RAINBOWS BETWEEN ART AND SCIENCE

AN UNCONVENTIONAL ANALYSIS

Alessio Bortot
University of Trieste
Department of Engineering and Architecture
alessio.bortot@units.it

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OPTICS
KNOWLEDGE IMAGES LEARNING
VISUAL SIMULATION
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ART AND SCIENCE

What do have in common a friar lived in the 17th century, a contemporary American artist of the Land Art movement and an Italian structural engineer popular between the two World Wars? The answer can be certainly found in the common scientific approach of the three authors, but more precisely in their shared passion for the natural phenomenon of rainbow. This paper focuses on the contextualization of studies related to this atmospheric phenomenon starting from the classical period – considering its depictions in the history of science and art. Between the protagonists of this story, whose approaches go from aesthetic researches to natural philosophy, we can find the friar Emmanuel Maignan (1601-1676): a scholar of optics who was the author of one of the most important gnomonic treatises in the Baroque period. Since 1980 the artist Charles Ross has used big glass prisms –precisely oriented– to project the chromatic spectrum within architectural scale installations. Then, in the early decades of the 20th century the engineer Arturo Danusso (1880-1968) developed a method to evaluate the tension stress of the reinforced concrete structures based on photoelasticity. In addition to the examination of the heterogeneous uses of rainbow in art and science, this paper also intends to focus on the relationship between light and optics intended as a ‘universal method’ to study natural phenomena over the centuries.

OPTICS AND RAINBOW IN HISTORY

The first description on the functioning of rainbow phenomenon can be found in the third century B.C. in Alexander from Afrodisia's work –200 B.C.– who considered the rainbow as a combination of light and colors, but didn't define a precise law. Aristotle (384-322 B.C.) was the first who considered the formation of rainbow directly connected to the optical laws. In his treatise *Meteorologia* the philosopher affirmed that the sight, compared to all the other senses, is the only one that allows the perception of colors. Other elements perceived by our sight, such as the shape of objects, could be known via our touch as well. He studied the origin of the second rainbow –sometimes visible in the sky– and at the end of his analysis he discovered the following issues. First, the center of rainbows is always between the observer's position and the sun; second, its shape is an arch of circumference never bigger than a half-circle; third, rainbows are caused by the reflective power of rain drops, able to show only three colors (Maitte, 2006). Seneca –who lived in the first century A.C.– in his book *Naturales Quaestiones* explains that the rainbow comes from a reflection of sun rays on the rain drops. He affirms also that is possible to see it within a cylinder of glass crossed by a ray of light. Even if the theories of these authors were not so precise about the difference between reflection and refraction, they influenced the researches on this topic until the 18th century, highlighting the relationship between optics, light and rainbow.

During the Arabian Middle Age some researchers such as al-Fārisī –who lived in the 13th century– started to consider the colored arch in the sky as a product of reflections and refractions according to the theories of the mathematician Alhazen in the 10th century in his treatise about optics. Well known is the work of Alhazen, published by Friederick Riesner (1533-1580) in Basil in 1572 with the title *Opticae Thesaurus*. In its frontispiece, among many optical phenomena, a rainbow is represented in the background. The Arabian science influenced the middle-aged Latin culture: for example Roger Bacon (1214-1292), following the theories of Robert Grosseteste (1175-1253) about reflection and refraction, affirmed that the rainbow can be considered the basis of an imaginary cone whose vertex is the sun and whose axis is the line connecting sun, the observer's eye and the center of the arch. Finally, in the same period, the most precise description of this phenomenon is given by Teodorico von Freiberg (1250-1311), similar to the one currently accepted: using a big sphere filled with water –like a big drop of rain– he experimented that the colors were produced by two refractions and one reflection.

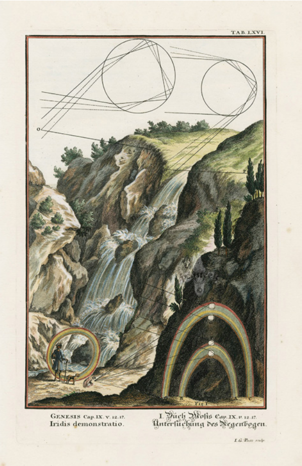

Fig. 1 Scheuchzer, J. J. (1731), *Physica Sacra*, tab. LXVI, Iridis Demonstration.

In the Renaissance period the rainbow was studied by other authors like Giovanni Battista Della Porta (1535-1615) and Marco Antonio De Dominicis (1560-1624). What's more, it started to appear in the frontispieces of treatises about optics and physics (Figure 1) and in the engraving *Melancolia I* by Albrecht Dürer (1471-1528) because of its symbolic and mystic implications (Boyer, 1987).

Teodorico's experiment was carried out by René Descartes (1596-1650) in the baroque period. Using the sphere filled with water he was able to calculate that the colors appeared when the angle between the axis and the generatrix of the imaginary cone of light was around 42°. Descartes became famous for the codification of the refraction law, today known as Snell-Descartes law. Thanks to an instrument of his own invention –composed by a board with a hole covered with a glass prism– he was able to observe the appearance of different colors depending on the inclination of the source of light. Descartes was really fascinated by the magnifying power of lenses, so that the last chapter of his treatise *La Dioptrique* is completely dedicated to the description of grinding machines for the production of these tools. In a letter written to an artisan –a lenses maker– he expresses his desire to demonstrate the existence of alien life in the solar system using telescope or the possibility to project messages on the surface of the moon by employing light and lenses.

More generally Descartes was able to develop a theory about light, reflection and refraction using a geometrical and experimental method.

Less than one century later Isaac Newton (1642-1726), with the experiment of the prism, demonstrated that the white light is composed by the seven colors of the rainbow – each of them characterized by a different wavelength (Corradi, 2016). In detail, Newton decided to communicate his theory about light and colors via a letter, today known as *Letter to Oldenburg*, addressed to the Royal Society in 1672. In this document the scholar explains that during the experiment he employed a dark room and a prism crossed by a sun beam coming inside the room from a small hole: on the opposite wall he observed a vivid colored and extended spot. At the side of his theory about rainbow there is a new physical explanation of light phenomena: light is composed by different corpuscles that are deviated in various ways thanks to refraction, producing the decomposition of light in colors. Each color is characterized by a degree of refractivity –lower for red compared to violet– that cannot be modified. According to Newton's theory there are two kinds of colors: the primary and secondary – which are composed by first ones. The primary are red, yellow, green, blue, violet, orange and indigo, this is the theory of seven color explained also in his 1704 *Opticks*. He also noticed that the most unexpected and wonderful color is white, composed by all the seven primary colors mentioned before. According to the scientist white seems to be the purest and simplest color, but in reality it became assembled and heterogeneous. In another letter addressed to Robert Hooke (1635-1703) Newton compares the refraction of a light ray to the string of a musical instrument pressed by the player's finger: the refractive surface can be seen as the position of the finger, the white light as the part of the string without vibration and the different colors as the vibrant part of the same string. The analogy between light and music continues when the scholar describes his well-known chromatic circle, comparing the seven colors of rainbow to the seven musical notes and the combination of colors to the octaves. In this context we can notice how Newton arranged physical laws according to the order of the world, in the same way as Johannes Kepler (1571-1630) had done before him.

EMMANUEL MAIGNAN. A RAINBOW FOR A SUNDIAL

In a recent research I focused on the digital reconstruction of an unrealized project for a scientific villa designed by Francesco Borromini (1599-1667) around 1644 for Cardinal Camillo Pamphilj. I'm referring to Villa Dorja Pamphilj which was finally built following a totally different project conceived by Alessandro Algardi (1598-1654) and Francesco Grimaldi (1606-1680). The documents on this topic are stored in the Vatican Apostolic Library and in the State Archives of Rome. These sources are both graphic and written: the graphic materials are composed by the blueprint by Francesco Borromini, a plan and a symmetrical facade in two solutions. The literary documents include a handwritten in Latin by the monk Emmanuel Maignan (1601-1676), where 21 scientific games are described and conceived to decorate the villa (Maignan, n.d.).

The games by Maignan represent investigations on optics, gnomonics, void existence, acoustics, astronomy and so on with the typical geometrical approach of that time. The French friar Maignan –belonging to order of Minims– spent a part of his life in the convent of the Santissima Trinità dei Monti in Rome from 1637 to 1650. In the corridors of the cloister at the first floor he depicted the portrait of Saint Francis of Paola in anomorphosis and a catoptric sundial. In 1648 Maignan realized a similar clock for Bernardino Spada (1594-1661) in his palace Capo di Ferro. Thanks to a small mirror positioned on the windowsill it is possible to read the time observing the reflected sunray moving on the ceiling where the hours line had been previously calculated and traced. In point six of Maignan's handwritten for Villa Pamphilj –reconstructed with digital tools combining Borromini drawings and Maignan's description– the monk refers to the realization of a catoptric sundial on the vaults of two angular towers (Bortot, 2020), the same solar clocks he practically built in Trinità dei Monti and in Palazzo Spada. The monk writes

> on both the vaults of the northern towers and the wall around, through the art of catoptrics it will be put a device indicating whatever it refers to both the motion of sun and stars, thanks to the reflection of a sunbeam. Likewise, in the same place two mirrors will be arranged so that on the wall or on the vault a perpetual iris will be produced. The rainbow will indicate the parallel where the sun will be and thus it will show single places, such as cities or regions where the sun will reach its zenith that day. (Maignan, n.d., pp. 627-628)

Maignan thinks to align the geographic places of the world where it is possible to know the astronomical midday, along the projection on the spherical vault of a perpetual arch of light obtained through a tool called *Iride Horariae Dioptricae*, shown in the fourth book of his treatise about gnomonic entitled *Perspectiva Horaria* (Maignan, 1648). In other words, the position of the arc points out the parallel where the sun is

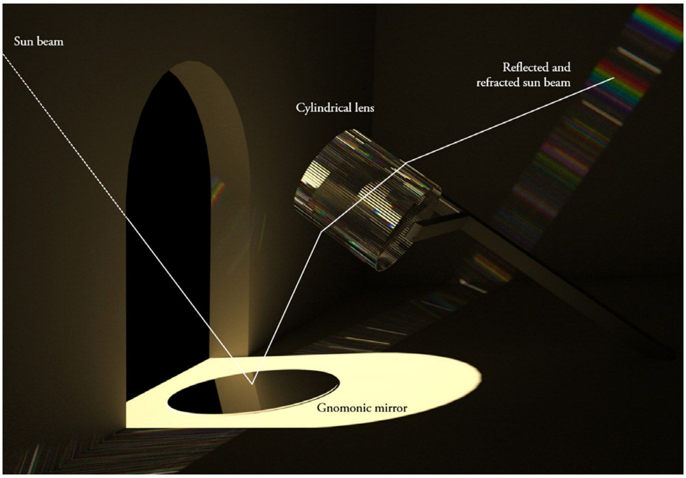

Fig. 2 Explanation of *Iride Horariae Dioptricae* by Maignan (digital reconstruction by the author).

located, it changes in the course of the year indicating every day the places where the star is at its zenith. In the clocks of Trinità dei Monti and Palazzo Spada, these locations are more simply arranged along a line marked in black. The Book IV of *Perspectiva Horaria* is therefore entirely dedicated to the explanation of how to achieve these refraction sundials, but not only. Maignan focuses on the theme of the 'iris', produced by an instrument called *Iride Horariae Dioptricae*. The Father states "the reflected light shows only the whiteness that is typical of its nature. Instead, when it is refracted according to the way and the amount of refraction, becomes yellow, green, purple and blue".

The digital simulations necessarily lead back to point six of the manuscript for Villa Pamphilj (Figure 2). Fixed the planar gnomonic mirror on the windowsill, we will see an arc of a refracted circle of light, split off in the rainbow colors, intersecting the cone of light refracted with a cylinder of a transparent material (Figure 3). In short, it is once again a problem due to the conical sections, already explained by Apollonius of Perga in the second century B.C. which is no more connected to abstract geometrical objects but to astronomical phenomena. Maignan uses his devices to create sundials, but also to study the nature of light and the way it spreads around.

Fig. 3 The projection of the rainbow using the device described by Maignan (digital reconstruction by the author).

In the Book IV of *Perspectiva Horaria* the *Iride Horariae Dioptricae* is described in detail. In particular it is exposed how to make the *Iride* more brightly through the use of the transparent cylinder

> nevertheless you can obtain more vivid colors if you will make small grooves on the cylindrical surface, with equal and very frequent intervals, because the effect of the rainbow would be more beautiful if these facets [those belonging to the grooves], followed each other very quickly and progressively. In fact in this way the rainbow would be interrupted and it would be not a continuous arc but necessarily an arc with breaks. (Maignan, 1648, pp. 684-685)

In order to obtain the desired effect, therefore it will not be sufficient to smooth the external surface of the crystal cylinder, but to highlight its generatrix by engraving it with the aim of amplifying the refractive phenomenon. A variant to the device is offered by the friar in the Book III of *Perspectiva Horaria*, a section of the treatise dedicated to phenomena of reflection. In this case the device is called *Iride Horariae Catoptricae*: leaving the gnomonic planar mirror fixed on the window sill, we will obtain two distinct admirable effects using a reflective cylinder or a dioptric one, mounted on suitable supports. With the mirroring cylinder we will have a projection of a luminous arc on the hemispherical vault, if the portion of the cone of reflected light –product of the infinite generatrix of solar rays– will intercept –when reflected obliquely– an inclined mirroring cylinder according to the desired coverage area to illuminate. According to Maignan the value of *Iride Horariae Dioptricae* is not only related to scientific experiments or to the art of wonder, but also to symbolic and religious interpretation of light, as it will be explained in the conclusion of this paper.

CHARLES ROSS. TANGIBLE RAINBOW

Charles Ross is an American artist born in 1937 with a Bachelor of Arts and Mathematics. He belongs to a generation of artists defined minimalists whose works are based on natural phenomena and interaction with the landscape in order to produce precise perceptual effects. Among the artworks we can mention Larry Bell's vacuum chamber, Donald Judd's Plexiglas boxes, Robert Morris's mirrored cubes, Robert Smithson's inverted mirrored pyramid, John McCracken's fiberglass sculptures, Dan Flavin's fluorescent light bulbs, Robert Irwin's white circular aluminum discs, etc. Since 1971 Ross has been creating an earthwork known as Star Axis in New Mexico desert which is a naked eye observatory, a huge sundial and an architectonic sculpture.

The Star Tunnel is the central element of Star Axis and it is precisely aligned with the earth's axis. In 1993 he realized *Day Burns: Solstice to Equinox*, a series of canvas obtained with some magnifying lenses, capable of burning the support thanks to the exposition to sun rays. Starting from the end of the Sixties, fascinated by the refraction of light, he started a series of sculptures called Prisms. These geometric transparent objects produce effects of reflection, distortion, fragmentation and dislocation in the observer. According to Klaus Ottmann "these objects do not refract light as much as they provide an experience of relativity by containing or presenting various perspectives. Thanks to them the world can be observed simultaneously from several sides or moving at different speeds" (McEvilley, 2012, p. 17). His relation with architecture is highlighted by the installation with large-scale glass prisms which he used to project rainbows. The spectrums continuously evolve throughout the day, spreading bright white light or contracting into brilliant bands of solar color moving through the space. For example in 1996 he realized the Dwan Light Sanctuary in collaboration with the architect Laban Wingert (Figure 4). The building is provided with twenty-four large scale prisms specifically aligned with the sun to project different and precise spectrum events for every season. The inner circular white plaster space is aligned not

Fig. 4 Rainbow projections inside the Dwan Sanctuary, © 2021 Charles Ross Artists Rights Society (ARS), New York.

only with the sun, but also with the moon and stars in order to focus on specific seasonal events like winter and summer solstice, equinox, midsummer, midwinter, etc. The twenty-four prisms produce changing solar-spectrum events that circulate across the walls and floor during the day, and lunar spectrums at full moon. The relation between architecture and artwork offers not only the experience of color and light to visitors, but also the passing of time. The aim of the artist is to connect human beings with the laws of the universe. This is the reason why Ross' ultimate goal is to create a nexus of solar spectrum artworks all over the world so that the spectrum installed in one location, is always rising in another. Considering the aforementioned sundials by Maignan, some unexpected analogies arise along with the work of Ross: first, a common intention of transporting an open air phenomena –the one of rainbow– in a close chamber; second, the idea of using the solar spectrum as a sign of time passing. It is also significative the use of rainbows for Ross' Chapel. In fact, according to him, light can raise spirits regardless of a specific religion. The breakdown of light in its visible spectrum –as it was done by Newton in his experiment– also fascinated the Italian artist Marinellia Pirelli (1925-2009). Between the unrealized works of Pirelli the one called *The Skewered Butterfly* is essential for our topic: from the sketches of her project for the installation we deduce that a double rainbow, simulating the wings of an insect, would have been projected in a dark space, thanks to a light source placed on the floor and refracted by a lens designed for this purpose. Marinellia asked the light physicist Vasco Ronchi (1897-1988) to carry out a feasibility study of the prisms necessary for obtaining the effect: the answer provided by the scholar demonstrated the high costs of execution of these small and indispensable objects. At the time, there was only one company which could build these prisms: the Steg & Reuter of Bad Homburg. However, Marinellia decided to give up the realization of the lens because it seemed immoral that a work of art –or even just a piece of it– could cost more than the salary of professor

Ronchi. The fascination for luminous phenomena is reflected in a large part of the Marinellia's production. Using artificial light sources, translucent surfaces and prismatic lenses, she conceived works whose titles unequivocally demonstrate the seductive power exercised by celestial bodies: *Meteore* (1970-1972), *Room of Light* (1969-2003), *Pulsar 360°* (1970-2001), *Meteorites* (1965) and so on. "In this eighteenth-century villa, using advanced technologies, I sum up the optical games characterizing the century of lights" (Pirelli, 2003, p. 62), says Marinellia Pirelli in the occasion of the *Ombra Luce* exhibition, set up at the *Villa Menafoglio Litta Panza* in Varese in 2003. In this context it seems appropriate to mention also the work of the artist Olafur Eliasson. He uses technical devices and natural elements such as light, water and fog to transform exhibition spaces into immersive, site-specific environments. The main themes are human perception and our relationship to the natural world. Rainbows are protagonists of some of his artworks such as *Beauty* (1993): in a darkened space some nozzles are arranged in a row spraying a curtain of fine mist from the ceiling into the bright beam of a spotlight. From certain perspectives, a rainbow can be seen in the falling water; it shifts in intensity or disappears as the viewer approaches it or moves away. Another example is the installation *Round Rainbow* (2005) that shows a variety of refractive phenomena: a halogen light mounted on a tripod illuminates a plexi-torus suspended in the center of a dark room thanks to a transparent wire that allows it to rotate on the vertical axis. Varying the rotation of torus in relation to the fixed spot light it is possible to observe the projections of a circular rainbow on the walls of the room, or the shadow of the solid or a circumference of light.

ARTURO DANUSSO. THE RAINBOW OF STRUCTURES

Arturo Danusso (1880-1968) was an Italian engineer and one of the protagonists of the history of structural engineering in the 20th century. The specific history of construction is quite interesting because, before the two World Wars and then during the reconstruction, there was a prolific generation of engineers who became popular worldwide. To support this statement we can affirm that the peak of his success is well represented by the great number of Italian projects exhibited in the *Twentieth Century Engineering* show at the Museum of Modern Art in New York in 1964. The Italian structural engineering was a part of the Italian style, widely recognized thanks to the ability of producing technologically advanced objects with handcrafted characteristics. It also significant the huge number of patents acquired during the reconstruction of Italy after the Second World War: for example the one by Pier Luigi Nervi (1891-1979) for his invention of ferrocement (Iori & Poretti, 2020). In the same topic we can also mention the researches by Gustavo Colonnetti (1886-1968) on elasticity and the application of prestressed concrete. The importance of this 'Italian school' is not only connected with the realization of innovative structures –bridges, big domes, hangars, dams, skyscrapers, etc.– but also with original methods for the calculation of the projects. Colonnetti had an analytical approach, while Danusso preferred an empirical one. More in detail, Danusso developed a theory formulated at the beginning of 1800 by the physicist Dawid Brewster (1781-1868) and later applied to structural calculation by Augustin-Charles-Marie Mesnager (1862-1933). The method, called Photoelasticity, experimentally determines the stress distribution in a material under mechanical deformation. When illuminating –via a polarized light– a semi-transparent

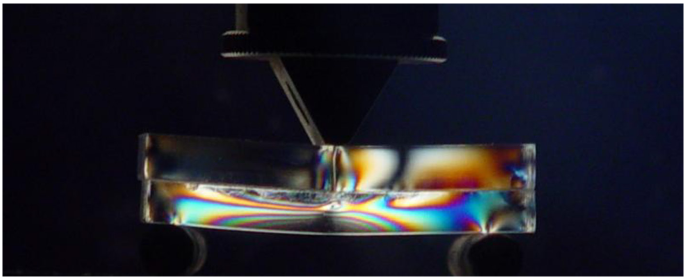

Fig. 5 Example of isocline on a prism made of plexiglass (photoelastic stress test by Elena Sperotto).

–i.e. made of polycarbonate– maquette of a structure with loads applied it is possible to observe the stress tensional states in form of colored isostatic curves (Mondina, 1958) (Figure 5). Danusso preferred this optical approach to the analytical one because he thought that mathematical methods at that time couldn't evaluate all the forces in a reinforced concrete structure. He founded the Prove modelli e costruzioni laboratory at the Politecnico di Milano in 1931 and ISMES –Istituto Sperimentale Modelli e Strutture– in Bergamo in 1951. Until the seventies these laboratories became a reference for structural analysis worldwide. In addition to the technical applications of Photoelasticity, it is interesting to consider the role of light in this approach explained by Danusso

> this method uses the most subtle and attentive of observers, giving it the task of inspecting the stress tensor in every point. The structure is represented by a transparent model: the light polarized ray following our orders, penetrates it; it puts in contact for a moment its own vitality with the most intimate parts of model, tormented by efforts comparable to those that the real construction will have to sustain; then the ray goes out and loyally describes on the screen, with an elegant succession of shades and hues, everything that he has seen. (1932, p. 206)

This passage highlights a humanistic approach to science. In fact Danusso like all of his colleagues at that time, was influenced by the neo idealistic philosophy by Benedetto Croce. He was also a fervent catholic and in his lectures he usually refers to the physical order as an analog mirror of the moral order outlining suggestive analogies between mechanics and life (Desideri et al., 2012).

CONCLUSIONS

The essential history of rainbow described at the beginning highlights the great curiosity for this meteorologic phenomenon, but also the complexity of its explanation considering the relation with the nature of light and to the refraction law. We haven't mentioned the great fascination for rainbow reflected by mythological tales and literal works during the centuries. We can observe that the historical experiment and researches about light have a strict relation with the concept of projection before this method became a form of geometrical representation. The relation between light and optics is also highlighted by a similar physical behavior of light and visual rays, probably is not for chance that the studies about rainbow have been geometrically carried out in combination with sight perception.

The investigations in this field start to become artwork –and no more experiments– in our contemporary time reproducing a physical phenomenon thanks to the control of reflection and refraction laws. The three protagonists of this story, even if belonging to different historical period and with completely different personal interests, are gathered by the unveiling role of light. It looks like a religious man, an artist and an engineer recognized the value of light as a primordial element and a spiritual representation. Another monk belonging to the order of Minims, father Marin Mersenne, quoting San Paolo, affirms "everything that appears is light" but "as our eyes are too weak to bear its glow, colors are offered to us to appreciate its perfection" (Beaulieu & De Waard, 1933, p. 451). This affirmation highlights the divine nature of light and the inability of man to tolerate its image if not broken down in its spectrum of color.

We can state that light –and rainbow– is one of the natural phenomena that mostly attracted scientists and artists, marking in this way the short distance between these two areas of research and expression. In the Greek mythology the goddess Iride was born from the relationship between Taumante –son of Earth and Sea– and Elettra – daughter of Ocean. Iride is symbolically considered the intermediary, the one who is able to connect Night and Day, Earth and Sky, Gods and man.

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