Check for updates

The Kaleidoscopic Image as an Intersection Between Art and Science: From Microscopic Forms to Cosmological Models

9

Mari Nieves Vergara

From this I reach what I might call a philosophy; at any rate it is a constant idea of mine; that behind the cotton wool is hidden a pattern; that we –I mean all human beings– are connected with this; that the whole world is a work of art; that we are parts of the work of art. […] Mine is that there is a pattern hid behind the cotton wool.

Virginia Woolf [1]

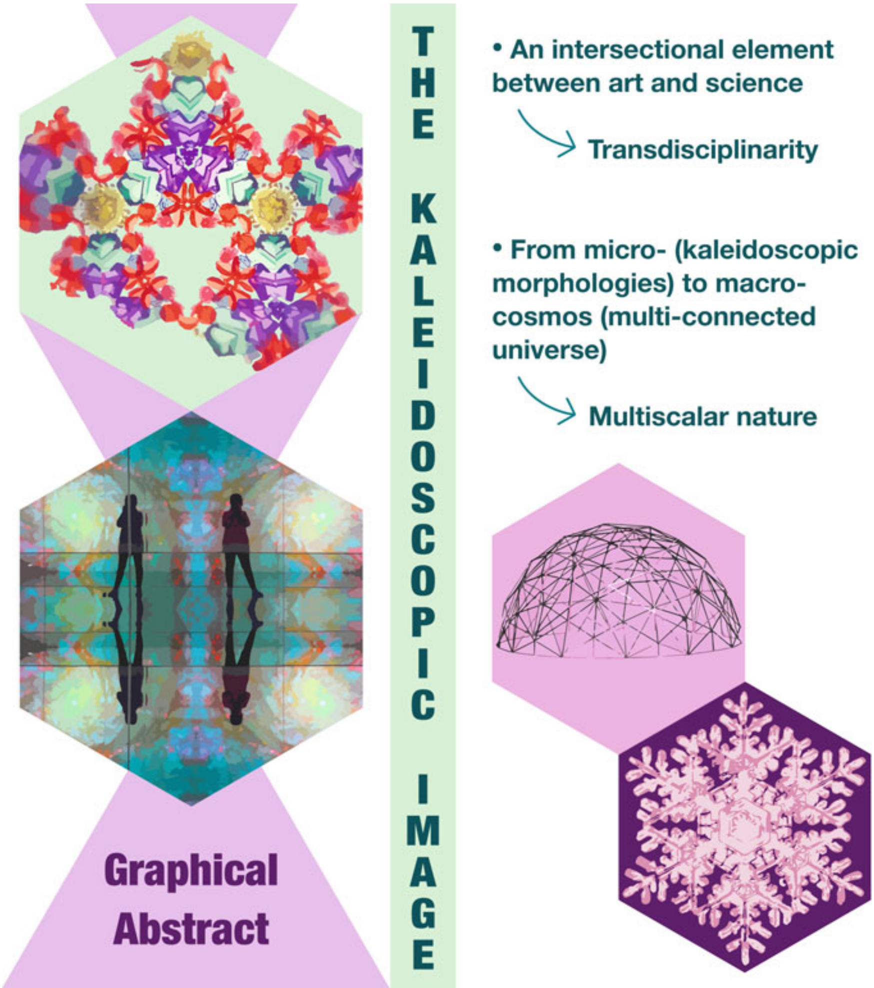
Summary

This chapter deepens on the structural connections and the visual correspondence between the morphology of different forms from nature and cosmological models or representations of the universe under the denomination of being kaleidoscopic. After a brief introduction on the kaleidoscopic issue from different aspects (Sect. "1"), its relation to fractal geometry, i.e., the image constructed by the kaleidoscope, will be considered an intersectional element between the fields of art and science. Within this platform, some cases will be presented, going from micro- to macro-cosmos. Microscopic forms such as diatoms, snowflakes, viruses, or fullerenes (Sects. "2", "3", and "4"), along with possible topologies and other representations of the universe (Sect. "5"), are categorized as kaleidoscopic. The connecting visual motif that will join all of these examples is a kaleidoscopic image. The comparison based on visual correspondence to study issues commonly related to scientific disciplines is an

M. N. Vergara (✉)
Department of Contemporary Art History, Fine Arts School, Complutense University of Madrid, C/ Pintor El Greco 2, 28040 Madrid, Spain

N. Rezaei (ed.), *Transdisciplinarity*, Integrated Science 5,
https://doi.org/10.1007/978-3-030-94651-7_9

important aspect for artistic research, concretely for the visual studies area. This transdisciplinary approach includes recognizing particularly hybrid cases associated with kaleidoscopic configurations, like protein design. It concludes that the kaleidoscopic image manifests a multiscale nature (Sect. "6") since it is a configuration present from microscopic forms to the representations of a multi-connected universe.



Kaleidoscopic nature.

The code of this chapter is 01001011 01100001 01101100 01100101 01101001 01100100 01101111 01110011 01100011 01101111 01110000 01100101.

1 Introduction: The Kaleidoscopic Image as an Intersectional Element Between Art and Science

Virginia Woolf thought that behind the cotton wool, there is a hidden pattern, that everything is part of a connected work of art, which is the entire world [1]. Certainly, she *visualized the invisible* thanks to the creative intuition of recognizing new patterns, those artistic processes stated by the artist Agnes Denes in her *Manifesto*, as a way of questioning the accepted reality [2]. Surprisingly, Woolf's literary work resulted in being multifractal [3]. Accordingly, there is a hidden pattern *behind* her writing, which at the same time is related to the kaleidoscopic experience [4],[1] forming a correspondence between artistic work and scientific discovery.

In the Renaissance, art and science were highly related disciplines since individuals looked at knowledge as a whole. Nevertheless, from the seventeenth century, the cosmological view of knowledge has progressively partitioned into increasingly specialized disciplines [5]. This historical fact has provided more rigorous knowledge. However, the connection between disciplines and the findings that could have appeared from their interaction had been lost.[2] Nowadays, after some collaborative work between different areas within the last two centuries, a new paradigm in the relationship between art and science related to the kaleidoscopic nature is emerging after being essentially separated disciplines [6].

This chapter shows the research on some kaleidoscopic images from the morphology of microscopic forms to the structural and conceptual connections with multi-connected cosmological models and representations of the universe. In this regard, some cases will be presented, going from micro- to macro-cosmos. The study of kaleidoscopic images is of high importance for visual studies in artistic research since the kaleidoscopic quality appears to play an important role as an intersectional element between the fields of art and science. In this line, a recently published article [7] presented the results of a study on the kaleidoscopic condition of quantum behavior and the multiverse theory. It reflected on Borges' literary work and displayed an artistic research experiment reflecting on phenomena such as interference or the double-slit experiment was pointed out by Vergara [7]. By the end of this chapter, it will be noticed how the morphology in nature and other theories or representations from the scientific field are highly interrelated to the kaleidoscopic issue, which opens a transdisciplinary scope regarding the collaboration between the fields of art and science.

The kaleidoscope is an optical device invented in 1815 by physicist David Brewster. Although nowadays it is considered as a toy, its invention was aiming to be a medium with practical application in the work of designers and artists. In this way, it promoted an industrial paradigm that started at the beginning of the

[1] Many literary works that have been categorised as kaleidoscopic and usually inscribed within the stream of consciousness literary style—works such as the *Ulysses* (James Joyce) or *Hopscotch* (Julio Cortázar)—present a multifractal pattern as in Woolf's narrative [3,4].

[2] There are some cases in which art, science, and other disciplines were collaborating, although it was not the most common line to follow, almost not like in the Renaissance period.

nineteenth century, with the scientific purpose of revealing and democratize the techniques of the illusion [8, 9]. In Brewster's words, the kaleidoscope "*will create, in a single hour, what a thousand artists could not invent in the course of a year […] with a corresponding beauty and precision*" [10]. Previous to the kaleidoscope's invention, we find many geometrical decorative patterns from different cultures that present a kaleidoscopic condition. This device has influenced many artists, writers, and scientists from the nineteenth century to the present day. It has held a distinguished position with the first abstract representations at the beginning of the twentieth century [9], as well as due to its presence as a primary connective structure in Agnes Denes' work during the pre-internet era [11].

Nowadays, there are a wide variety of kaleidoscopes. The kaleidoscopic image can show colorful images and abstract shapes (Fig. 1a) when the tube has color pieces on the opposite side of the eye viewer hole. One can consider this kaleidoscope as a classic kaleidoscope. When it shows a kaleidoscopically fragmented reality, where mirrors reflect surrounding elements, it is called a telescopic kaleidoscope, also known as teleidoscope. When the term "kaleidoscopic image" is referred to, it could indicate a kaleidoscopic shape or the item's kaleidoscopic condition due to its similarity with this image. At the same time, it should be specified that the kaleidoscope would be the one constituted by a cylindrical tube with three mirrors inside the device, placed forming the shape of an equilateral triangle. Therefore, the structure that organizes the image through the kaleidoscope will be visually like an isometric grid that will remain denominated as a kaleidoscopic structure (Fig. 1b). This structure is invisible to the eye but remains as the structural component that organizes the image kaleidoscopically.

Throughout this chapter, the results presented mainly come from the kaleidoscopic cases' visual condition, except for Sect. "5.1", in which some theoretical issues are involved. Hence, most of the results will refer to the kaleidoscopic configuration in microscopic forms or cosmologies that belong to the scientific research field, aiming to categorize these different cases as "kaleidoscopic" depending on their visual correlation with the mentioned image. In some cases, also the creative motivation would be associated with the production of kaleidoscopic compositions, as will be seen in the kaleidoscopic arrangements that are presented in Sect. "2". Also, hybrid examples of transdisciplinarity between scientific research and art will be presented, such as the design of proteins or Buckminster Fuller's influence in discovering viruses' icosahedral structure in Sects. "3" and "4", respectively.

The high presence of kaleidoscopic configurations in nature is principally due to the connection between fractal geometry and the kaleidoscopic image. Since the view of kaleidoscopic images can be defined as a virtually infinite and repetitive geometric vision, it shares a visual correspondence with the geometry of nature, presenting a fractal condition. The most relevant properties of fractal geometry are also related to the kaleidoscopic image and structure. These properties are iteration —infinite repetition of an element—self-similarity—he different constituent parts appear to be like the whole—and scale invariance—fractal structures do not change, independently from the scale in which they are viewed [12, 13]. Therefore, it is the reason why many examples from the natural world could be categorized as

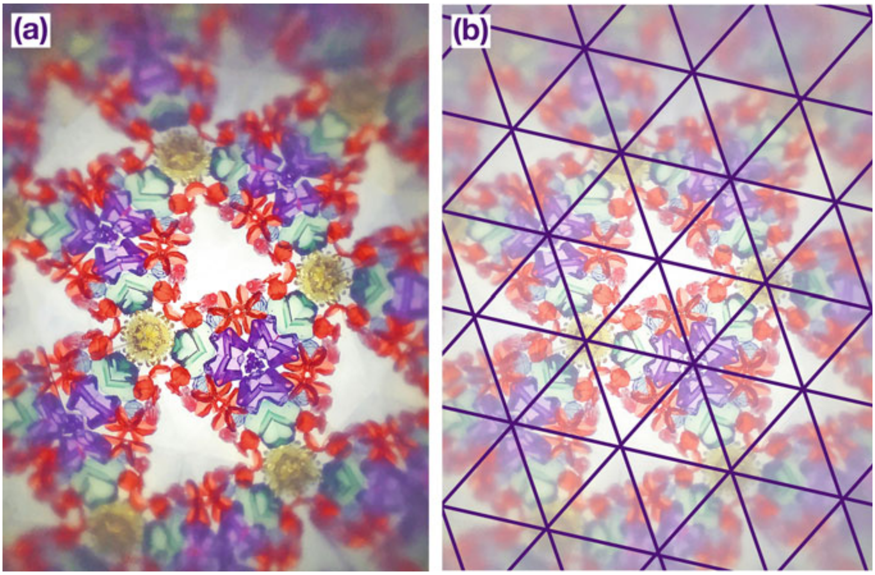


Fig. 1 Difference between "kaleidoscopic image" and "kaleidoscopic structure": **a** Kaleidoscopic image that can be seen through the classic kaleidoscope, in which various types of kaleidoscopic shapes are observed; **b** Kaleidoscopic structure is the organizing structure of the kaleidoscopic image, in most of the cases an isometric grid. (Photo by Vergara, 2019)

kaleidoscopic. However, this geometry does not explain all of the cases proposed within the chapter, such as creating the universe's mirrored representations.

In Sect. "2", examples of microscopic forms like diatoms or snowflakes will be presented, while in Sect. "3", the structure of viruses is studied regarding Buckminster Fuller's architecture influence. In Sect. "4", the morphology and the innovative case of designing new proteins will be introduced concerning the kaleidoscopic condition. Finally, Sect. "5" contains both the kaleidoscopic cosmological models and other kaleidoscopic representations of the universe in astronomical contexts, displaying the kaleidoscopic image as the main motif in this regard.

Please note that the shape of microscopic forms are more similar to the images that can be seen through the classic kaleidoscope, while the vision we might have of a kaleidoscopic universe would be related to the teleidoscopic kaleidoscope view.

2 The Structure of Microscopic Organisms and the Snowflakes

There are many cases in which forms of nature present fractal geometry and, at the same time, show a significant kaleidoscopic nature. About the structure of complex microscopic organisms, also including the radiolarians that Ernst Haeckel illustrated

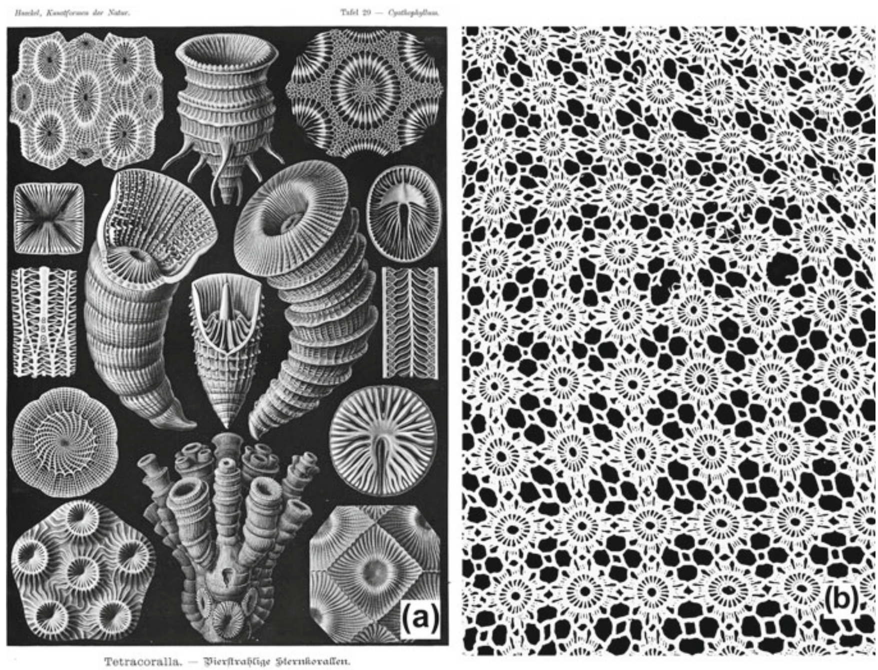


Fig. 2 Visual similarity between the images: **a** Ernst Haeckel, Tetracoralla in *Kunstformen der natur*, 1904 (Adapted from www.biolib.de GNU Free Document License); **b** Crocheted kaleidoscopic pattern. (Photo by Vergara, 2017)

at the end of the nineteenth century, Frank Wilczek specifies that they "*embody the Platonic solids*" referring to their shape. Also, he mentions that the radiolarians are very primitive organisms. For example, the oldest fossils that have been found corresponding to radiolarians that still inhabit our oceans [14]. Ernst Haeckel was the naturalist who created the term Ecology [15], representing in *Kunstformen der Natur*, published in 1904, different organisms that in most of the cases presented radial symmetry. For this reason, many of his engravings are kaleidoscopic and even visually reminiscent of the crocheted kaleidoscopic pattern [6]. This issue can be seen in the comparison of Figs. 2 and 3, displaying the visual similarity between the tetracoralla structure in Haeckel's illustration (Fig. 2a) and the mentioned crocheted pattern (Fig. 2b).

From a biological perspective, the most developed species, such as humans, have evolved to bilateral symmetry. The presence of the radial structure that we can see in kaleidoscopic compositions or the radiolarians mentioned above are usually related to very primitive organisms that have not undergone further evolutionary development [16]. Even though it is considered that the radial symmetry of an organism refers to its primitive condition and, in consequence, is an indicator of being less advanced, this perspective is currently being revised. Recent research indicates that the condition to evolve toward bilateral symmetry depends on the movement of organisms, as well as their relationship with conditions such as gravity [17]. For example, sessile filter-feeding organisms commonly live in a marine environment where gravity is less important, and since they do not require an active displacement like other animals, they did not evolve toward a bilateral geometry model. Considering the radial symmetry of many plants, it is observed that they do not move either and lack a nervous system so that it would be the same case in different conditions. As seen in Fig. 2, most of the organisms illustrated by Haeckel presented radial symmetry, including radiolarians, diatoms, jellyfish, or echinoderms. All of them present a kaleidoscopic morphology and, in the same way, also Haeckel's illustrations do.

In Haeckel's scientific illustration, we commonly find the diatoms, a type of microalgae that usually present a kaleidoscopic structure. If the diatom's shape is not kaleidoscopic, they are visually similar to the small color pieces found inside the classic kaleidoscope tube. The nineteenth century witnessed many kaleidoscopic examples created by scientists from the Victorian era. They were dedicated to the diatom art, almost coinciding in time with the kaleidoscope's invention by David Brewster in 1815. These scientists organized different shapes that presented these microscopic organisms in a microscopic plate to create kaleidoscopic compositions thanks to the diatom arrangement. Klaus Kemp, known as a diatomist, still makes these compositions at present. He was very interested in the diatom arrangement, so he investigated the method to make it. According to Kemp's declaration in the online short documentary on Kemp's work directed by Mathew Killip, *The diatomist*, the Victorian scientists did not leave any clue to discover how to keep diatoms fixed when organizing these compositions [18]. As it is evident in

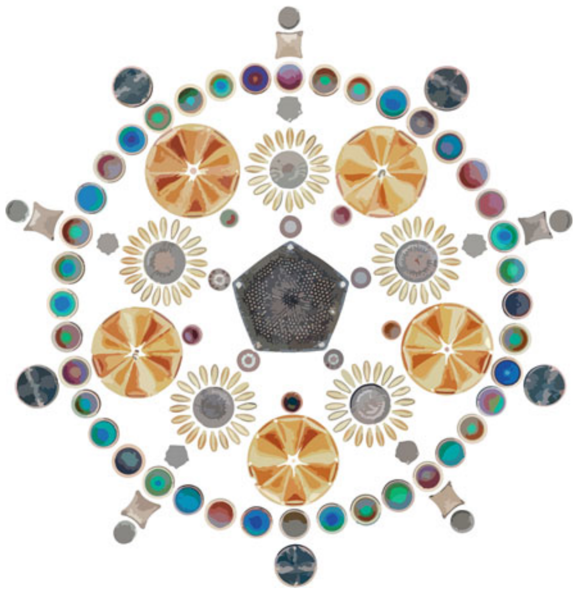


Fig. 3 Illustration based on Johann Diedrich Möller's diatom arrangement displaying the kaleidoscopic organization that the diatoms presented in the nineteenth century. Each item is a diatom. (Made by Vergara, 2020)

the images produced by Kemp or other examples from the nineteenth century, like the high number of images composed by Johann Diedrich Möller[3] (Fig. 3), the arrangement of diatoms into a kaleidoscopic manner is very interesting, considering that the diatoms also present a kaleidoscopic shape on their morphology. Certainly, the visual equivalence between these diatom art images and the vision through the kaleidoscope is very high. Considering that the Victorian scientists started to produce these arrangements after the invention of the kaleidoscope, surely, they received the influence of this device to make their microscopic kaleidoscopic images.

Not only were diatoms arranged kaleidoscopically, but also the snowflakes had been organized in this way by Wilson Alwyn Bentley (Fig. 4a), who made his first snowflake photomicrograph in 1885 [19]. Together with William H. Humphreys, he is the author of a 1931 publication, where a total of 2453 snowflakes are collected. Each snowflake is totally different since the possibility of variations is infinite [20]. He is mostly recognized for capturing different designs, having photographed around five thousand snowflakes throughout his life [19].

Every snowflake within the arranged composition presents a kaleidoscopic shape based on a repetitive fractal pattern similar to the Koch curve due to the snow-crystal radial symmetry with the hexagon as the geometrical basis, as it happens in kaleidoscopic structure. The kaleidoscopic snowflakes arrangement is organized over the isometric grid (Fig. 4b), which was present inside the kaleidoscope (Fig. 1b). At the same time, each one of the snowflakes presents a hexagonal symmetry individually, so the image results to be kaleidoscopic in a double sense.

Like the image constructed by the kaleidoscope, Bentley stated that there is no repetition in the snowflakes' design. That was why he started taking photomicrographs since he thought that the beauty of snowflakes was forever lost without any record [19].

Also, Laure Albin Guillot, born after Bentley, made great artistic contributions in microphotography at the beginning of the twentieth century. As in the case of Bentley, her artistic production had the purpose of crossing borders between art and science, naming their photomicrographs as decorative micrographies instead of microphotography. Furthermore, the results of many of her micrographs are similar to some vortographies took through the vortoscope by Alvin Langdon Coburn. He invented the vortoscope, an optical device that was very similar to the kaleidoscope [9]. What differentiates Albin Guillot from the diatom art compositions already presented or Bentley's microphotography is her intentionality since her purpose was fully artistic and decorative—even though she used elements that traditionally belonged to the scientific field. Among the elements that appear in the

[3] In this case, the figure included that shows the structural disposition of the diatom arrangement made by Möller present a pentagonal organization to continue the structure marked by the central item, not a hexagonal one as it was mentioned in relation to the kaleidoscope. Nonetheless, the kaleidoscopic sense remains present in the composition. Anyway, Möller and other authors have a large production with cases that correspond to hexagonal symmetry as it happens in the most common kaleidoscopic structure.

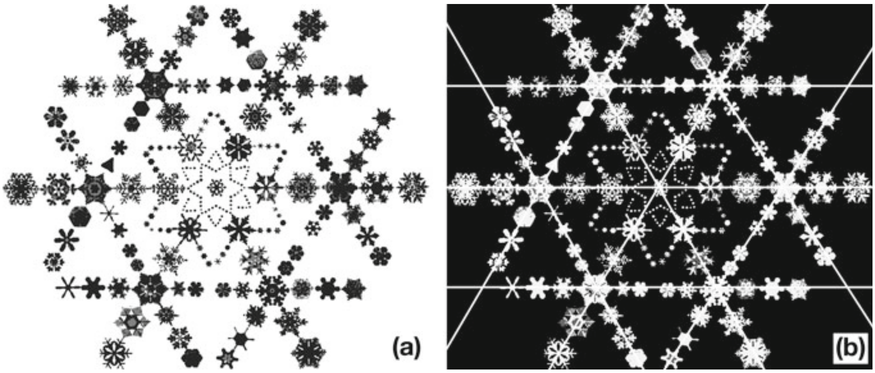


Fig. 4 Illustrations based on a kaleidoscopic composition produced by Wilson Alwyn Bentley: **a** The illustration displays the position of the arranged snowflakes; **b** In the illustration, the kaleidoscopic structure that organizes the composition over an isometric grid is indicated. (Made by Vergara, 2020)

microphotographs made by Albin Guillot, she precisely used the diatoms. Nevertheless, she did not compose the popular kaleidoscopic compositions from nineteenth-century diatom art. Instead, she was interested in showing the kaleidoscopic structure of the diatoms.

In addition to microphotography, Albin Guillot also developed other types of photographic work. About the kaleidoscopic image, her photograph entitled *Les tierces alternées* is very notable. It consists of a kaleidoscopic composition in which multiple repeated hands playing the piano could be seen. One more time, this photograph also remembers the vortographs made by Coburn in the first two decades of the twentieth century [9]. She made it at the end of her career, in 1948, to illustrate *Préludes*, a musical composition by Claude Debussy [21].

3 The Kaleidoscopic Geodesic Dome Designed by Buckminster Fuller and the Morphology of Microscopic Forms Like Viruses or Fullerenes

Buckminster Fuller was the architect who designed and built the geodesic dome in the Black Mountain College (North Carolina) in 1948. It is highly noted that Fuller built the geodesic dome for the first time in Black Mountain College, an idealistic experimental faculty to study arts with a transdisciplinary approach. Figures such as John Dewey, Albert Einstein, or Carl Gustav Jung composed its advisory council, among others [22]. Concerning the procedures used in Black Mountain, Josef Albers—the artist who established a teaching curriculum in 1933—said that *"works of art"* were experiments to gather experience [23]. In Black Mountain, we find kaleidoscopic patterns in artworks made by Ruth Asawa, who studied at Black Mountain, and Anni Albers, the weaving and art teacher. Fuller's geodesic dome presents a kaleidoscopic structure since it is generated by the repetition of equilateral triangles that generate an icosahedron. Regarding this polyhedron, Fuller projected the vertexes to appear as a circumscribed sphere [24].

Regarding Fuller's geodesic dome, its geometric similarity with Islamic art should be noted. Although it does not present any decorative pattern, if a geodesic dome is compared to the Islamic architecture domes, there is a structural correspondence between these two cases. For example, William Harvey's drawings on the structure of the Alhambra's domes are very similar to the geodesic structure. In this regard, Fuller thought that the tetrahedron was the most suitable polyhedron to measured volume instead of the cube: "*he felt that the very nature of space requires the tetrahedron to supplant the cube as the unit of space*" [24]. Certainly, the tetrahedron has the property of covering the entire space through various combinations, closer to the kaleidoscopic structure, since each one of its faces is an equilateral triangle. At the same time, the tetrahedron presents a better geometrical correspondence for the stacking issue in regular polyhedral configurations, for example, regarding the combinations with the octahedron and the icosahedron, than the cube.

Many viruses present icosahedral symmetry concerning their structure, which is also present in Fuller's geodesic dome [24]. It is notable how Fuller's work finally inspired scientists from 1962 when Caspar and Klug published their research on regular viruses' capsids, inspired both in polyhedral figures and the geodesic dome [25]. In their publication, there are images of the geodesic dome and the icosahedral grid that was also the structural pattern in the kaleidoscope, viewed as a plain isometric grid, concretely in the section dedicated to icosahedral viruses [25]. The arranging consisted of icosahedral capsids, which are quite kaleidoscopic concerning their structure (Figs. 5, 6, 7 and 8 in the publication by Caspar and Klug [25]). Afterward, they triangulated the sphere to visualize the shape of viruses' capsids, starting from the isometric grid, designated as "*equilateral-triangular plane net*" within the article, inspired by Fuller's architectural work. They even included a geodesic dome photograph (Fig. 5 in the publication by Caspar and Klug [25]). Recent research in this field showed that Fuller's work still serves as inspiration, considering the previous work by Caspar and Klug, among other authors [26].

Along with the geodesic dome's geometry, we also find an allotropic form of carbon molecule with a truncated icosahedral structure named "Buckminsterfullerene" to honor Buckminster Fuller, which was discovered serendipitously [27]. Fullerenes could work as capsids for other molecules and atoms and were discovered by Kroto et al. in 1985 [28]. The fullerene is formed into a lattice of hexagons and pentagons that seems like a soccer ball [24]. Certainly, these geometrical patterns are particularly kaleidoscopic since the same cell is repeated all along with the "spherical" shape. Carbon appears under different allotropes because the atoms are born together to form different networks [24]. All of these allotropic forms are quite kaleidoscopic as well. In line with the structure of viruses and fullerenes, proteins also present a kaleidoscopic configuration, as discussed in detail in the next section.

These carbon allotropic structures appear in nature, presenting different types of kaleidoscopic grids. Recently, complex fullerenes found in outer space have become the basis for a theory that proposes fullerenes C_{60} found in meteorites to be responsible for carrying extraterrestrial substances that might have started life on the Earth [29]. What could make it possible is fundamentally due to the fullerene configuration as a cage, which would encapsulate atoms or molecules inside. In this sense, it is worth mentioning that Buckminster Fuller thought of possible connections between polyhedral configurations and nature, speculating that "*the icosahedron is immersed within the harmony of the spheres and serves as the origin of life itself*" [24]. If the theory mentioned above were finally proved, Fuller's testimony would acquire an exceptional meaning. In the same way, to conclude this section, Fuller's work was very important not only for architectural and artistic purposes but also for science development concerning viruses' structure and allotropes of carbon, which is very significant regarding transdisciplinary approaches.

4 The Kaleidoscopic Image and the Protein Structure: Designing New Conformations in Protein Folding

Regarding the relation in which kaleidoscopic image and visual arts were involved as interrelated fields of study in the twentieth century, many artists entered the scientific sphere, getting inspiration from discoveries and innovations related to this field. However, it should be noted that artists were preeminent in showing fractal geometry in their artworks many years before fractal geometry was discovered [12]. Throughout the twentieth century, the relationship between science and art has evolved from merely inspiration or scientific photography and illustration to a deeper connection between these areas. Nowadays, the connection between art and science has become progressively more transdisciplinary. For example, this relationship can be found in protein folding, the art of designing new models of proteins with scientific purposes, applying the artistic composition in the kaleidoscopic structure of proteins to create new configurations that did not exist before.

The protein folding and its relation to kaleidoscopic configurations are clear from a visual viewpoint. In 2016, the research on proteins developed by Jacob B. Bale, David Baker, and other authors was published in the journal *Science* [30]. The new designs of proteins, whose application is principally addressed to the field of health and medical issues, can allow the treatment of illnesses or genetic disorders, to separate compounds like gluten from food, etc. For the moment, their functions are simpler than those since the research field of protein folding is almost unexplored considering the possibilities that the design of proteins could offer. Along with this field's development, immeasurable new molecules could be designed like the infinite images that appear within the kaleidoscope. This way, the combinations in protein folding would be related to molecules with unimaginable purposes that do not exist at present. According to Baker, the director of The Institute for Protein Design, usually, the new proteins findings refer to proteins already present in nature and, consequently, with no design involved, which is very unsatisfying. The proteins from nature are a bit limited compared to the "protein universe" that could be newly designed. In other words, he refers to *"all the proteins that could possibly be* *made with varying combinations of amino acids"* [31], which remembers to the infinite condition of the kaleidoscope.

As we see, the design of proteins is moving beyond a transdisciplinary paradigm with a revolutionary approach. The designs are multiple like it happens in the kaleidoscopic device, characteristic for presenting the same structure displayed in the planar representation of an icosahedral surface like an isometric grid. This representation is similar to the mentioned geodesic dome and, at the same time, served as a structure in the illustration for the kaleidoscopic cover in the journal *Science* that was published on July 22 in 2016, Vol. 353, issue 6297. This image, named *Self-assembling protein cages*, was computationally designed by the science illustrator Valerie Altounian [32]. It represents a kaleidoscope that aims to illustrate the protein folding issue in relation to the articles published by Bale et al. [30] and Robert F. Service [33], respectively, named as "Accurate design of megadalton-scale two-component icosahedral protein complexes" and "Rules of the game." Visually, the image contains *"120-subunit icosahedral protein nanoparticles (yellow, dimers; blue: trimers; green, pentamers)"* for creating a kaleidoscopic array [32], based on protein models provided by Bale [34]. Therefore, the colored pieces that are *inside the kaleidoscope* that is displayed on the cover, at the same time, create a pattern that visually refers to the proteins. At the same time, the kaleidoscopic image on the cover is distinguishing proteins by colors, aiming to represent the nanoparticles that form the different protein cages. Compared to the photomicrographs from the article by Bale et al. [30], where most of the proteins present an icosahedral axis, proteins and both kaleidoscopic image and structure displayed in the cover are very similar from a visual viewpoint.

According to the *Science* statement on the cover, the combination of pieces within *"these shapes result in a kaleidoscopic array of self-assembling protein complexes, each of which rivals the size of a small viral capsid"* [34]. These proteins, assembled in a kaleidoscopic way, *"could form the basis for a new generation of biomolecular machines"* with customizable applications [34]. In consequence, the design of kaleidoscopic as the changing shapes within the kaleidoscope opens the transdisciplinary paradigm called *the protein folding revolution*. There is an interesting explicative video where Altounian's kaleidoscopic illustration is animated [35]. This way, the vision of a kaleidoscopic image is also defined as its property of being a continuously changing shape.

5 The Presence of Kaleidoscopic Image as the Main Motif in Cosmological Models and Other Representations of the Universe

The astronomical community is interested in the kaleidoscopic approach, both regarding cosmology and the universe's representation. In fields such as Astrophysics or Cosmology, it has been found how there is a kaleidoscopic representation system to visualize the universe in this way.

5.1 Kaleidoscopic Cosmological Models: The Geometry of Finite Topologies that are Visually Infinite

Similar to the truncated icosahedron shape of the fullerene or other examples seen above, within this section, we principally refer to another Platonic solid: the dodecahedron. This regular polyhedron has regular pentagons as faces instead of equilateral triangles, as in the case of the icosahedron, but it could be considered as kaleidoscopic for being fully composed by the conjunction of pentagons. In 2003, based on the background microwave radiation, an article was published indicating that the universe could take the form of the dodecahedral space, based on Poincaré's geometry in contrast with the standard cosmological model of an infinite flat universe. This cosmological model, proposed by Luminet et al. [36], presents a multi-connected condition, which is very close to the kaleidoscopic nature.

This theory proposes a visually infinite universe within spatial boundaries. Then, it would be like being inside an infinite space, as it would happen if we could enter as observers in between the mirrors of a kaleidoscopic finite space. In fact, the first author of the study, the astrophysicist Jean-Pierre Luminet, refers to the kaleidoscopic nature of the space to introduce the dodecahedral universe issue in one of his publications, in the section entitled as *The Hall of Mirrors*. Concretely, he introduces the multi-connected topology of Poincaré's dodecahedral space and other related models, referring to a cubic one to introduce this issue. To do this, he uses the metaphor of a room entirely covered by mirrors *"on all six surfaces"* where *"a kaleidoscopic effect will be produced"* [37]. Within this type of multi-connected topology, *"any object in space may possess several copies of itself"* [37], as it happens in the kaleidoscopic image. According to this theory, there would be a possibility of being into a kaleidoscopic universe. Luminet explains that cosmic space could immerse us in that same illusion without the presence of walls or mirrors. In this case, the kaleidoscopic nature would be generated by the *"multiplication of the light ray trajectories following the folds of a wraparound universe"* [37]. Thus, he refers that we could be *"in a physical space which is closed, small and multiple-connected"* and still being able to see a larger observed space *"like a part of a tessellation made of repetitions"* [37], falling into an illusion even though our view would come from the mirrored repetition of a "fundamental cell" where the observer is located [37]. This description is extremely interesting dealing with the kaleidoscope, a very small, closed, and physical space that visually generates an infinite virtual space. While the image that is seen through the kaleidoscope could be categorized as fictional, the observer is involved like it were a real view, which is effectively produced by the repetition of an element that comes from reality [7, 11]. The reference to the tessellation is very notable as well since the kaleidoscope displays an image that is very similar to the patterns from decorative arts, as was introduced in Sect. "1".

The reason for presenting this theory is that it is quite significant for visual studies and, obviously, about the kaleidoscopic nature. Regarding the existence of a kaleidoscopic dodecahedral universe, it is worth noting that Plato referred to the dodecahedron as the form that contains the whole universe, while the other four Platonic solids correspond to the four elements: water, air, earth, and fire [38].

In 1900, the architect Eugène Hénard designed *The Hall of Illusions* [39], which was the first surrounding kaleidoscopic space [9]. The same year, the astronomer and physicist Karl Schwarzchild, suggested the existence of a kaleidoscopic cosmology, characteristic for referring to a finite space with boundaries that at the same time generated the illusion of infinity [40]. In this way, Schwarzchild refers to a kaleidoscopic cubic space made of identical repetitions of the Milky Way galaxy, tilling an infinite three-dimensional space that remembers to Escher's creations like *Cubic Space Division (Cubic Space Filling)*: *"One could imagine that as a result of enormously extended astronomical experience, the entire universe consists of countless identical copies of our Milky Way, that the infinite space can be partitioned into cubes each containing an identical copy of our Milky Way. Would we really cling on to the assumption of infinitely many identical repetitions of the same world? We would be much happier with the view that these repetitions are illusory, that in reality space has peculiar connection properties so that if we leave any one cube through a side, then we immediately reenter it through the opposite side"* [40].

Escher's images are intended to suggest the coexistence of simultaneous worlds [41], so it is not strange to find a correspondence between his work and Schwarzschild's statement. Together with Escher, both Hénard's *Hall of Illusions* and the dodecahedral universe theory are analogous to the condition expressed by Schwarzschild. Indeed, Luminet has found inspiration concerning this quote for the dodecahedral universe theory [36], as shown in an older publication by Luminet and Roukema [42]. In the end, all of these references reflect visually infinite spaces, although they are finite and present boundaries, which correspond with the kaleidoscopic nature. As Schwarzchild stated within his proposal, to cross through one of the boundaries would lead the subject to reenter into the same space from the opposite side. In this line, it is essential to refer to Jeff Weeks' work, the second author of the dodecahedral cosmological model [36], whose dedication is geometric topology and cosmology.

Although at present it is not known which one is the cosmological model that our universe presents—Weeks mentions the fact that the universe could be finite or infinite—some proposals for visualizing these cosmological models have been considered [43]. Interestingly, Weeks refers to the multiple copies of the Milky Way, which in a certain way could work as a reminiscence of Schwarzchild's suggestion. Weeks goes further and refers to the enormous complexity of this matter. When the universe is observed, the speed of light factor should be considered. On the opposite case of the identical images that could be seen through the kaleidoscope, within a kaleidoscopic universe, the observer will be watching not the present but the past in any direction [43].

In Schwarzchild's line, Weeks introduces that one of the possibilities is to be part of a finite universe with boundaries that at the same time could be visually infinite [43]. This is that something could be infinite and, at the same time, present a boundary as it happens in the kaleidoscope. Once again, this formulation coincides with the hypothesis presented on the dodecahedral universe [36]. To visualize this type of spaces, among other applications, Weeks designed the flight simulator *Curved Spaces* [44, 45], whose software—which is available for computers and mobile phones—allows the subject to interact within a space where different geometric topologies of multi-connected universes can be explored like a multiverse. These universes are visually infinite, although they present boundaries, so the repetition of the same cell generates the kaleidoscopic image. The options for visualizing the universe in this way correspond to flat, hyperbolic or spherical topologies. It also allows seeing a kaleidoscopic view with no walls, having the Earth, a galaxy, or a gyroscope as the main repetitive motif, or to close the walls of the room to get an understanding of the space morphology. The person can interact within the walls, so the structure could be seen with geometric lines that divide the different kaleidoscopic cells.

Curved spaces software allows the visualization of many geometric models with the kaleidoscopic universe as the central motif. For example, the model of the dodecahedral universe and other topologies can be visualized as well. Although the geometrical models are different, in general, all of them share the same characteristics of being multi-connected and visually infinite cosmologies. Together with the mentioned issue, there is the possibility of being inside mirrored and non-mirrored universes. About the kaleidoscopic image, the visualization of mirrored geometries is more suitable for being kaleidoscopic than the non-mirrored ones. In this way, the subjects could be participants of their juxtaposition of ubiquities within the self [7]. It is allowed thanks to a spaceship view that indicates the position where the observer is situated, which corresponds to multiple views of the kaleidoscopic universe where the subject is repeated.

In addition to the aforementioned *Curved Spaces*, there are two applications designed by Weeks: *Kaleidopaint* [46, 47] and *Kaleidotile* [48, 49]. As it is indicated in the title, *Kaleidopaint* allows the subject to produce kaleidoscopic designs similar to those that could be found in a decorative pattern. Thus, when something is painted, the pattern becomes simultaneously painted within the rest of the composition kaleidoscopically. *Kaleidotile* makes it possible to visualize kaleidoscopic designs on polyhedral shapes and Euclidean or hyperbolic planes, as well as the transition between different polyhedra—for example, to transform a dodecahedron into an icosahedron.

In every case, there are kaleidoscopic motifs on the faces of the polyhedron or the plane. In consequence, the transformation of these shapes also means to visualize the kaleidoscopic image continuous metamorphosis. Without a doubt, it is striking that Weeks designed his software both to visualize kaleidoscopic cosmological models and to design kaleidoscopic images in different applications. In this sense, a remarkable correspondence is detected in a double association: the kaleidoscopic visualization of the universe and the design of kaleidoscopic images with different purposes—mathematical, geometric, artistic, etc.

5.2 Kaleidoscopic Representations of the Universe in Astronomical Contexts: *Zero Gravity—Multi Mirror Projection Room* (ESA, 2010) and *GTC Kaleidoscope* [50]

As presented in the previous section, kaleidoscopic cosmological models have been proposed. Consequently, it is not strange to find resources where the universe was represented kaleidoscopically, specifically in astronomical dissemination contexts. These spaces, whose main constituents are mirrors, generate multiple repeated images characterized by their kaleidoscopic nature. Furthermore, these characteristic mirrored spaces offer the observer the possibility of seeing, or even being totally immersed, within a kaleidoscopic space. Subsequently, this experience may produce the feeling of floating inside a multiverse, where the subjects are together with their own copies. For this reason, the study of the universe's kaleidoscopic representations that have been found in Spain, Europe, has been considered very relevant.

At the City of Arts and Sciences in Valencia was where one of these kaleidoscopic immersive spaces had been found. It is a video installation that forms part of the permanent exhibition *Zero Gravity* at the *Science Museum* and is organized by the European Space Agency (ESA). The immersive kaleidoscope is named *Multi Mirror Projection Room*, having been exhibited in the museum since 2010. In a certain way, this kaleidoscopic, virtual and immersive space shares similarity with the *Hall of Illusions* designed by Hénard in 1900. However, instead of infinitely reproduce the appearance of the room that became an ornamented palace, there is not a repeated architectural motif or decoration, but an image commonly related to the universe view (Fig. 5). Therefore, it is more similar to the perspective introduced by Luminet regarding the kaleidoscopic hall, as well as to the Weeks' software for the visualization of an infinitely multi-connected universe. The *Zero*

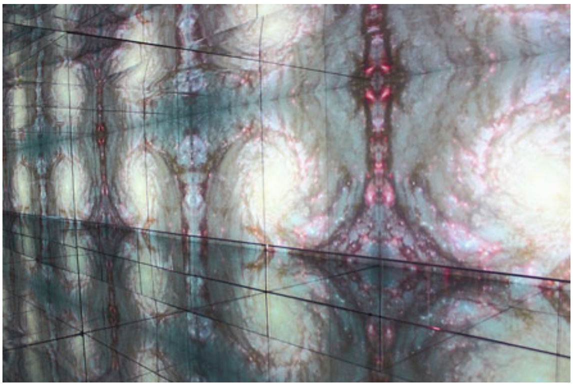


Fig. 5 Multi mirror projection room (*Zero Gravity*, ESA, 2010): a visible pattern that shows an infinite kaleidoscopic universe. The kaleidoscopic image motif corresponds to the Whirpool galaxy (NASA, ESA, STScI, AURA). (Photo by Vergara, 2019)

Gravity mirrored cube video installation works perfectly to experience Luminet and Weeks' proposals.

This immersive kaleidoscope is entirely composed of mirrors: all the walls, the floor, and the ceiling are completely covered. Images of the universe are projected over one of the walls, specifically over a 237" screen with 16:9 format that at the same time presents an optical reflection mirror where aerial photographies of planet Earth, astronomical objects, astronauts, or space stations are observed, among other motifs.[4] Therefore, a kaleidoscopic pattern is generated by the projected motif mirrored repetitions and the reflections of the people that are inside the room that works as the central cell. As a consequence of being inside a mirrored room of considerable dimensions,[5] the subject participates in a multisensorial space where being infinitely repeated, floating within a multi-connected universe (Fig. 6). Given this circumstance, the observers are immersed inside a kaleidoscopic universe where everybody is seeing themselves in every direction.

Concerning the kaleidoscopic image (Fig. 7a), the room structure is also very important. The mirrors that cover all the room are rectangular and right-angled at the corners. For this reason, the view is visually like the cubic geometries in *Curved Spaces*. For example, if the observer looks to the corner, the view is quite similar to the visualization of a three-dimensional multi-connected torus (Fig. 7b).

A prototype of the immersive kaleidoscope has been studied as well. Since it is a video installation model, it is named *Zero Gravity—Multi Mirror Projection Room Model*. It is located at the European Center for Space Astronomy (ESAC) in Villanueva de la Cañada, Madrid, although in this case, it is not an immersive kaleidoscope but a small cube covered by mirrors. The observer could look into the inner cube to see a visually infinite universe. Within the cube, two videos produced by ESA were projected: on the one hand, the same video that was projected in the kaleidoscopic immersive room, *Zero gravity* (2010), and *Our Changing Planet* (2007), which showed images that mostly belonged to the ESA archives and is not projected in the mirrored room video installation.[6]

---

[4] In the video, most of the images' source of origin are the ESA and NASA images archives, although the video installation also presents images from the following organisations: CNES, ARIANESPACE, GSFC, METI, ERSDAC, JAROS, Silicon Worlds, MPS, OSRIS Team, UDP, LAM, IAA, RSSD, INTA, UPM, IDA, DLR, FU Berlin (G. Neukum), JPL, Space Science Institute, University of Arizona, SOHO-EIT, STScI, AURA, PACS & SPIRE Consortium, HOBYS Key Programme Consortia.

[5] Some technical information on the *Zero Gravity—Multi Mirror Projection Room* video installation: The floor area in the projection room is, approximately, 43 m^2. The dimensions of the mirrored room are the size of 79.57 m^2 (13.26 $\times$ 6 m) and 3 m as height. From the outside, the room has the appearance of a diagonally leaning cube, so its height ranges from 3.74 to 5.36 m. Video length: approximately 7 min.

[6] The sources of the images that appear in the video *Our changing planet* (ESA, 2007): ESA, Europe's metereological missions (Meteosat, Meteosat Second Generation, Meteosat Third Generation, MetOp), ESA's environmental missions (ERS-1, ERS-2, Envisat, Proba-1), Earth Explorers (GOCE, SMOS, CryoSat-2, Adm-Aeolus, Swarm, EarthCARE), GMES dedicated missions (Sontinel-1, Sontinel-2, Sontinel-3, Sontinel-4, Sontinel-5), Envisat, Technical University of Denmark, NASA.

Fig. 6 Multi mirror projection room (*Zero Gravity*, ESA, 2010). The mirrored room where the subject's multiple reflections could be observed. The kaleidoscopic image motif corresponds to the planet Earth (Envisat, ESA). (Photo by Vergara, 2019)

The prototype reproduces the mirrored room on a minor scale, where the mirrors infinitely repeat the images projected over one of the cube faces. Both the immersive kaleidoscope that is suitable for the human scale as well as its prototype model generates a kaleidoscopic experience by reflecting an original motif—the one projected over one of the cube faces—along with the copies of the people that are inside the room, in the case of the immersive kaleidoscope (Fig. 8). Likewise, the kaleidoscopic image's fractal condition is notable in relation to these spaces since it means to visualize fractal configurations from nature—for example, galaxies or fractal elements from aerial views of planet Earth—in a kaleidoscopic way (Figs. 5 and 7a). In other words, the subject inside the mirrored room participates in a "double fractal" view, which is produced both by the kaleidoscopic structure and due to the fractal condition that the projected images present.

Compared to the kaleidoscopic room, few variations are when the *Zero Gravity* video is played in the prototype. Inside the model, the video length is slower than in the immersive room. Also, the music is different in each case. In the immersive video installation, the *Gymnopédies*, composed by Erik Satie, is played, while in the ESAC prototype, there is relaxing and repetitive ambient music.

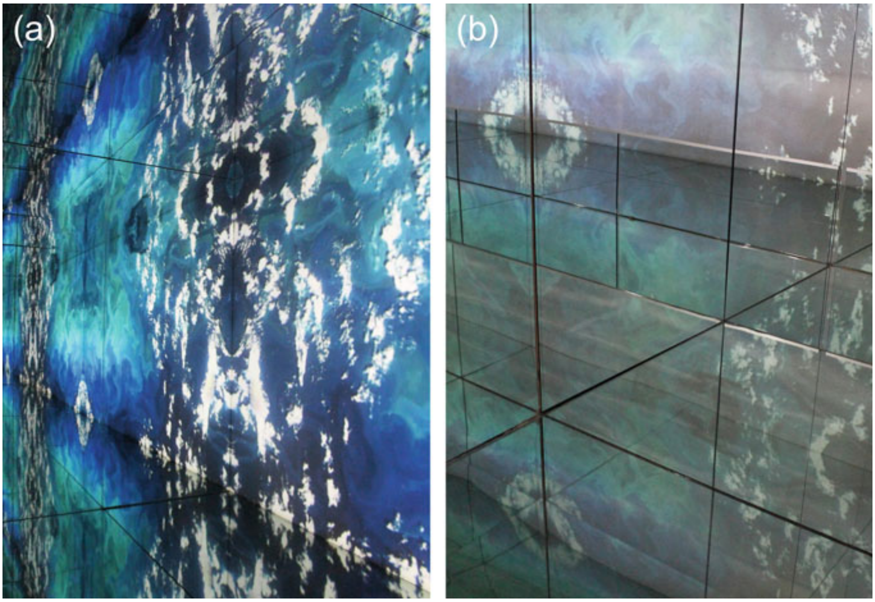


Fig. 7 Multi mirror projection room (*Zero Gravity*, ESA, 2010). The kaleidoscopic image motif corresponds to the plankton proliferation in the Barents Sea (ESA): **a** Pattern that shows an infinite kaleidoscopic image; **b** Structure formed by the mirrors, whose view in the corner is quite similar to a three-dimensional multi-connected cubic torus. (Photo by Vergara, 2019)

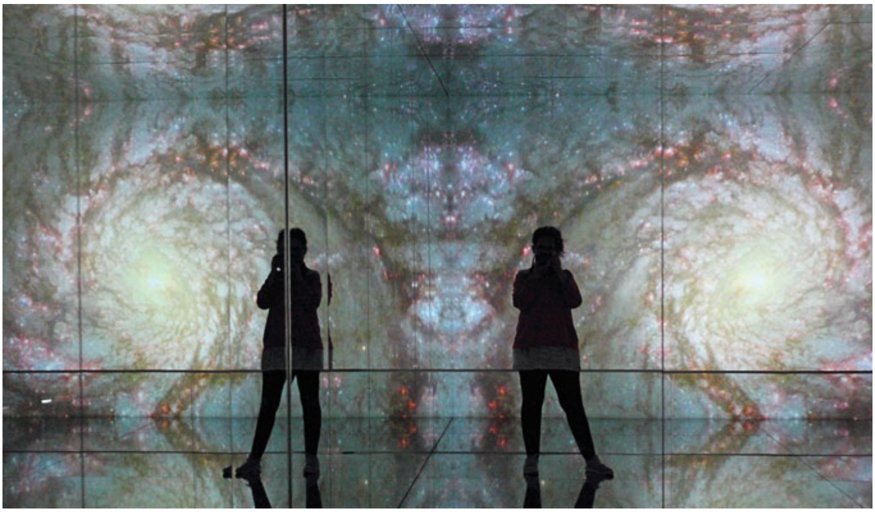


Fig. 8 Multi mirror projection room (Zero Gravity, ESA, 2010). Mirrored cube where the subject's multiple reflections could be observed. The kaleidoscopic image motif corresponds to the Whirpool galaxy (NASA, ESA, STScI, AURA). (Photo by Vergara, 2019)

Apart from these issues, the main difference between the room and the model is related to the subject's multisensory experience. The kaleidoscopic room incorporates the subject as part of the video installation, while the kaleidoscopic image that could be seen inside the prototype is observable, but the reflections do not show the observer as part of the kaleidoscopic space.

With a similar configuration of the *Zero Gravity—Multi Mirror Projection Room* (ESA, 2010), another case has been found. It is the *GTC Kaleidoscope* video installation at the Canary Islands Astrophysics Institute (IAC). Specifically, the *GTC Kaleidoscope* video installation was produced in 2015 by the IAC for the exhibition *Lights of the Universe: 30 Years of the Canary Telescopes* in Tenerife and La Palma. The title refers to the Gran Telescopio Canarias (GTC), the Observatory Telescope, located at Roque de los Muchachos, La Palma. *GTC Kaleidoscope* was an immersive space that, once more, generated the view of a kaleidoscopic universe where the projected video was repeated infinitely. In this case, we find the direct reference to the term "kaleidoscope," which replaces the word "telescope." Within the description of the *GTC Kaleidoscope* video installation, it is mentioned that the visualization of this type of space in cosmological models refers to the view of a kaleidoscopic universe [50]. For this reason, it worked as an immersive video installation whose principal aim was to experience the kaleidoscopic infinite universe, similar to the *Multi Mirror Projection Room* in the *Zero Gravity* exhibition (ESA, 2010), which is still displayed at present.

6 Conclusion

The kaleidoscopic image manifests a multiscale nature since it is present from microscopic forms to the mirrored multi-connected representations of the universe. Surprisingly, it follows the condition enunciated in an ancient proverb: *As above, so below. As below, so above*. This is not only because of the similar morphologies and topologies that have been categorized as "kaleidoscopic" in this chapter. But also, there is a correspondence between the micro- and the macro-cosmos views when the kaleidoscopic image is involved. At the same time, it should be noted that the shape of these forms is based on repetition, producing a mirrored pattern.

Overall, the visualization of the kaleidoscopic image and its structure corresponds both to the scientific and the artistic field, being an important topic for the visual studies area. In conclusion, it is a visual configuration whose geometry is extensively present in fractal examples from nature, as well as structurally displayed in proposals of multi-connected cosmologies. Definitely, this image is suitable for being investigated from many perspectives and disciplines with different purposes, so it should be considered for developing transdisciplinary approaches. The kaleidoscopic paradigm as an intersection between art and science would bring and open new perspectives, discoveries, and possibilities for both areas of knowledge, as can be seen in transdisciplinary research like protein design.

Core Messages

- In nature, there are similar morphologies and topologies whose shapes result from the repetition, producing a mirrored pattern categorized as "kaleidoscopic".
- The kaleidoscopic image is a visual configuration present from microscopic forms to the mirrored multi-connected representations of the universe.
- The nature of the kaleidoscopic image is multiscale, showing the correspondence between the micro- and the macro-cosmos views.
- The visualization and research on the kaleidoscopic image and its structure correspond both to scientific and artistic fields.
- The study of the kaleidoscopic image as an intersectional element opens a transdisciplinary paradigm that would bring new perspectives and discoveries.

Acknowledgements The author would like to thank the expertise collaboration of the astrophysicist Dr. José Antonio Caballero, who is a researcher at the Center for Astrobiology (CAB) (National Institute of Aerospace Technology [INTA], The Spanish National Research Council [CSIC]) at the European Space Astronomy Centre (ESAC), Spain, and Dr. Juan J. Vergara, Professor of Marine Ecology at University of Cádiz (UCA), Spain. The author also would like to thank the supervision of Dr. José María Parreño and Dr. Daniel Silvo on the issues presented within this chapter during the development of her Ph.D. Thesis (Complutense University of Madrid 2019) and expresses her gratitude for the attention she received from Rosa Martí at the Sciences Museum (The City of Arts and Sciences, Valencia).

References

1. Woolf V (1985) Moments of being. Harcourt Brace and Company, New York
2. Denes A (2020) Agnes denes. Manifesto 1970. Available via agnes denes' website. http://www.agnesdenesstudio.com/works15.html. Accessed 10 July 2020
3. Drożdż S, Oświęcimka P, Kulig A, Kwapień J, Bazarnik K, Grabska-Gradzińska I, Rybicki J, Stanuszek M (2016) Quantifying origin and character of long-range correlations in narrative texts. Inf Sci 331:32–44. https://doi.org/10.1016/j.ins.2015.10.023
4. Vergara MN (2019) The kaleidoscopic experience within every-day-life: on authorship, intertextual narrative, stream of consciousness and multifractality. Popular inquiry 2:12–22. Available via Aaltodoc website. http://urn.fi/URN:NBN:fi:aalto-202001021003. Accessed 10 July 2020
5. Müsch I, Seba A (2015) Gabinete de curiosidades naturales. Taschen, Barcelona
6. Vergara MN (2017) La perspectiva caleidoscópica y la asociación visual como metodología de investigación artística. In: Facultad de Bellas Artes (ed) 1ª Jornada PhDay Complutense Bellas Artes. Universidad Complutense, Madrid, pp 110–116. Available via Eprints Complutense. https://eprints.ucm.es/50393/. Accessed 10 July 2020
7. Vergara MN (2020) The kaleidoscopic interference and the double-slit project: borges' thought, quantum behaviour and multiverse theory. Artnodes 25:1–12. https://doi.org/10.7238/a.v0i25.3317

8. Crary J (1990) Techniques of the observer: on vision and modernity in the nineteenth century. MIT Press, Cambridge
9. Vergara MN (2018) La imagen caleidoscópica como primera forma de abstracción en los inicios del arte moderno. ANIAV 3:80–95. https://doi.org/10.4995/aniav.2018.10068
10. Brewster D (1819) A teatrise on the kaleidoscope. Archibald Constable and Company, Edinburgh
11. Vergara MN (2019) Visualizando lo invisible: La imagen caleidoscópica y los procedimientos asociados a la visualidad líquida, múltiple y conectiva. ASRI 17:52–69. Available via ASRI. https://www.eumed.net/rev/asri/17/visualidad-liquida.html. Accessed 10 July 2020
12. Mandelbrot B (2009) La geometría fractal de la naturaleza. Tusquets, Barcelona
13. Garrido H, García Ruíz JM (2009) Armonía fractal de Doñana y las Marismas. Lunwerg, Barcelona
14. Wilczek F (2016) El mundo como obra de arte. Drakontos, Barcelona
15. Deléage JP (1993) Historia de la ecología. Icaria, Barcelona
16. Martindale MQ, Henry JQ (1998) The development of radial and biradial symmetry: the evolution of bilaterality. Am Zool 38(4):672–684. https://doi.org/10.1093/icb/38.4.672
17. Holló G (2015) A new paradigm for animal symmetry. Interface Focus 5(6):1–10. https://doi.org/10.1098/rsfs.2015.0032
18. Killip M (2014) The diatomist. Available via Vimeo. https://vimeo.com/90160649. Accessed 10 July 2020
19. Blanchard DC, Bentley WA (1998) The snowflake man: a biography of Wilson A. Bentley. The McDonalds and Woodward Publishing Company, Blacksburg
20. Gombrich EH (1999) El sentido del orden: estudio sobre la psicología de las artes decorativas. Debate, Madrid
21. Tachon F (2020) Albin Guillot laure. Available via France’s culture ministry website. https://www.culture.gouv.fr/Sites-thematiques/Musees/Nos-musees/Valorisation-des-collections/Les-femmes-artistes-sortent-de-leur-reserve/Icones/Albin-Guillot-Laure. Accessed 10 July 2020
22. Miguel V (2015) Looking back at the impact of black mountain college. Artsy, October 26. Available via Artsy. https://www.artsy.net/article/the-art-genome-project-looking-back-at-the-impact-of-black-mountain-college. Accessed 10 July 2020
23. Asawa R (2020) Black mountain college. Available via Ruth Asawa’s website. https://www.ruthasawa.com/life/black-mountain-college/. Accessed 10 July 2020
24. Kappraff J (2001) Connections: the geometric bridge between art and science. World Scientific, Singapore
25. Caspar DLD, Klug A (1962) Physical principles in the construction of regular viruses. Cold Spring Harbor Symp Quant Biol, New York 27:1–24. https://doi.org/10.1101/SQB.1962.027.001.005
26. Cepelewicz J (2017) The illuminating geometry of viruses. Quanta magazine, July 19. Available via Quanta magazine. https://www.quantamagazine.org/the-illuminating-geometry-of-viruses-20170719. Accessed 10 July 2020
27. Kroto H (1993) The birth of C_{60}: buckminsterfullerene. In: Kuzmany H, Fink J, Mehring M, Roth S (eds) Electronic properties of fullerenes. Springer series in solid-state sciences, vol 117. Springer, Berlin, Heidelberg, pp 1–7. https://doi.org/10.1007/978-3-642-85049-3_1
28. Kroto HW, Heath JR, O’Brien SC, Curl RF, Smalley RE (1985) C_{60}: buckminsterfullerene. Nature 318:162–163. https://doi.org/10.1038/318162a0
29. Instituto de Astrofísica de Canarias (2013) Las moléculas más complejas del universo. Available via IAC website. http://www.iac.es/es/divulgacion/noticias/las-moleculas-mas-complejas-del-universo. Accessed 10 July 2020
30. Bale JB, Gonen S, Liu Y, Sheffler W, Ellis D, Thomas C, Cascio D, Yeates TO, Gonen T, King NP, Baker D (2016) Accurate design of megadalton-scale two-component icosahedral protein complexes. Science 353(6297):389–394. https://doi.org/10.1126/science.aaf8818
31. Zimmer C (2017) Scientists are designing artisanal proteins for your body. The New York times, December 26. Available via The New York Times. https://www.nytimes.com/2017/12/26/science/protein-design-david-baker.html. Accessed 10 July 2020

32. Altounian V (2016) Self-assembling protein cages. Available via Valerie Altounian's website. https://www.altounianillustration.com/portfolio/self-assembling-protein-cages. Accessed 10 July 2020
33. Service RF (2016) Rules of the game. Science 353(6297):338–341. https://doi.org/10.1126/science.353.6297.338
34. Science (2016) On the cover. Science 353(6297):325
35. Science Magazine (2016) The protein folding revolution. Available via the Youtube account of Science Magazine. https://youtu.be/cAJQbSLlonI. Accessed 10 July 2020
36. Luminet J-P, Weeks JR, Riazuelo A, Lehoucq R, Uzan J-P (2003) Dodecahedral space topology as an explanation for weak wide-angle temperature correlations in the cosmic microwave background. Nature 425:593–595. https://doi.org/10.1038/nature01944
37. Luminet J-P (2008) The shape and topology of the universe. In: Proceedings of conference tessellations: the world a jigsaw, Leyden (Netherlands), march 2006. Cornell University Library, New York, pp 1–21. Available via arXiv preprint. https://arxiv.org/abs/0802.2236. Accessed 10 July 2020
38. Giomini C (2003) Timaeus's insight on the shape of the universe. Nature 425:899. https://doi.org/10.1038/425899c
39. Sazatornil L (2012) De Diebitsch a Hénard: El 'Estilo Alhambra' y la industrialización del orientalismo. In: Calatrava J, Zucconi G (eds) Orientalismos. Arte y Arquitectura entre Granada y Venecia. Abada, Madrid, pp 53–72
40. Schwarzschild K (1998) On the permissible curvature of space. Class Quantum Gravity 15(9): 2539–2544
41. Ernst B, Escher MC (2007) El espejo mágico de MC Escher. Taschen, Madrid
42. Luminet J-P, Roukema BF (1999) Topology of the universe: theory and observation. In: Lachièze-Rey M (ed) Theoretical and observational cosmology. NATO science series (Series C: mathematical and physical sciences), vol 541. Springer, Dordrecht, pp 117–156. https://doi.org/10.1007/978-94-011-4455-1_2
43. Weeks J (2013) Jeff Weeks: "Shape of Space"—Aalto university MathArt colloquium. Available via the Youtube account of Aalto university. https://youtu.be/j3BlLo1QfmU. Accessed 10 July 2020
44. Weeks J (2020) Curved spaces. Available via geometry games website. http://www.geometrygames.org/CurvedSpaces/index.html.en. Accessed 10 July 2020
45. Weeks J (2020) Curved spaces. Available via app store. https://apps.apple.com/us/app/curved-spaces/id1417178571. Accessed 10 July 2020
46. Weeks J (2020) Kaleidopaint. Available via geometry games website. http://geometrygames.org/KaleidoPaint/index.html. Accessed 10 July 2020
47. Weeks J (2020) Kaleidopaint. Available via app store. https://apps.apple.com/us/app/kaleidopaint/id518275953. Accessed 10 July 2020
48. Weeks J (2020) Kaleidotile. Available via geometry games website. http://www.geometrygames.org/KaleidoTile/index.html.en. Accessed 10 July 2020
49. Weeks J (2020) Kaleidotile. Available via app store. https://apps.apple.com/us/app/kaleidotile/id1374849164. Accessed 10 July 2020
50. Instituto de Astrofísica de Canarias (2015) Luces del universo. Available via IAC website. http://www.iac.es/es/divulgacion/noticias/luces-del-universo. Accessed 10 July 2020

Mari Nieves Vergara (Málaga 1990) holds a Ph.D. in Fine Arts with the Extraordinary Ph.D. Award (Thesis defended in 2018-2019 at the Fine Arts School, Complutense University of Madrid, Spain) and International Mention, whose thesis title was *"The Juxtaposition of Ubiquities in Kaleidoscopic Image."* In autumn semester 2016, she was granted an Erasmus + fellowship for a postgraduate Ph.D. stay in the Department of Art of the School of Arts, Design and Architecture at Aalto University in Helsinki, Finland, where she collaborated as a researcher and visiting teacher. She has a Degree in Fine Arts (University of Málaga 2012) and finished her studies at Malmö University, Sweden, in an Erasmus annual exchange. She has completed a Master's Degree in Artistic Research and Creation and a Master's Degree in Teaching in Visual Art Education (Complutense University of Madrid). As a visual artist, she participated in exhibitions in Spain and had been awarded for her artwork. Mari Nieves has published her scholarly work in books and academic journals such as ANIAV, ASRI, Popular Inquiry, and Artnodes.