwerk (Brechungsindex, Orientierungsgitter, Bildmauer) schiebt sich der Bildschirm in die Lücke zwischen Beobachter und Beobachtung.*"

70 [Translated by Author] = *"Das Medium öffnet Fenster zur Welt, ist Schaltstelle der Industrialisierung, Planung, Produktion, Politik und Kriegsführung sowie der Weltbeobachtung, Medienwelt, Physik, Medizin, Forschung etc. Und es ist zugleich auch Sozialisationsinstanz"*

Practical Part

For speculations about the further developments of screens, the area of secure research has to be left. To manifest my thoughts and explore potential futures of screenization I developed two experimental approaches, in which I focused on the tendency for diffusion of screenic elements. In the process I was strongly influenced by various science fiction stories and projects on the transition between art, design and technology which deal with the diffusion, blurring or ubiquity of screenic properties.

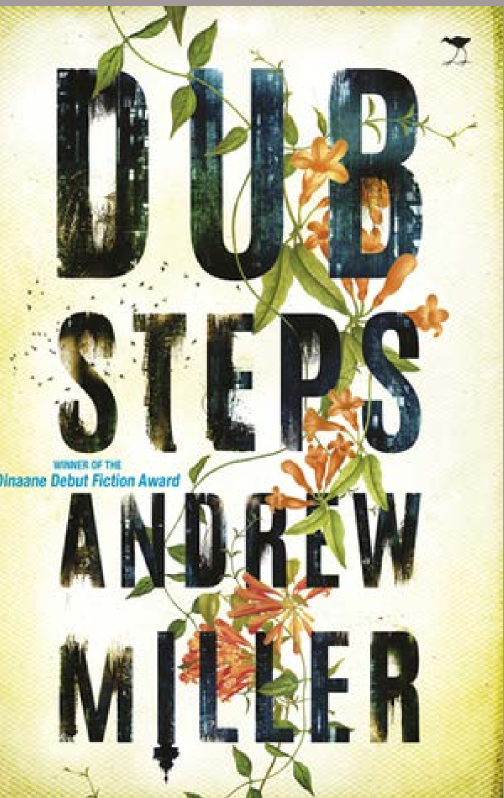
One of them – the book "Dubsteps" by Andrew Miller – raises the concept of what he calls transmission paint. On only a small paragraph he describes the idea of a paint that can be spread onto any given surface to turn it into a screen. In this idea, many of my thoughts regarding screenization were reflected, and I considered it as the starting point for my practical research.

Both of my projects follow the same idea of screens not being bound to a flat rectangle anymore, by extracting the screenic properties from their current functionality and turning them into an even more mutable entity.

The first experiment shows an approach to a technical principle that could be used to achieve this effect, and can be seen as a technical proof-of-concept. The second is a visual model – you might called a mock-up – that makes the speculative result and consequences of this effect visible and tangible.

Following the screens tendency for ambiguity, both outcomes can be seen as experimental infrastructures that open up many new and unexpected possibilities, instead of committing to a specific usage or interpretation. It is not so much of what they actually show, but what their concepts could mean in the context of the diffusion of screenic elements in the future.

Inspiration



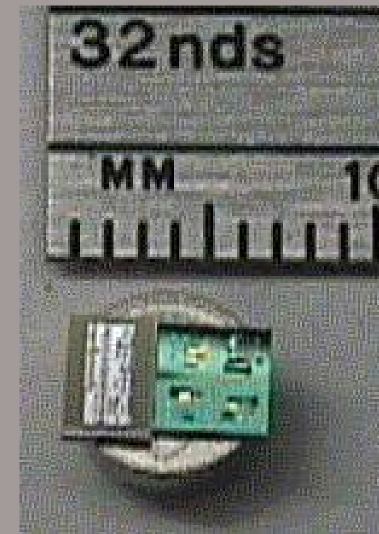
Science Fiction novel set in a dystopian South Africa - Miller, Andrew (2015)

"Transmission paint was cheap. And simple. Lash the dirty brown onto any surface. Wait for it to dry. Enter pin. Pair. Broadcast."

- MILLER 2015: P. 10

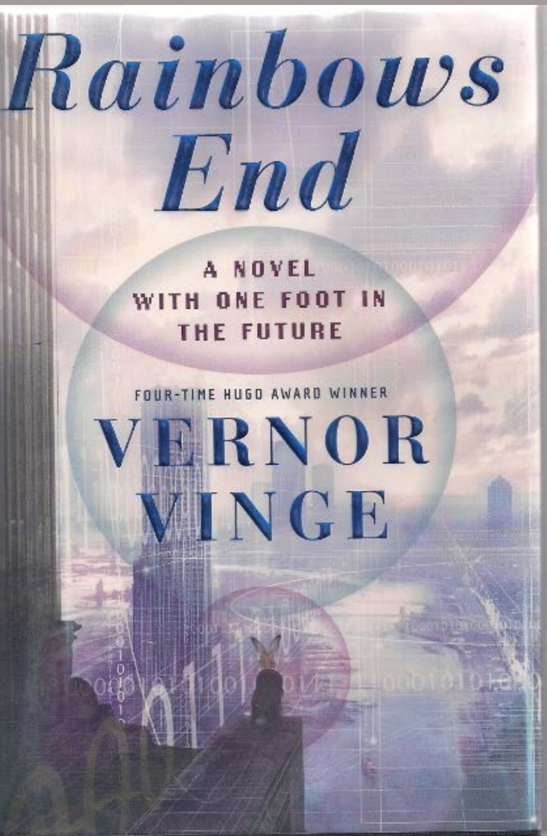
Sprayable screen material envisioned by "Universal Everything" in their "Screens of the Future series" - http://universaleverything.com/projects/screens-of-the-future

LED Throwies to be distributed in urban space, an idea by "Graffitti Research Lab"- http://www.graffitiresearchlab.com/blog/projects/the-first-led-throwie/#video

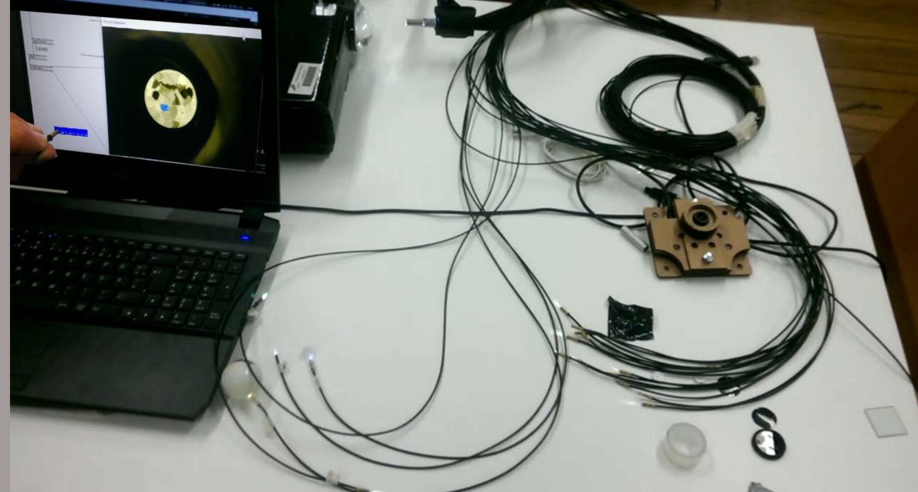


SMART DUST: Autonomous sensing and communication units developed by a research group at University of California, Berkley- https://people.eecs.berkeley.edu/ pister/SmartDust/

A mixed reality storytelling platform that creates collaborative immersion by Arvind Sanjeev - http://arvindsanjeev.com/lumen.html



Science Fiction novel in which Augmented Reality lenses can be used to switch and share different layers of augmentation - Vinge, Vernor (2006): Rainbows End

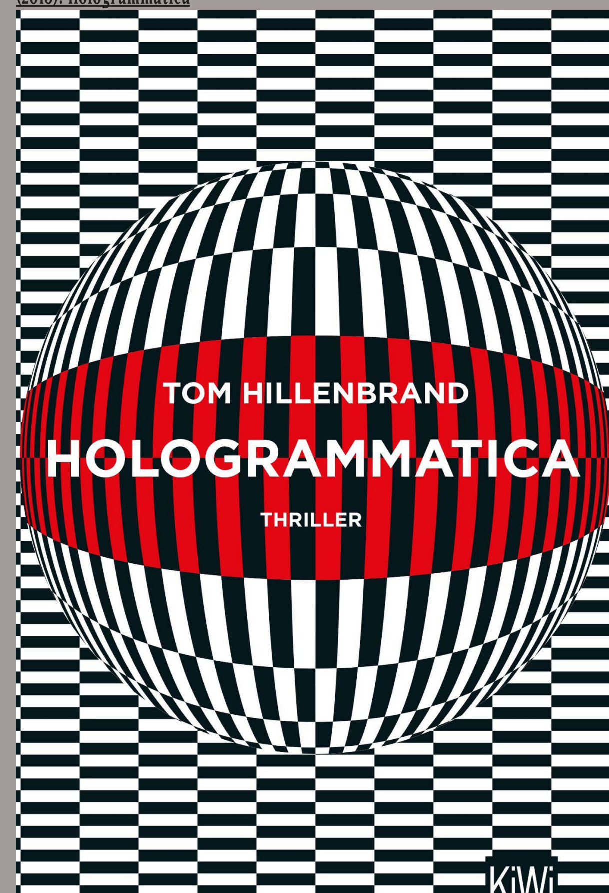


Early experiments with projections on fibre glass cables to distribute light spatially.

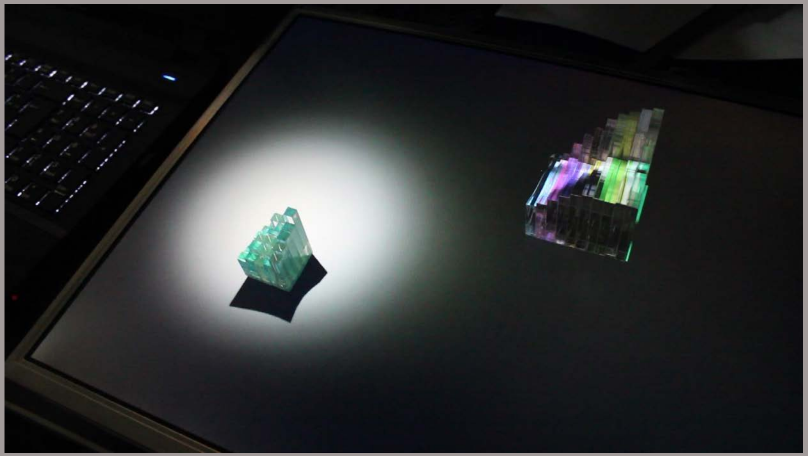
Conceptual short film by Keiichi Matsuda about a vision of the future, where physical and virtual realities have merged, and the city is saturated in media - http://hyper-reality.co/

Photo series of people interacting with smartphones by Antoine Geiger- http://antoinegeiger.com/filter/art/SUR-FAKE

Thriller, in which a global system of holograms augments everybodies visual perception - Hillenbrand, Tom (2018): Hologrammatica



TV—Screen sculpture "Turtle" - Nam June Paik (1993)



Experiments of placing shapes that were laser cut from acrylic glass on a LCD screen and producing custom fitting animations

Floor sculpture with integrated monitor - Lindsey White (2011)

"Have a Seat": A chair consisting of screens showing different chairs by Manasse Pinsuwan - http://digital-media-bremen.de/project/have-a-seat/

"As we Are": LED sculpture by Matthew Mohr that can display faces taken by a photo booth inside - http://www.meetusinco-lumbus.com/as-we-are/

"Anima Iki": Sculpture that modifies sound and visuals as it reacts to and forages in its environment by Onformative - http://onformative.com/work/anima-iki

Screenization Experiment 01: Autonomous Pixels

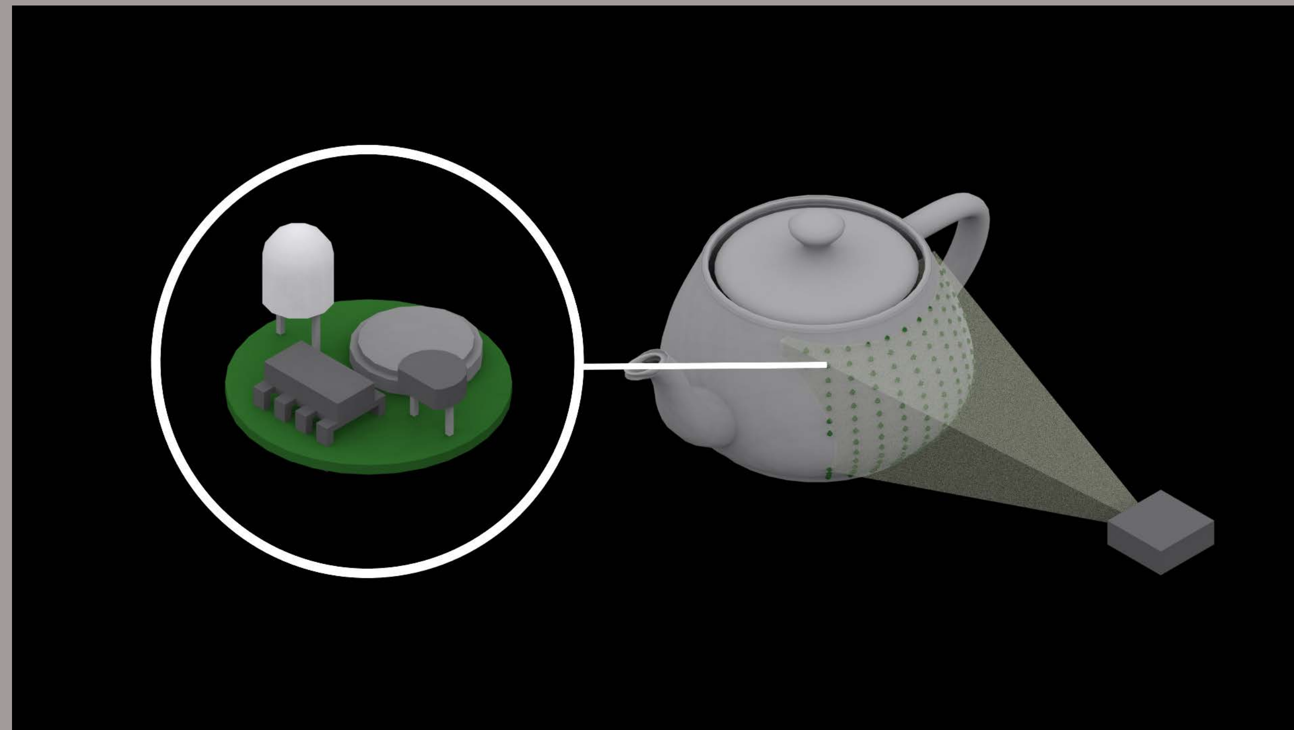
What if pixels could be spread like paint? What if they would not need to know about their position and context in relation to the “bigger picture”? What if individual pixels became autonomous, in the sense of power supply, input and output? What if they could memorize the content that they are showing?

For this experiment, a series of autonomous pixel units were build, each consisting of a power supply, a micro-controller, a light sensor and a light emitting diode (LED) that are combined on a custom 3D printed mount and covered by a plastic sphere for uniform light diffusion. Whenever the light sensor receives a certain light pattern it starts recording the following sequence of light intensities. Afterwards this sequence is replayed and emitted by the LED.

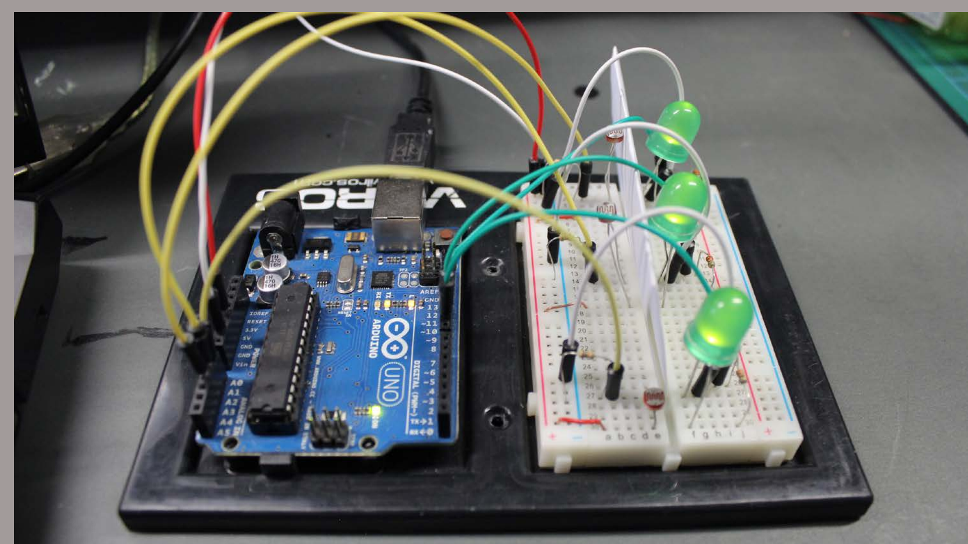
The units can be equipped with magnets or adhesive parts, so they can be distributed on almost every surface. An initial custom-fitting projection can be used to “imprint” light patterns onto a large number of units spread over a surface and addressing each unit individually. Afterwards they are able to show even complex animations as a synchronized whole – a sort of “meta-screen” – even if the individual units are not connected and don’t know about their position or relation to the others at all.

To demonstrate the principle functionality, fifty autonomous pixel units have been built and presented in an experimental setup. Thinking further, in theory it would be possible to realize three of the fundamental functionalities with the technology of LEDs alone: Obviously they can emit light, but also they can be reverse-biased to generate electricity and to act as light sensors. Also it should be possible to display colors, either by using one RGB LED or three colored ones. The size of the unit could be reduced dramatically by using SMD components and super capacitors for power supply. Utilizing the computation capabilities of the micro-controller it could also be possible to transmit string-based instructions (e.g. through already established one-dimensional bar codes), that enable a real-time reprogramming of the chip.

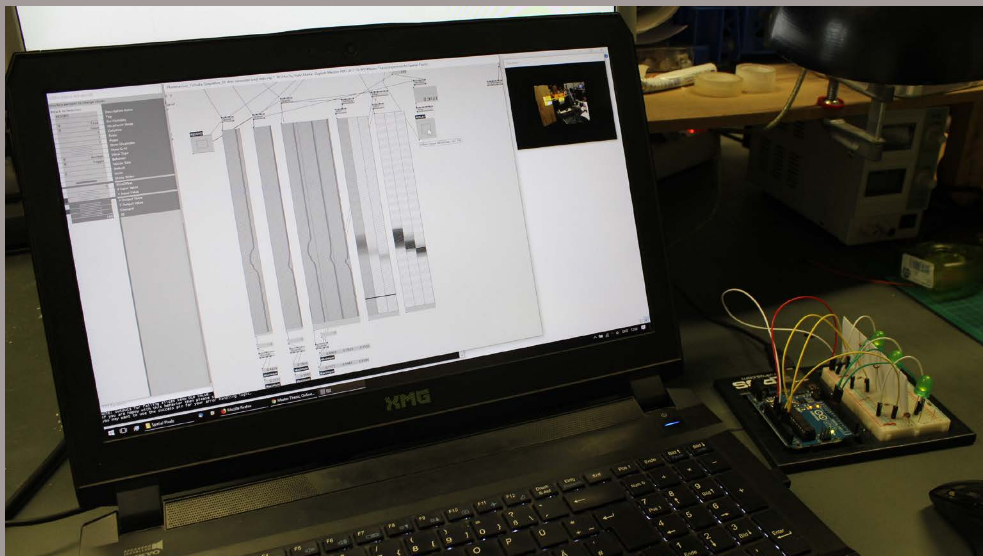
The initial idea for the autonomous pixel units came while seeing this LEDs blinking for customers attention at a supermarket.



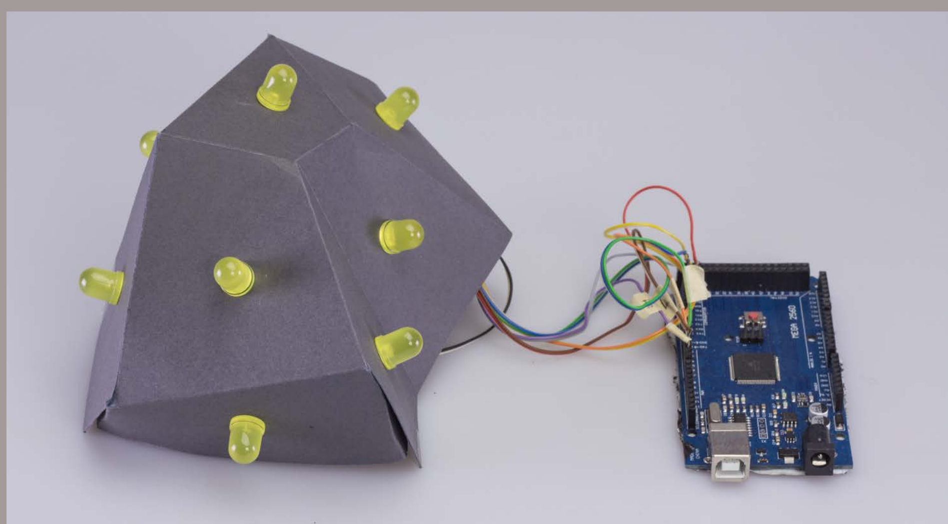
This visualisation explains the concept to equip every unit with a brightness sensor and, distribute them over any given object and to "imprint" images onto them with a custom—fitting projection



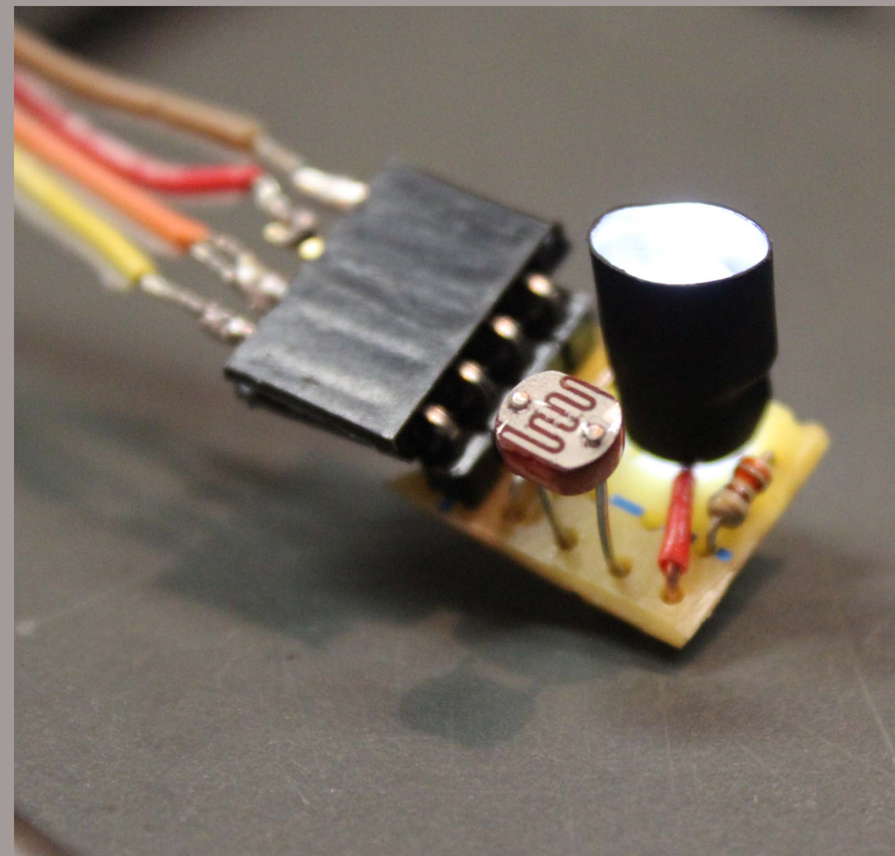
For the first tests LEDs and photosensors were connected to an Arduino.



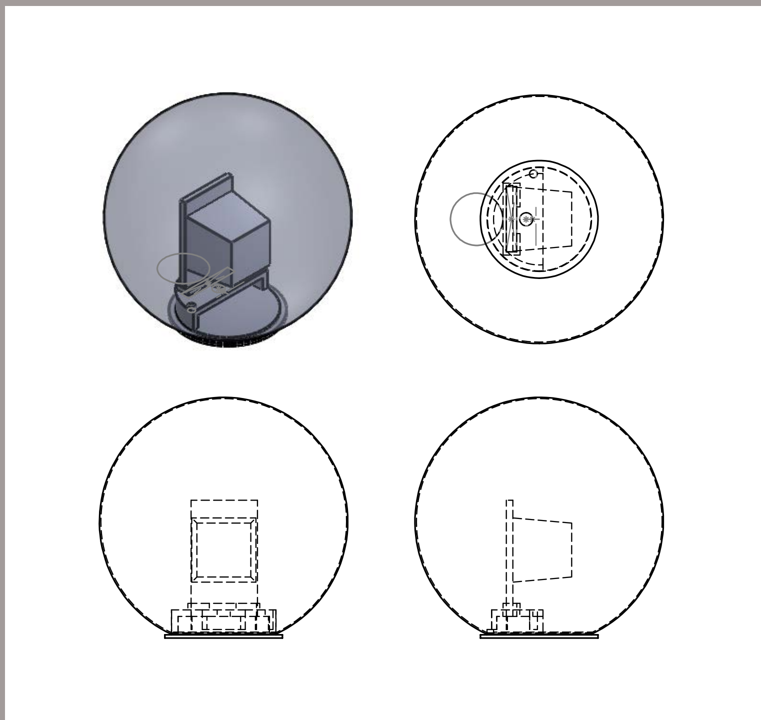
To be able to monitor and debug the behaviour of the units a visualisation using serial communication and the live–programming environment VVVV was developed.



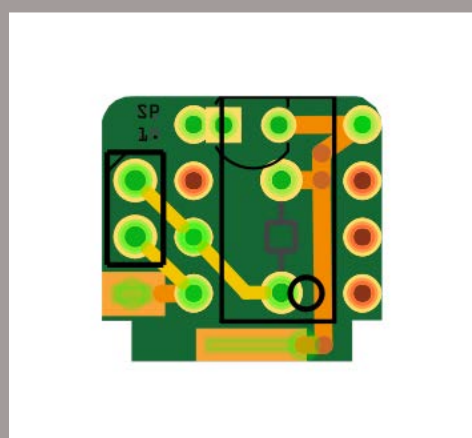
Also experiments using LEDs as photosensor were conducted and arranged on a spatial object.



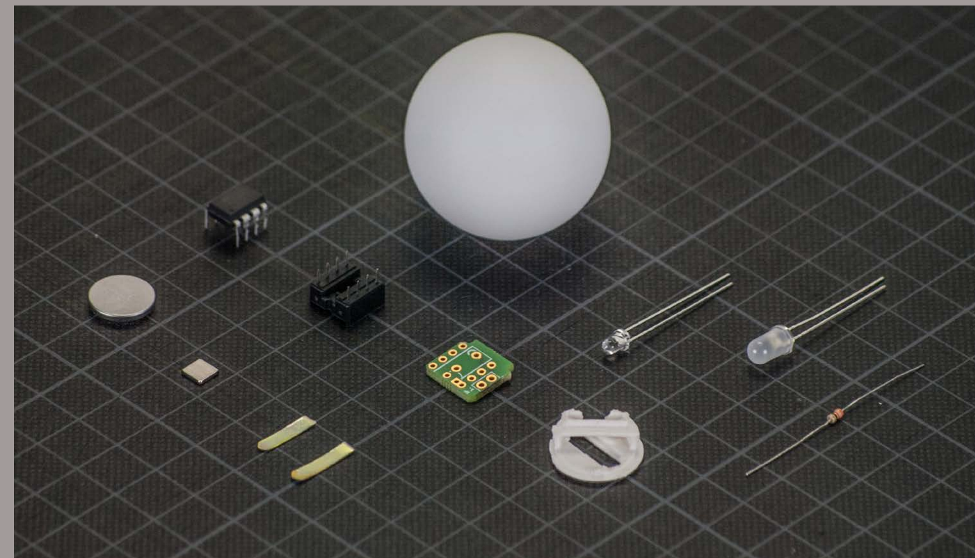
The first prototype of a individual measuring and glowing unit, where the calculations were still conducted on a computer.



Schematic view of the unit as constructed in a CAD software for printing the battery holder

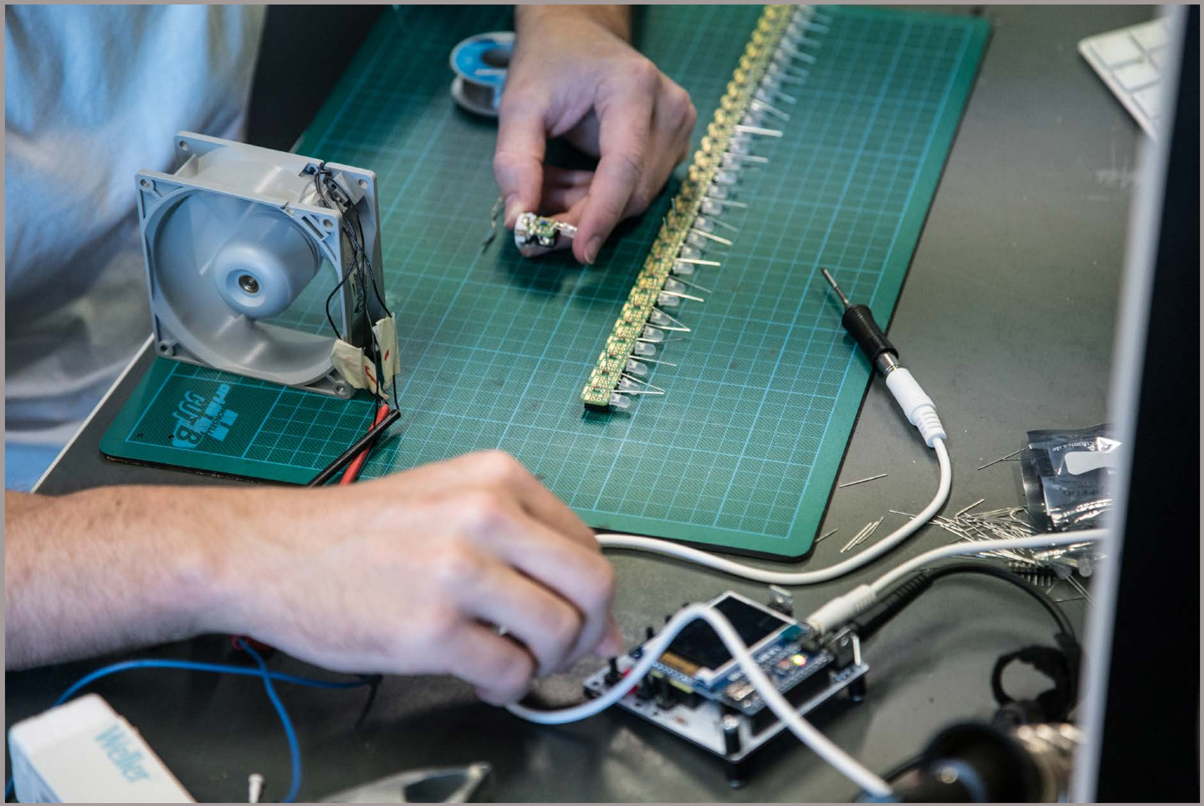


Schematics of the circuit used for the units.



All the components of a unit disassembled: A battery, a magnet, two contacts, an ATtiny85–20 PU micro controller, a 8 pin IC socket, a custom 3d printed holder, a ball for diffusion, a photo sensor, a LED, a breadboard, and a resistor.

An assembled unit placed on the battery holder



Mass assembly and soldering of the units.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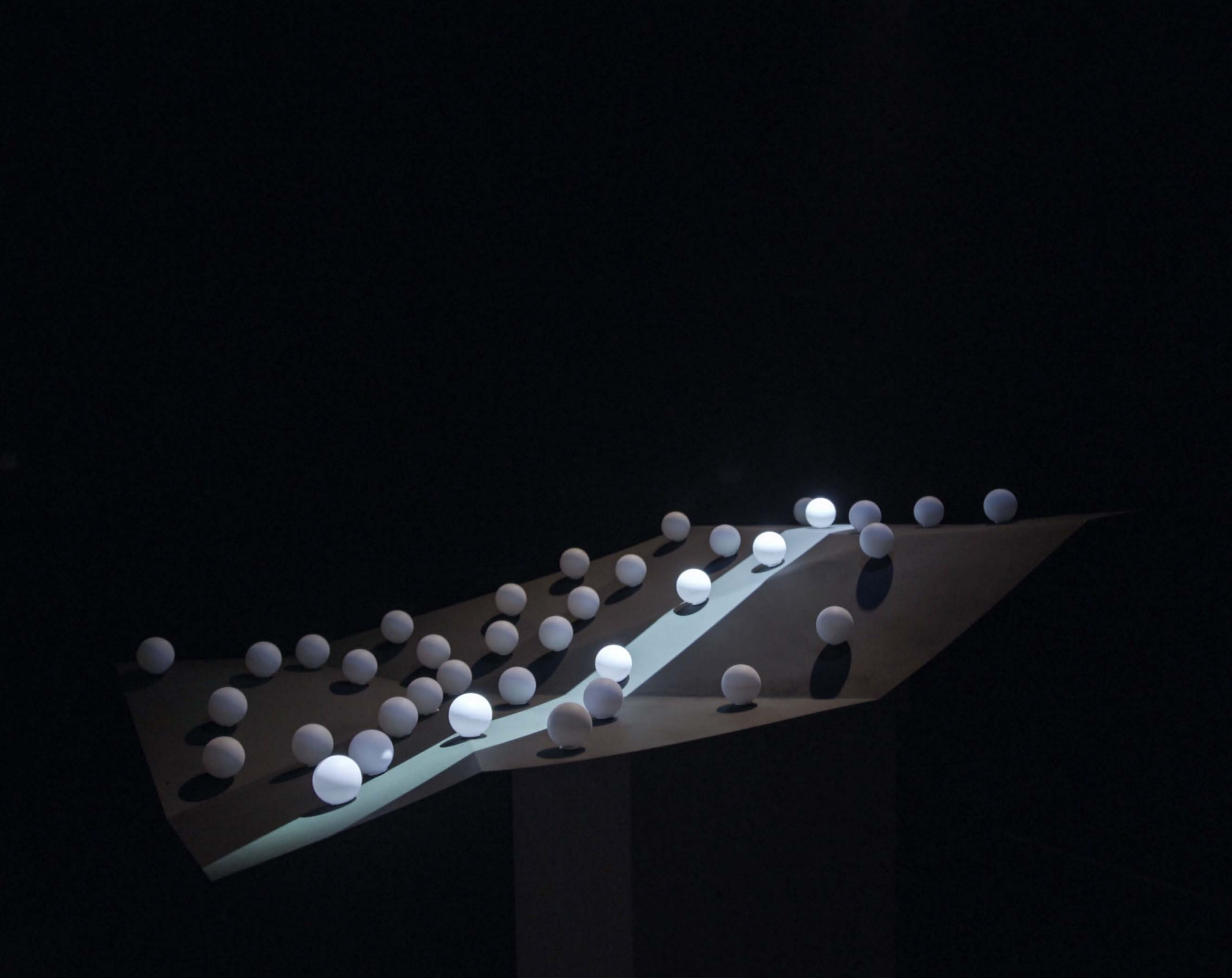
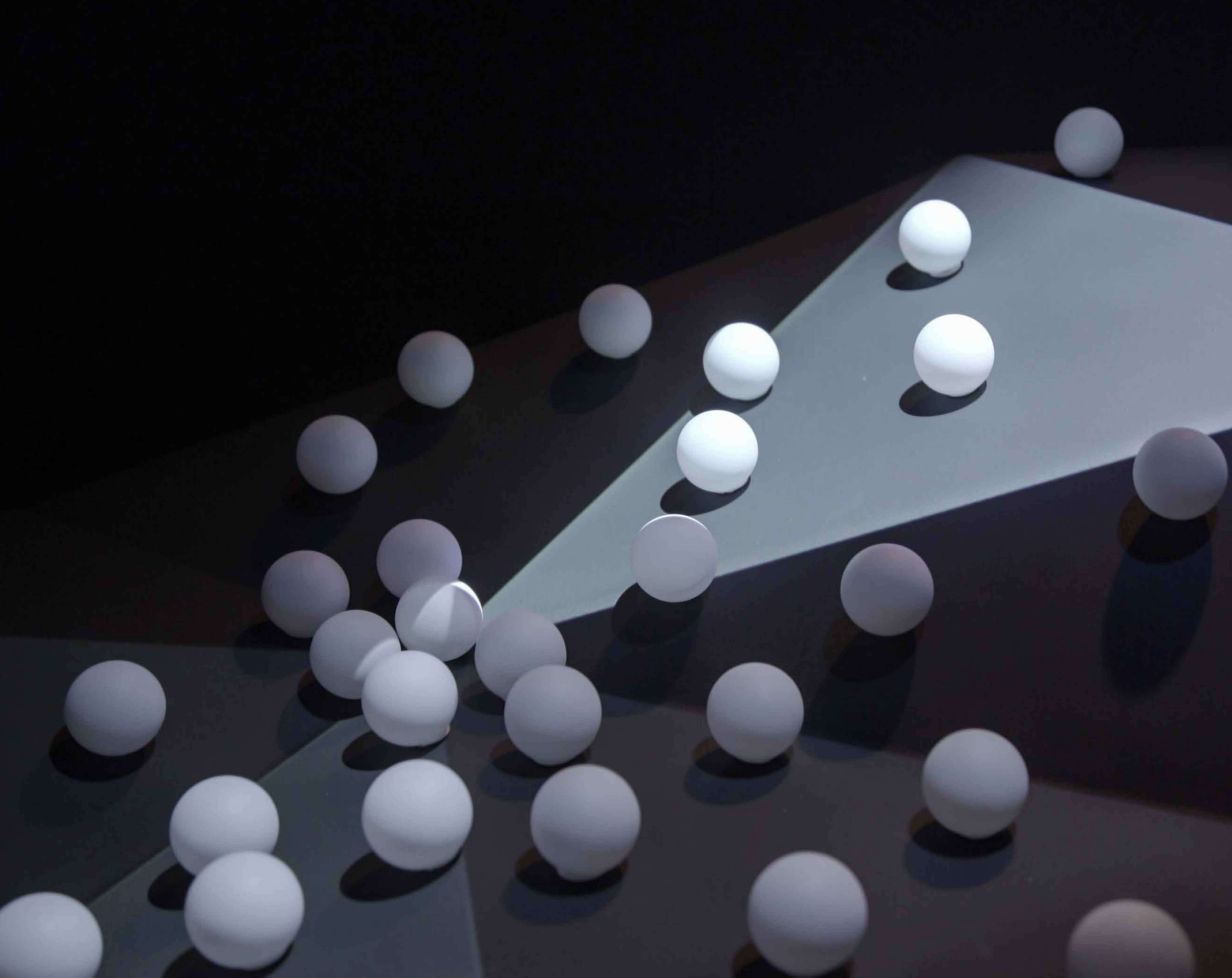
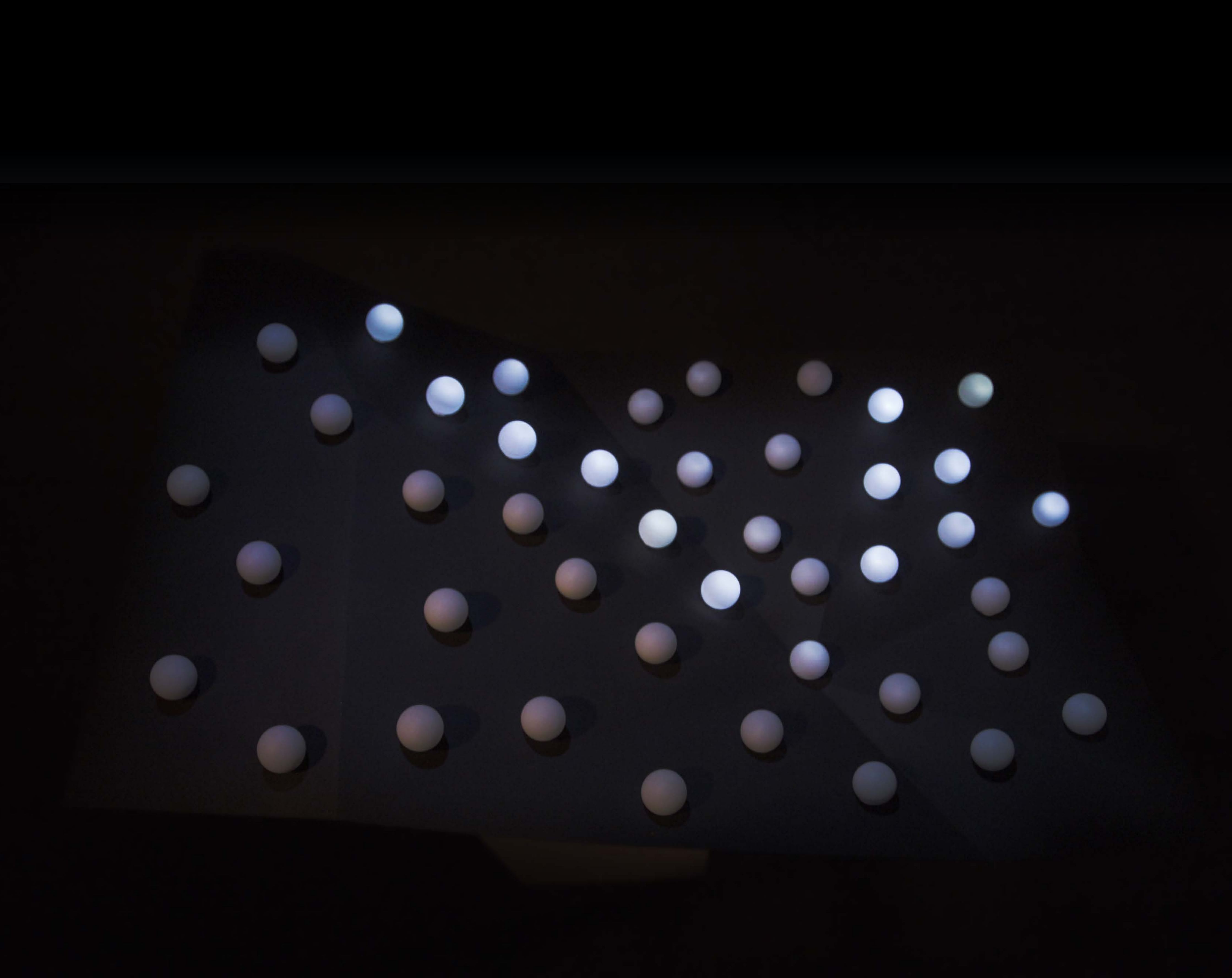
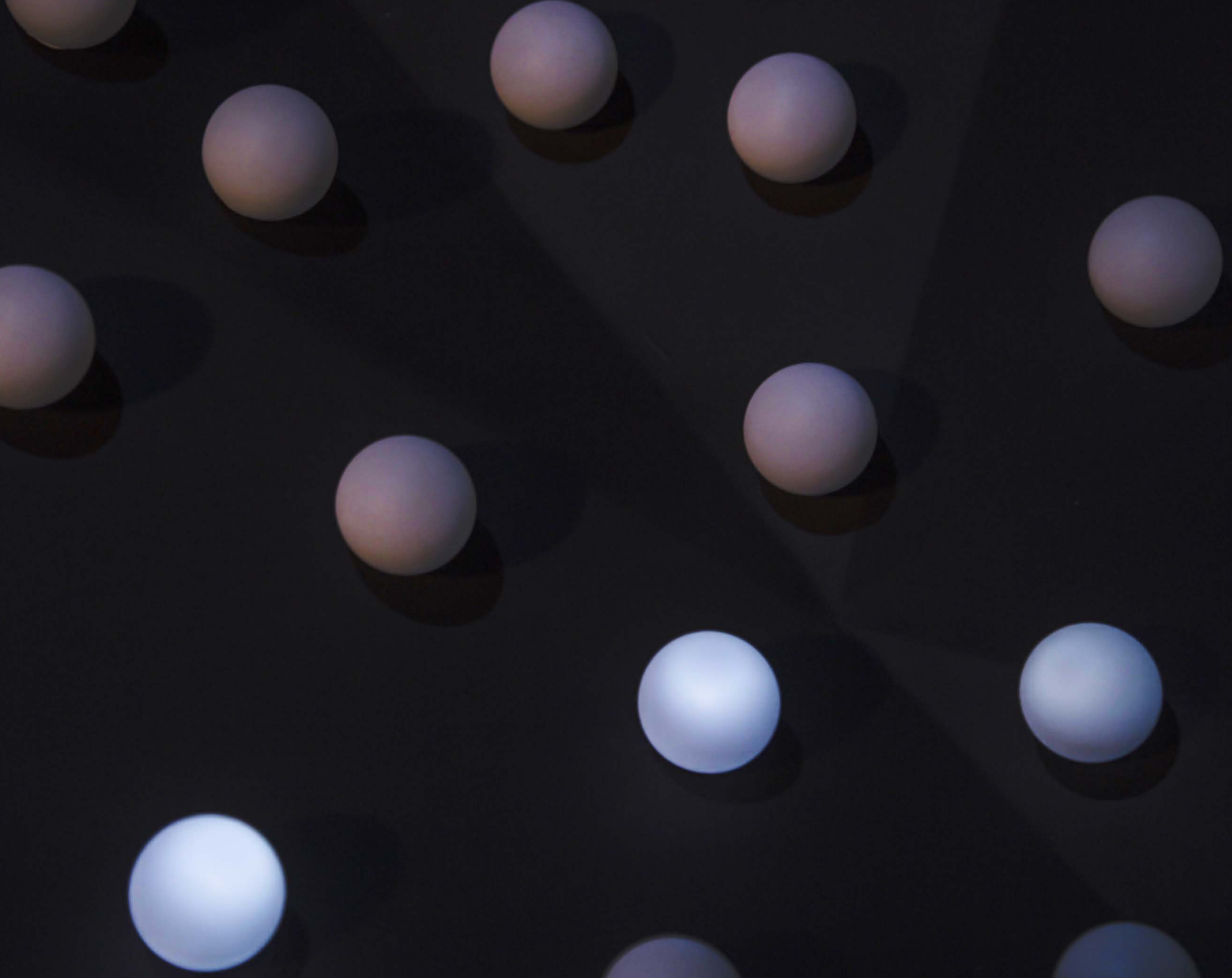
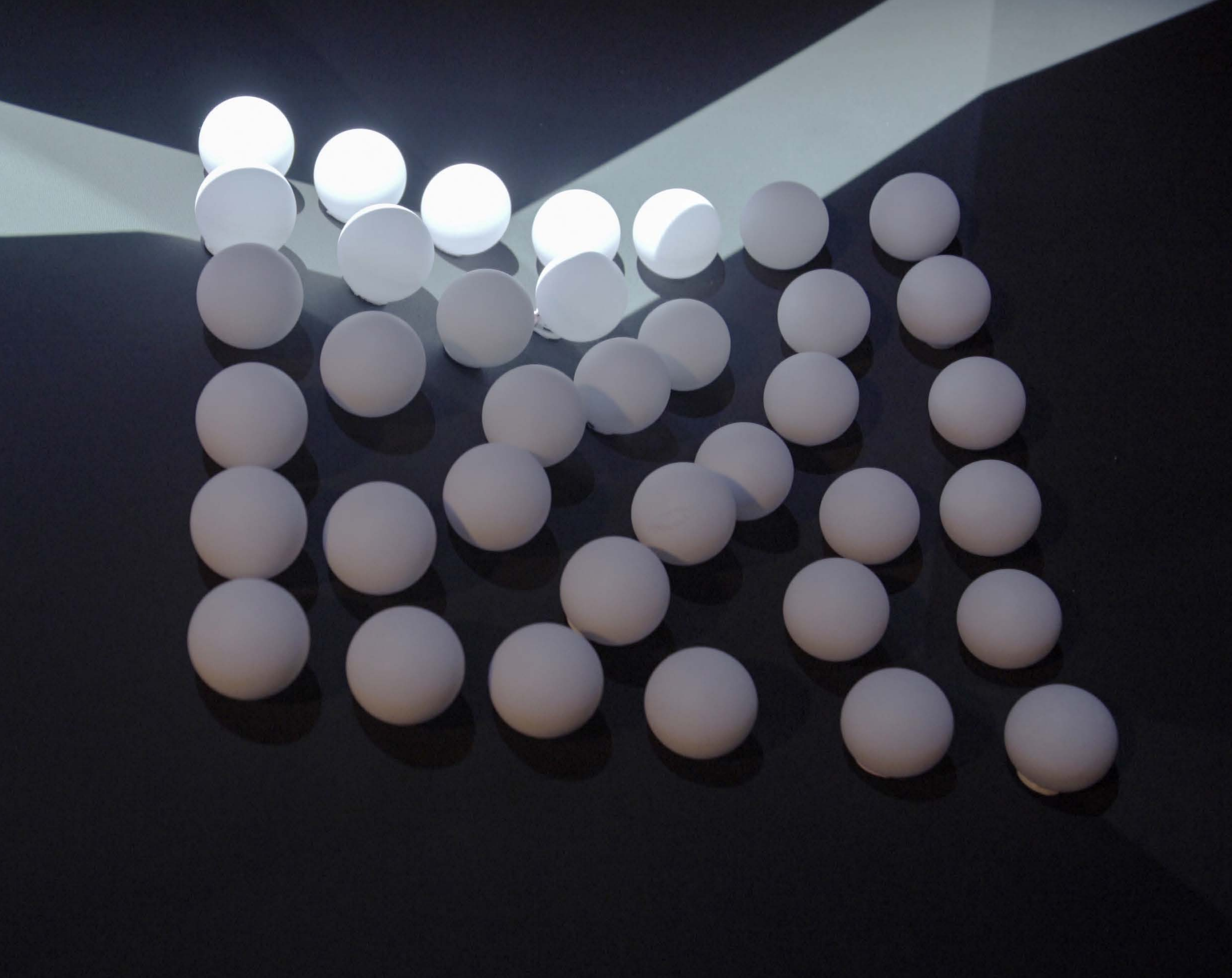
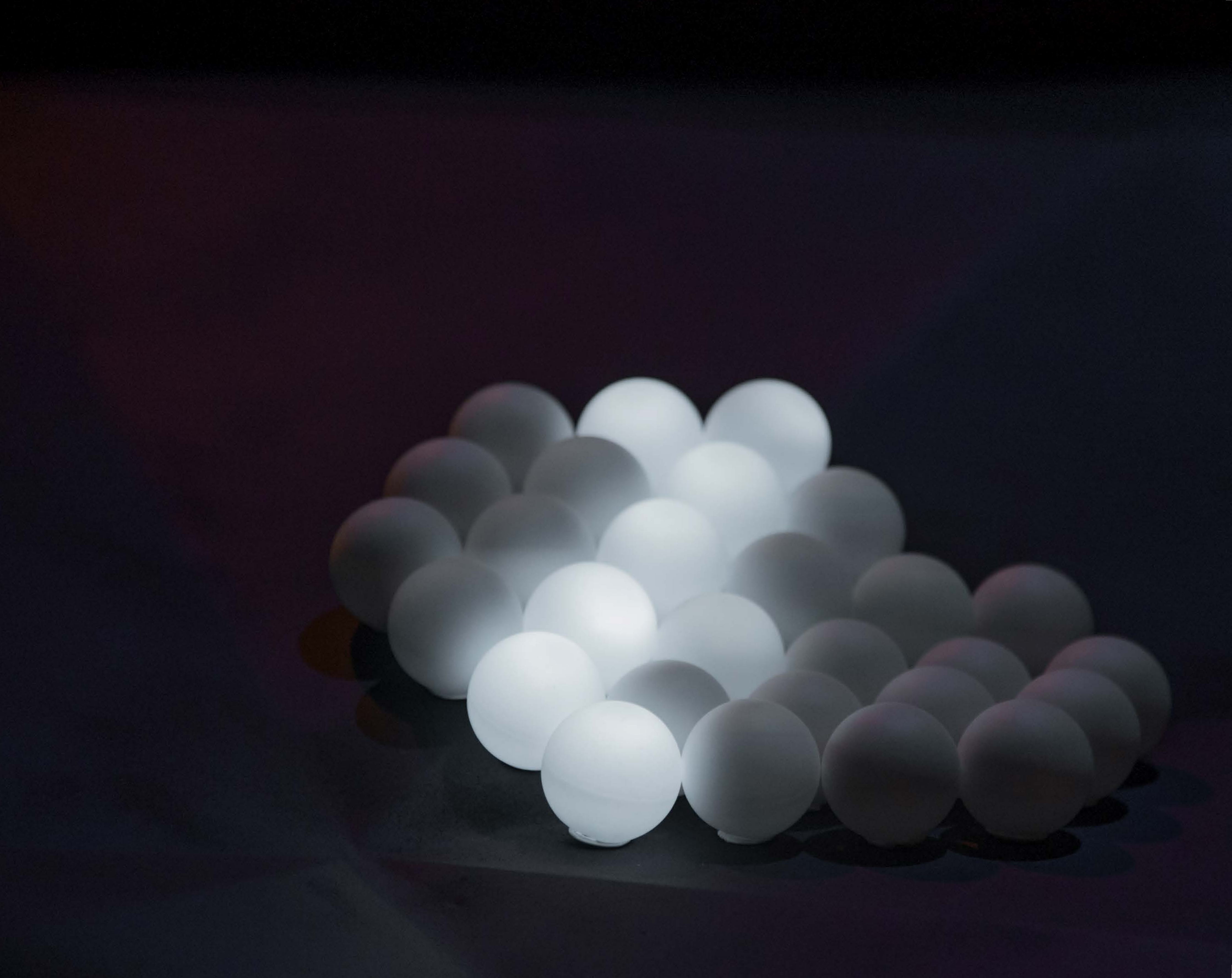












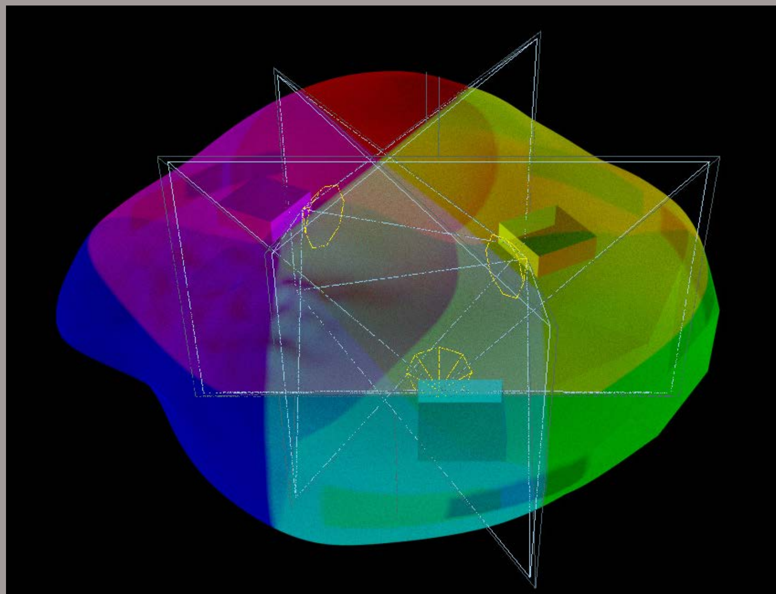
Screenization Experiment 02: Screen Sculpture

What if screens could be shaped into any form? What if every surface could gain screenic properties? What if the screen's quality to change its appearance left the flat rectangle that it is currently bound to? What would happen to our expectations of forms and materiality, if every surface could gain the ability to change its appearance?

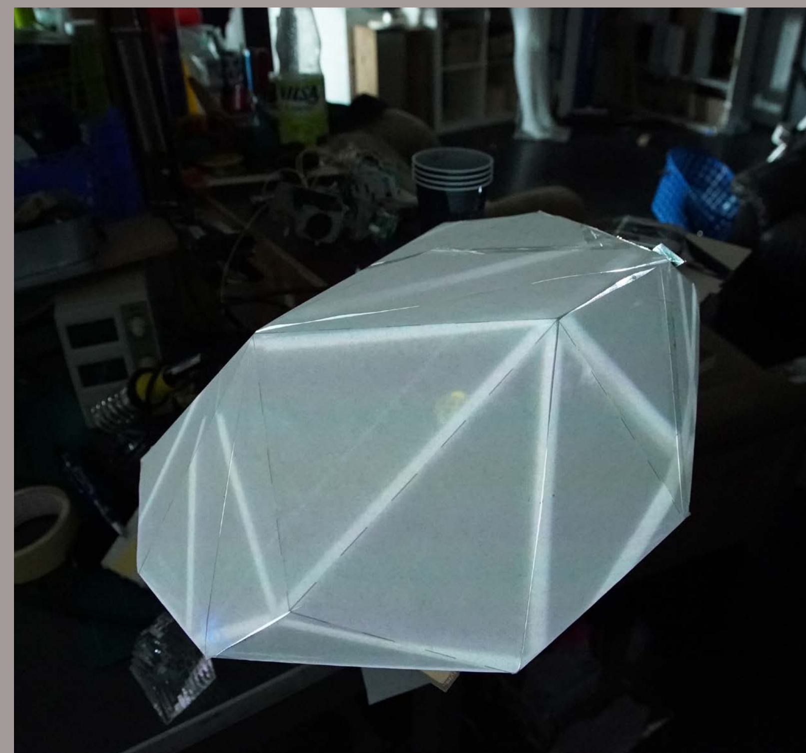
A screenic sculpture was built, that consists of a thin mold of semi-transparent plastic, cast from epoxy resin. The form of the object is deliberately designed as a "non-shape", not representing any known form and also the materiality of the plastic is strangely unfamiliar.

In the inside three mini-projectors are mounted with a custom-built short-throw lens system. A specific projection setup creates a seamless coverage that fills the whole object from the inside. The projectors are battery driven and wireless connected, and therefore allow for the sculpture to be moved around in space freely without limitations or shadowing. The images shown on the surface can reach from abstract shapes to concrete depictions and are controlled by an external computer. A parallel existing digital version of the object is used to merge virtually simulated properties with the physical appearance of the object in real-time. Using different sensors for tilting or touch recognition, the object can behave according to its context and be interacted with.

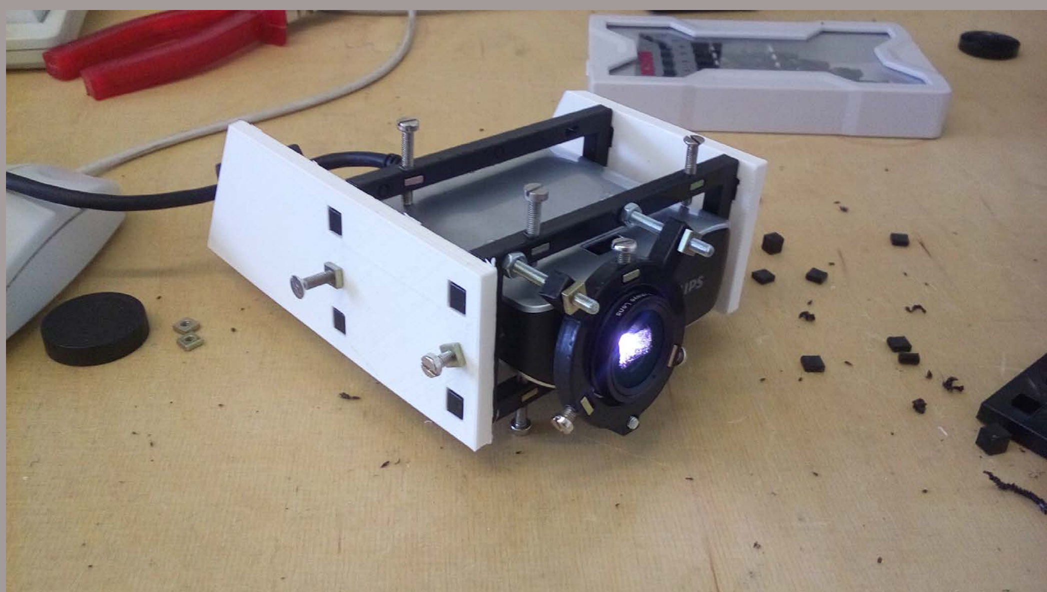
As an mock-up of an screenitized object, the sculpture simulates the behavior of individual picture elements spread over a surface while retaining a coherent appearance, by projecting them from the inside. Following the tendency of screens for self-effacement, the materiality and surface condition of the object step back in favor of its content: The appearance of the sculpture is defined purely by its screenic materiality. As a mock-up of a screenitized object, the sculpture simulates the behavior of screenic properties outside a flat rectangle. Regardless the technologies used, the sculpture questions our understanding of shape, material and surface in a world where screens are increasingly dominating our visual perception.



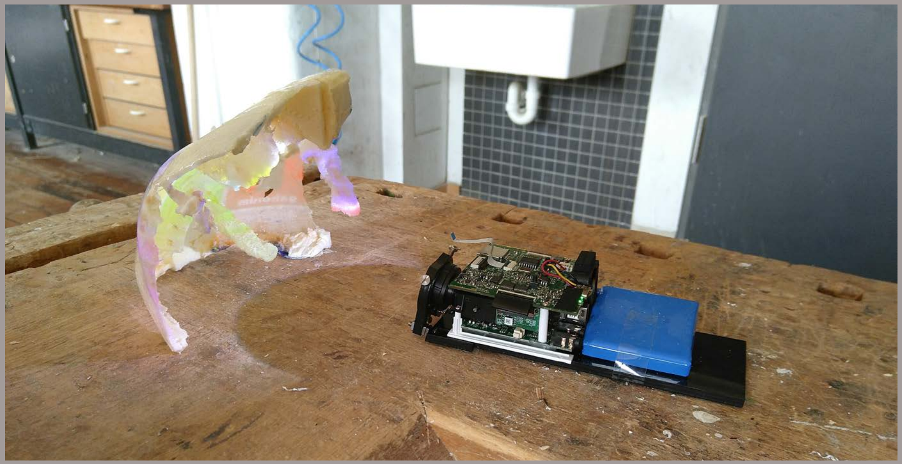
3D model of the object and planning of the positioning of the three projectors to minimize the casting of shadows.



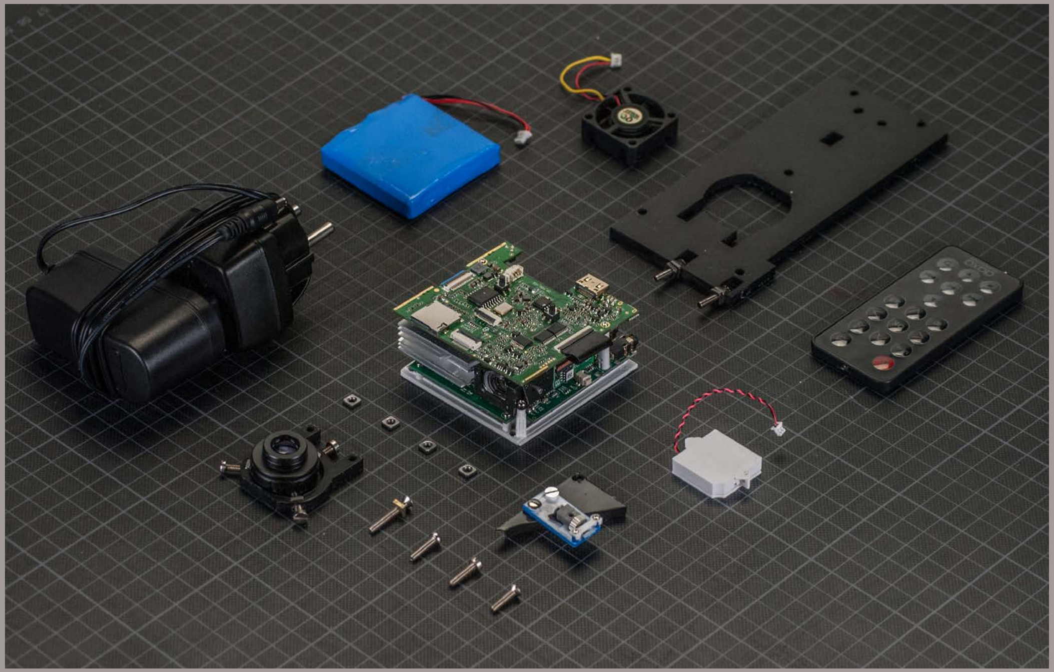
Tests with custom fitting projections inside a polygonal object.



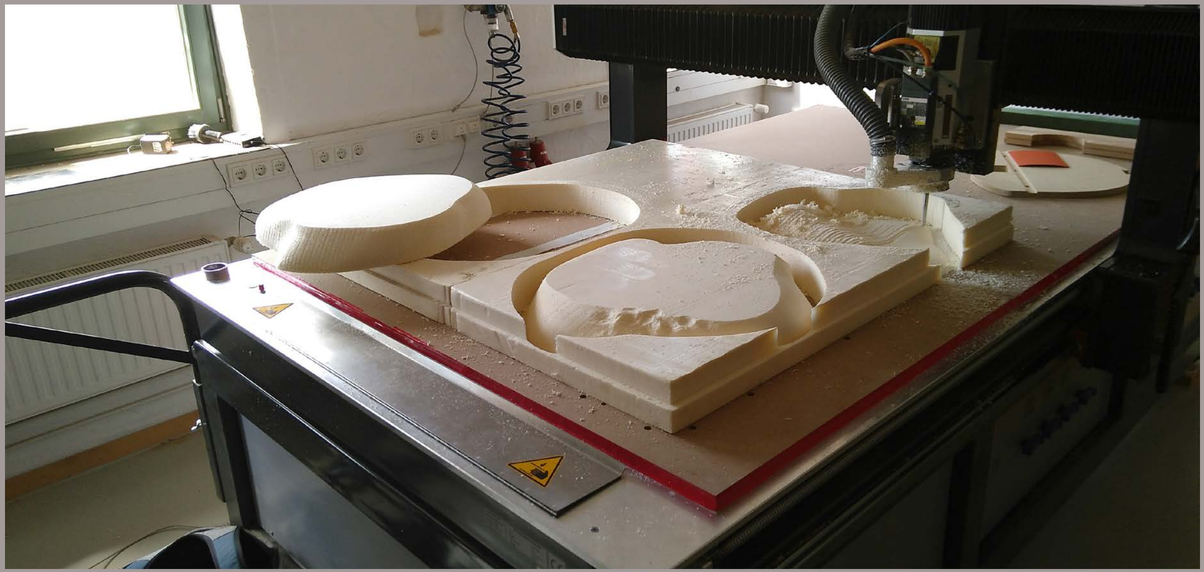
First tests of building a mount for a fish eye lens on a pico projector



To find the material with the best projection qualities several tests and experiments were conducted. Here the short throw pico projector projects onto a surface out of epoxy resin



The individual parts of the projector setup, including the Short—Throw lens mount.



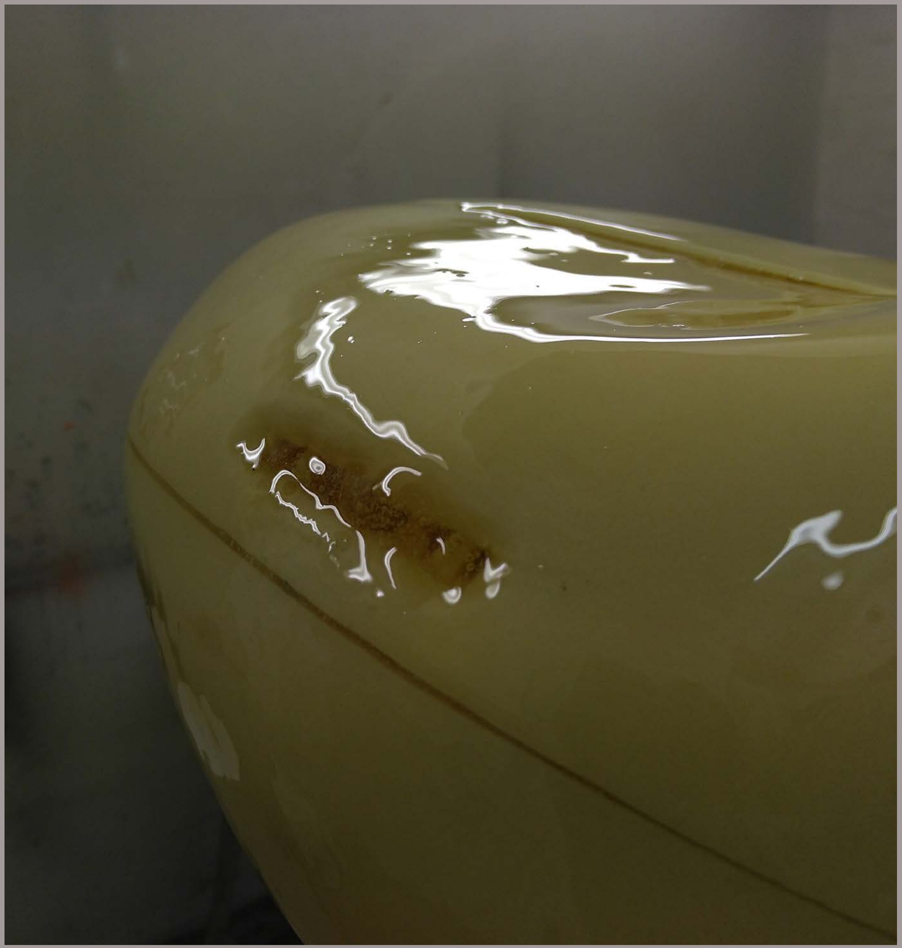
The positive mold was designed and planned in a 3D software and separated in four layers.

Each layer way cut by a CNC milling machine from Styrodur.

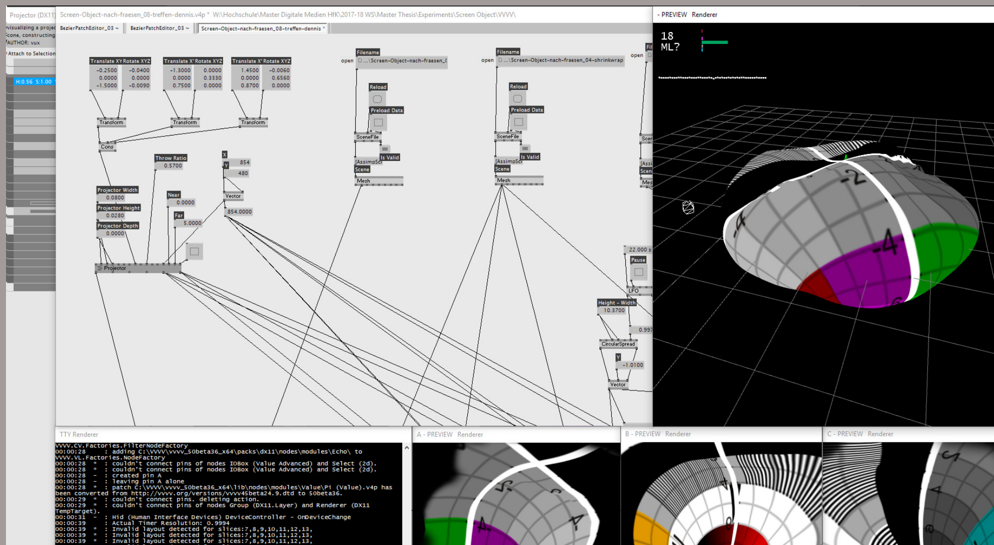
The four layers were scooped out by hand to save material and glued together to create the final shape of the positive mold.

The two—component epoxy resin was applied in multiple layers until the desired layer thickness of 3—4mm was reached.

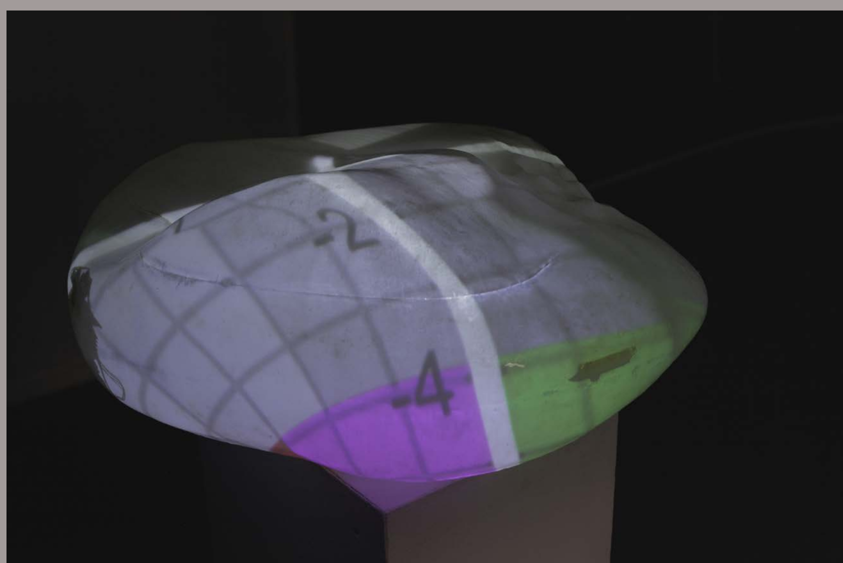
To remove the Polystyrol an opening at the bottom had to be cut and the material had to be removed by hand.



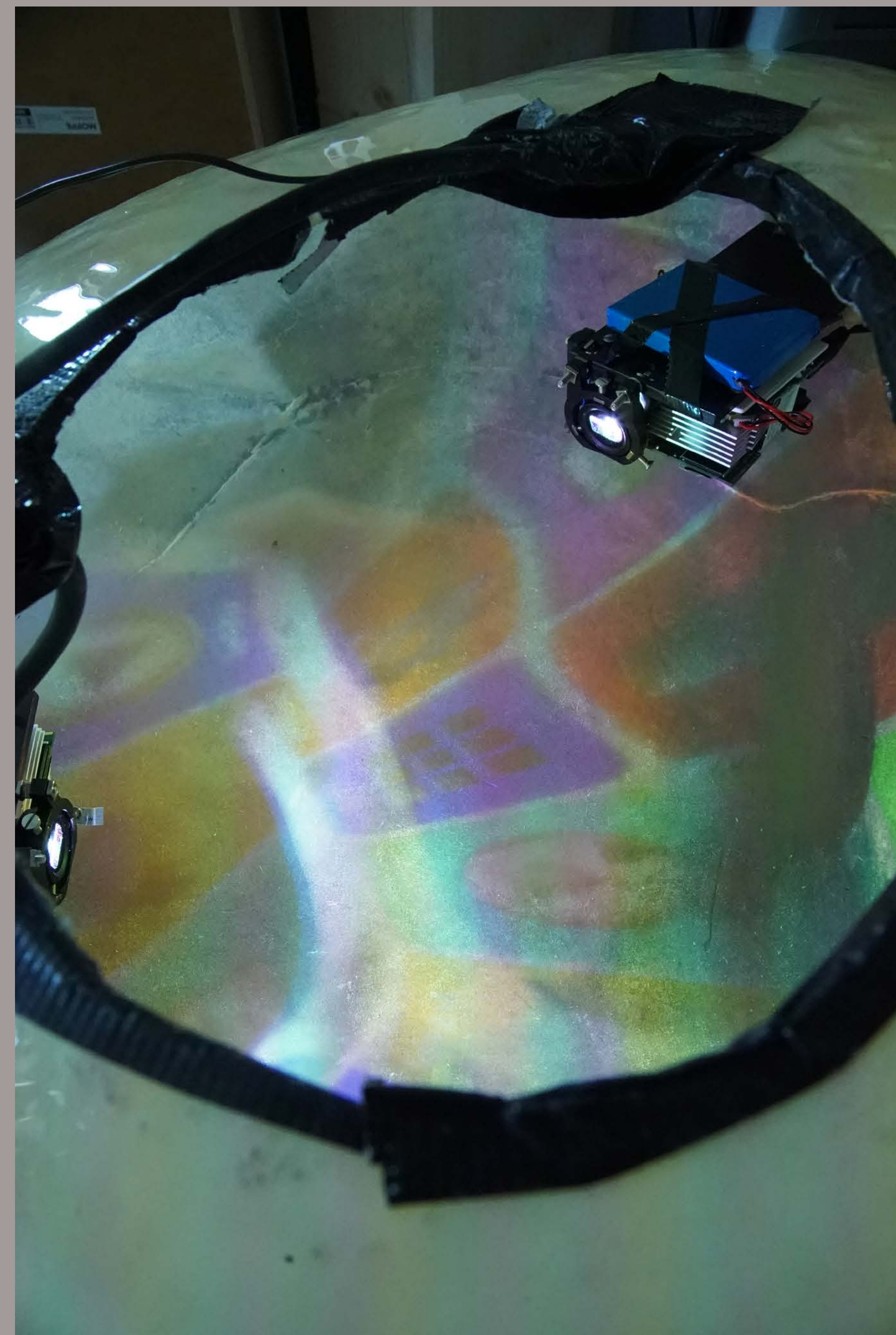
The mounts for the projectors were cast directly into the epoxy shape.



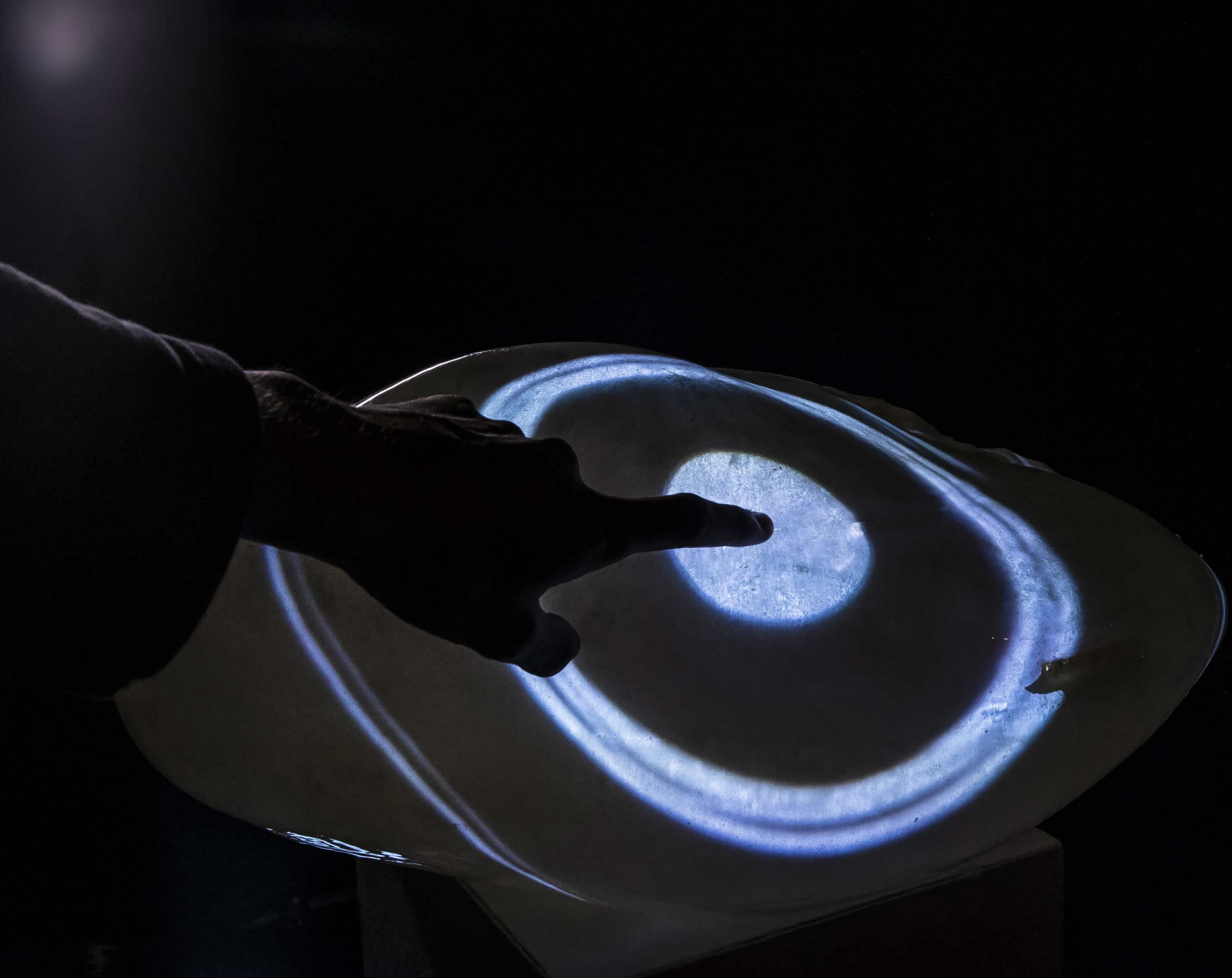
A virtual representation of the object and the projectors was created in the programming environment VVVV

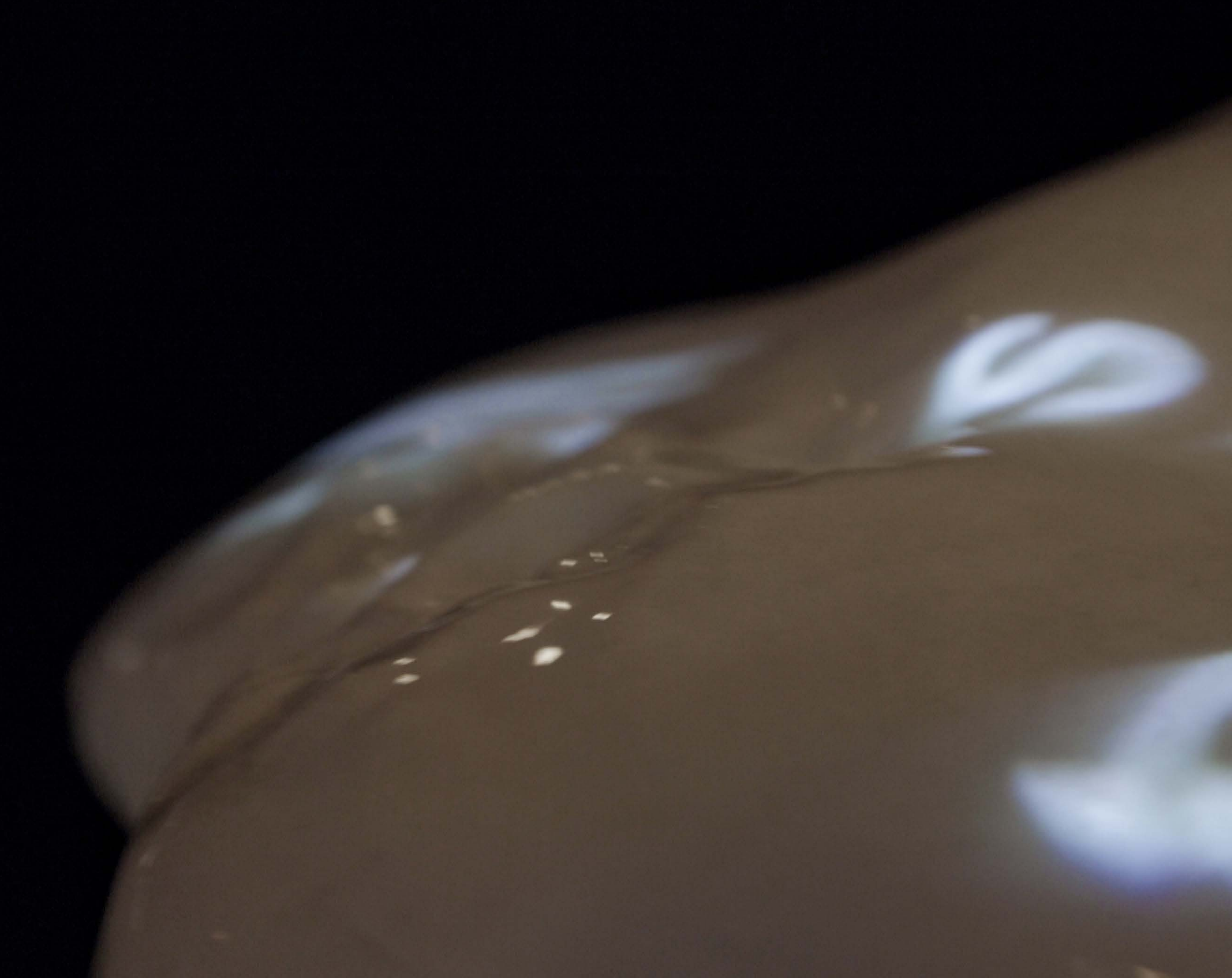


The images for the three projectors were rendered from the viewpoints of the virtual cameras and mapped onto the shape of the object.



The projectors receive the video signals via Wifi and are battery driven, which makes the whole object wireless.





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