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Universal Language of Geometry: Geometrical Grid – The Nature of Space

Abstract: The space of an artistic plane, as well as architectural space, has certain regularities, which different theories explain in various ways. Geometric regularities in space are visible through the theoretical and practical work of artists and architects. For centuries, ever since Vitruvius, theorists have been looking for valid criteria to analyze the beauty of architecture. Iosif Brodsky goes as far as to say that beauty is the purpose of evolution, while other authors define geometry as the source of all beauty. Based on these hypotheses, in the 20th century the words of the architect Buckminster Fuller must be highlighted. He says that geometry is the essence of everything that surrounds us. The importance of geometry in space conception and its analysis are stated throughout this paper.

Keywords: geometry; perception; reading architecture; structure; space

Introduction

Analyzing the world around us, scientists and theorists have come to the conclusion about regularities in relations among natural elements. In architecture and art, the geometrical image of space speaks about the relations of elements inside the whole. Connecting these elements with straight lines would make a geometrical grid through which is possible to read the relations, proportions and dimensions of space. Regardless of the object's architectural style, the universal language of geometry makes possible the communication between different objects so that their basic structural principles can be read. This allows for easier analysis and consideration of different projects and works.

Geometrical grid in contemporary architecture is one way of developing structural elements of complex forms. It is mostly used for space grid structures which enable the construction of curved surfaces in architectural projects. The extensive use of steel in the beginning of the 20th century inspired architects to consider new technologies in their work. Scientists meet the characteristics of the micro-universe of atoms and its elements, the time/space curve in Einsteins's Theory of Relativity, the appearance of Non-Euclidean geometry and similar phenomena. Their impact on the

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architect Buckminster Fuller will be shown in further analysis in this paper. Manifests of various artists question how to respond to the great development in the world of science and technology and how to (re)present it.

Throughout evolution, all bodies in nature, including the human, were developed through different chemical and physical processes. Searching for regularities in these structures regular polyhedrons – Platonic solids were spotted, which are formed out of regular polygons, then the harmonies expressed with irrational numbers, as well as the most intricate, the geometry of the golden section. In the book *Elements* by Euclid there is an exact explanation for the proportions of the golden section using the elementary polygons and their relations as the base.[1] Guided by these developments architects use geometry as a tool, inspiration or the mode of presentation, depending on the goals of their work.

Construction principles based on geometry

There are many examples of the use of geometry in architecture throughout history. The one that stands out is the use of geometry for structural system of buildings. In the structuring of architectural space, construction elements play a significant role in the final form of the object. Directions of transferring forces due to the loads on the object have a direct impact on the stresses in construction elements and their dimensions. Starting with this fact, architects and engineers of the 20th century used it as the starting point in their designs. The stability of the building depends on the joints between structural elements and the functioning of the whole structural system. It was noticed that the triangle is a stable geometrical figure, unlike a square that needs additional elements to give it stability. The relation between geometry and stability of the system can be seen in the examples of crystalline structures and in the behavior of solid substances found in nature. The tetrahedron as the basic unit of diamond's geometrical grid is at the same time the most stable element of any structural system because of its regular grid made of equilateral triangles. The stability of Platonic solids can be proved using Euler's formula for convex polygons. It proves that tetrahedron, octahedron and icosahedron, which are made of triangles, are stable, and hexahedron and dodecahedron unstable, if they are made of rods. When they are formed out of planes, hexahedron is stable and icosahedron unstable.[2] The use of this knowledge is especially visible in space grid structures. Simple trusses were used even in ancient Greece and Rome, but they fully developed during the 20th century. In that moment, the question of joints in such structural systems was opened because of an extensive use of steel and the acquaintance with its characteristics. One of the first architects who wrote in his manuscripts about the importance of good design of joints

[1] Alexander J. Hahn, *Mathematical Excursions to the World's Great Buildings* (Princeton: Princeton University Press, 2012), 18–23.

[2] Vladimir Georgijevski, *Lake metalne konstrukcije. Prostorni rešetkasti sistemi* (Beograd: Građevinska knjiga, 1990), 9–11.

is Viollet-le-Duc, who says that construction joints must respond to the overall design concept of the building.[3] Dr. Max Mengeringhausen made a significant contribution to space grid structures by inventing the MERO joint and thus providing the means for designing geometrical grids based on regular polyhedrons.[4] These geometrical structures have made possible the construction of curved forms in the contemporary world. Engineer René Motro says that geometry is the base of every designer's process and that it is related to the sectioning of space, whether two-dimensional or three-dimensional.[5] The use of geometrical principles for solving structural problems in architecture is especially visible in the work of the architect Buckminster Fuller.

Geometry as means of visual presentation

The existence of the golden section was one of the key points in designing architectural space, primarily in plans and on facades, thus influencing the appearance of the whole object. "[The] Human mind always tries to define a sense behind the pure optical impression […] Our mind together with the eye always seeks for understandable structures which show or seem to show sense in themselves."[6] It is considered common knowledge that people react to regularities in their environment, which is why architects use geometry in designing. The most significant geometrical principles are proportions and harmonic relations between the elements of space. Pythagoras came to the idea of irrational numbers which represent different harmonies by studying musical notes. The use of division into halves or thirds, which are then translated or symmetrically moved through architectural space, is one of the most used in architectural design.

Buckminster Fuller: synergy of geometric solids

About the author – wishes and opinions

Buckminster Fuller was an innovator, visionary and a philosopher. He didn't receive a work license until he was 79 years old even though he dedicated his life to architectural design. He searched for a solution for how to do *more with less*. His hard life in the beginning of the 20th century guided Fuller towards developing a solution for economical housing for everyone. His ideas were guided by the question: What

[3] Fil Hearn, "Honest Structure as the Framework of Design," in *Ideas That Shaped Buildings* (Cambridge: The MIT Press, 2003), 224–32.

[4] John Chilton, *Space Grid Structures* (Oxford: Architectural Press, 2000), 16–17.

[5] Rene Motro, "An Approach to Structural Morphology," in *An Anthology of Structural Morphology*, ed. Rene Motro (Singapore: World Scientific Publishing, 2009), 16–25.

[6] Michael Balz, "Phantasy in Space: On human Feeling Between the Shapes of the World and How to Look on Natural Structures" in *An Anthology of Structural Morphology*, ed. Rene Motro (Singapore: World Scientific Publishing, 2009), 112.

can a single man do that is significant for all mankind? Analyzing the work of Leonardo da Vinci and his contemporaries such as Le Corbusier, while at the same time influenced by the development in science, he wrote his first book, about new architecture that was based on time as the fourth dimension. Nevertheless, he always emphasized that all his projects were his own ideas and uninfluenced by other architects. The development of industrial production and technology inspired Fuller to work towards buildings made with light materials whose construction was based on the principle of tension and which could be easily moved by aircraft. At the very beginning of his career he formulated his basic design principles: use of tension forces, mass production, standardization, decentralization, transferability with aircraft, use of light construction elements, symmetry of the hexagon, educational reforms and controllable environments. The principle of tension forces was a logical choice due to the good ratio of the weight of the elements and the acceptance of the load, which allowed him to design light objects. The geometry of the hexagon made possible the evenly distributed acceptance of loads.[7] Throughout his life he wrote a great number of books, patented 28 of his inventions and received 47 honorary university diplomas.[8] He believed that he was searching for the working principles of nature, which he then used to design complex structures. Even at the very beginning of the 20th century he had an almost constructivist attitude towards design and no regard for the existing context in architecture.[9] As a proof that his structures could indeed be found at the micro level of nature, by the end of the previous century, scientists found a molecule with the geometry of a football, which they named *Buckminsterfullerene*.[10] Fuller was an important figure of the 20th century, not just as an architect or inventor, but also because of his specific view of the world. His life and work is still an inspiration for architects, engineers and scientists who put his theories into practice.

The Universe – synergy of all synergies

For Fuller, the whole concept of our surroundings was based on the analysis of the Universe. He said: “[The] Universe is the aggregate of all humanity’s consciously apprehended and communicated non-simultaneous and only partially overlapping experiences.”[11] *Aggregate* – because it is the sum of all events that do not have to be interrelated, *consciously apprehended* means that there is an awareness of the other, *communicated* – since there is an exchange in information, *non-simultaneous* – because they are not happening at the same time, and *partially overlapping* is used to describe that they don’t have the same beginning and ending in time.[12] He considered

[7] Michael John Gorman, *Buckminster Fuller, Designing for mobility* (Milano: Skira Editore S.p.A., 2005), 36.

[8] About Fuller, https://www.bfi.org/about-fuller, acc. April 27, 2018.

[9] Kenet Frempton, *Moderna arhitektura: kritička istorija* (Beograd: Orion art, 2004), 239.

[10] Gorman, *Buckminster Fuller*, 12.

[11] R. Buckminster Fuller, E. J. Applewhite, *Synergetics: Explorations in the Geometry of Thinking* (Sebastopol: Estate of R. Buckminster Fuller, 1997), 301.10.

[12] Ibid, 302.00

that the only right way to analyze the world was form macro to micro, unlike other scientists who approached the world by analyzing individual cases, and then creating the bigger picture. He would say that nothing can be forgotten if you start with the Universe. Final conclusions are reached using multiplication by division (arithmetical division of our aggregates of overlapping experiences).[13]

Realizing that until then no one had tried to define the world through the physical and metaphysical, he started working with synergies.[14] Since he came to the conclusion that the element itself cannot predict the behavior of the whole system, he started analyzing their mutual relations and connections. Energy is the physical world, it cannot be lost, it can only change its state. The metaphysical is synergy and it is unchangeable. Fuller defines synergy as the *behavior of the whole system unpredicted by any of its parts*, as is for example the attraction of two or more separate objects (or subjects). We know that objects gravitate towards the Earth, and that the Moon circles around the Earth, because it is proven with mathematical accuracy, however, there are also other relations between elements – metal or non-metal, which also gravitate towards each other and form a specific relation. Synergy presents even the love between two individuals. If they love each other, they will gravitate towards each other, and if there is no attraction among them, the weaker one will be 'thrown into the orbit'. Fuller finds proofs for his theories in the laws of physics, since they proved that there are no solids, but only waves, behaviors, verbs, relations that can be contemplated, but not proven empirically. Based on this knowledge, Fuller concludes that the Universe is the maximum, the synergy of all synergies. It is completely unpredicted by any of its parts or the hierarchy of synergies, just the same as chemistry or physics cannot predict the complex, organic behavior of human, by looking at the structure of his nail, in a way that language of synergy can.[15]

Geometry as an explanation of the Universe

The minimal structural element of the Universe is the tetrahedron, and the triangle is the only constant pattern. Fuller defines structure as an auto-stable complex of integrated patterns, which can be formed exclusively of triangles. Only a triangle is a constant pattern, and all other patterns are recognizable only by their triangulated structure of integrated patterns. Euler says that mankind works with patterns and that there are indivisible components of pattern, which is also the definition of mathematics. For Fuller patterns mark events, and structures are constellations of events. One line can be a pattern by itself and the section of two lines is the point of encounter which Euler considers the unique characteristic of patterns. Euler defines three elements of pattern: dot, line and plane, which are defined in theory of synergetics as trajectories, crossings and openings.[16] Every chemical element can be represented by its pattern, the same as every individual is a unique pattern, because relations in a

[13] Ibid, 304.00, 305.02

[14] Ibid, 305.04

[15] R. Buckminster Fuller, *Intuition* (New York: Doubleday & Company, Inc., 1972), 21–44.

[16] Fuller, Applewhite, *Synergetics*, 505.101, 505.11.

pattern depend on the way it receives information. Based on these analyses in which Fuller deconstructs the Universe on its smallest, indivisible components, he comes to the conclusion that the Universe is in perfect mathematical order even though events in reality seem random.

Considering Fuller's interest in science and the achievements of his contemporaries, but also in the processes that led to new discoveries, he formed a strategy for studying physics, chemistry and quantum mechanics based on the language of geometry. Making the tetrahedron the primary measuring unit of the Universe, he made a hierarchy of vectors and geometry, which allowed him to analyze these sciences. To analyze every science individually, the knowledge of their constants and the systems of explaining different phenomena is required. But, synergy makes possible the connecting of these sciences by using a unique system, which brings into correlation geometry and constants in given sciences. This new language can analyze simultaneously the law of gases, field equations, thermodynamic laws, Newton's theory of gravity, Euler's topology of points, areas, and lines, Einstein's energy equation and others. With the language of synergy he connects the XYZ coordinate system with CGtS unit system (centimeter, gram, temperature, second).[17]

In what way did Fuller come to the idea that the tetrahedron was the basic unit of the Universe? If the Universe is always in twos, such that it consists of the physical and metaphysical, energy and synergy, positive and negative, its unit must have that duality within itself. For Fuller, one tetrahedron consists of two triangulated energy events. Triangle is an energy vector of one event in the Universe whose sum of angles is 180^{o}, and it is shown in a zigzag pattern of light. This tripartite spiral is formed out of a triangle and has three vectors: action, reaction and resultant. Since each of them can be positive and negative, a positive and negative spiral must be made. By uniting these two spirals a tetrahedron is made and Fuller's equation that 1+1=4.[18] (Fig. 1) The duality of the Universe supposes the quadripartite system of events with its multiplication by division. Fuller says this system is connected with the fact that he has four senses he can explore the whole Universe with. He emphasizes that psychologists couldn't figure out that the 'second' isn't necessarily in a different entity from what is initial, original, real: the 'first'. Even in humans there are four completely different senses, separated and unique, which man uses to comprehend the tetrahedron as the basic unit of the Universe. All of his ideas Fuller explains with proofs: that the minimal polyhedron (tetrahedron) is formed exclusively out of minimal polygons (triangles); that the minimal polyhedron systematically and consistently divides the whole Universe in three parts: the outer macro-cosmos, the inner micro-cosmos and the rest of the Universe which constitutes the divided system; and one of most intriguing, that there is no space, just electromagnetic waves. Fuller's wish to explain the Universe, by bringing together geometry and physics in the language of synergy, can be seen in these proofs.[19]

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[17] Ibid, 201.22.

[18] Ibid, 108.01.

[19] Ibid, 270.17.

Fuller's fascination with the laws of the Universe resulted in a new theory of synergy, which explained the proofs of physics, chemistry and quantum mechanics using the language of geometry. That was his way of explaining all processes in nature, and because of his wish to design projects that effected and improved the environment, he incorporated all his theories into design.

Fuller's response to the laws of the Universe

I *Dymaxion Map*

Frustrated by the fact that we observe a distorted picture of the world, because the globe doesn't represent states and continents in their real dimensions, Fuller tried to find a way to geometrically reproduce the globe's surface to show the real dimensions. These ideas were the first steps towards forming geodesic domes.[20] The fact that the basis of Non-Euclidean geometry was spherical triangles cannot be unseen. The existence of hyperbolic and elliptic geometry was proved by the end of the 19th century, thus it is supposed that this influenced Fuller's research. Fuller himself says that there is no straight line in nature, even though he operates only with Euclidean geometry. In his book he mentions spherical Platonic solids, but doesn't try to prove them theoretically. The spherical solids can be seen in his geodesic domes.

He patented his first Dymaxion Map in 1946. The convex polyhedron – cuboctahedron, he used to transfer dimensions from sphere onto a map with, is constituted of six squares interconnected by equilateral triangles. He immediately gave it a name Dymaxion, made of words *dynamic*, *maximum* and *tension*. In the patent he gives all the necessary drawing and explanations of the method. He started his experiment by placing the center onto the North Pole, and then he draw lines over the plastic he put around the globe. The geometrical grid of the cuboctahedron could be easily moved and placed on a flat surface, thus giving the more real view of the world then by using standard mapping techniques. (Fig. 2) He drew the improved version of the map that same year using the icosahedron, because of its similarity to the sphere.[21]

This map is considered the first step towards a theory of synergy and geodesic domes. The geometry of cuboctahedron and the possibility to divide the square into four equal parts made him think about this geometry as the balance of vectors. With further analysis of this semi-regular solid and his parts, Fuller spotted one of the most important combinations of geometric solids – the tetrahedron and octahedron. This configuration will be analyzed later in the text as one on his patented spatial structures. All these experiments led to creating energetic-synergetic geometry with which he pulled out of the regular geometrical grid onto a three-dimensional grid with symmetry in 12 directions. His research in this period relied on the analyses of microstructures as well as on the analyses of the Earth's sphere. During the next period, Fuller completely dedicated himself to the theory of synergy and the understanding of the Universe.

[20] Gorman, *Buckminster Fuller*, 85–90.

[21] Ibid, 86.

II *Geodesic Dome*

The use of the spherical form in his constructions Fuller explains in the following way:

> [A] sheet of paper, it doesn't have any real structural strength, but you put it in a simple curvature and make a cylinder out of it, it makes a column and has some strength. Put in a compound curvature, you get the greatest strength. That's why very thin eggshells have such great strength. So you want to get the greatest strength, you go in the spherical, and if you want to get the most volume, you go in the spherical. That's why a geodesic dome, in the first place, is very economical and very strong.[22]

Starting his analyses on the globe and linking it to the cuboctahedron, Fuller came to new conclusions that led to his life philosophy. By trying to achieve the maximum number of rings around the sphere, he made a spherical icosahedron made of 31 rings, which is at the same time the maximum number of dots, lines and planes in polyhedrons. The spherical icosahedron was found to be unstable due to differences in length of its rods, so he returned to regular polyhedrons. In further research it can be seen that Fuller never went far from using the icosahedron because it was usually the base of his geodesic domes. (Fig. 3) The first models of Geodesic Domes were made by students of the Black Mountain College during the 1950s. They experimented with different triangle sections until they came up with the most economical solution, which had the maximum number of similar rods whose length could be precisely calculated.

In his projects with Geodesic Domes Fuller removed the central, 'privileged', vertical axis of symmetry, while following the wish for his domes to resist the forces of gravity. Symmetry used in these domes was five-fold symmetry. These ideas developed by looking at nature and animal exoskeletons, and also microorganisms such as radiolaria, for which he used to say that they developed against gravity. He thought that he was investigating "*nature's own coordinate system*".[23]

He patented his Geodesic Dome not long after the Dymaxion Map, in 1954. He emphasized that he never anticipates form, but starts with his design principles. For him, form is what comes at the end. However, if the final product isn't beautiful, Fuller supposed that there were irregularities during the design process. "*Beauty for me must be the result, and not the intention.*" When he made one of his first Geodesic Domes, two of the largest ones were in Rome weighting more than 30,000 tons, while his, the same in size, was "just" 30 tons, which is 1000 times less. In June 1970, he received a golden medal and recognition of the American Institute of Architects (AIA) for his geodesic domes as one of the most lightweight, most stable and most efficient projects known to mankind.[24]

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[22] How Buckminster Fuller Made A Dome Over Manhattan Sound Sensible, https://www.fastcodesign.com/3058386/how-buckminster-fuller-made-a-dome-over-manhattan-sound-sensible, acc. April 30, 2018.

[23] Gorman, *Buckminster Fuller*, 115–17.

[24] Ibid, 115.

It must be emphasized that Fuller got his wish to transfer his dome by air traffic when he collaborated with the US Army. (Fig. 4) Also, the US Army used his Geodesic Domes as shelter in the lands where they fought. Fuller succeeded in popularization of Geodesic Domes and encouraged the development of various movements based on technological development.[25] They were presented on various World exhibitions (EXPO) as American pavilions and one of them still stands in Montreal in Canada. Fuller's Geodesic Dome with the cover inside was placed in Alaska so that he could prove its resistance in different weather conditions, harsh winds, snow and the cold. Because of his achievements he was on the cover of *Time* magazine several times and he held lectures and workshops with students throughout the USA.

III *Octet Truss*

Studying geometry Fuller realized that certain geometrical figures and their combinations were more stable than classic structures. The combination of tetrahedron and octahedron was discovered during the work on the Dymaxion Map, and was first used on the floors of an automated cotton mill. (Fig. 5) This space grid structure consisted of 170 aluminum rods and weighted only 30 kg, but it could accept a load of 6 tons, which is the weight of one military tank. Fuller patented it in 1961 and some 20 years later the American government issued a directive for the Octet Truss to be used for building all space stations.

The combination of the tetrahedron and octahedron is the simplest natural structure, as stated by Fuller. Since it is impossible to fill a space only with tetrahedron, his complementary solid is octahedron. "*Together they form the simplest, strongest structural system of the Universe*". Using calculations and experiments Fuller came to the conclusion that if a Octet Truss was used for forming flat roofs, floors or walls, and if it was formed of rods of equal length, the overall stability of the whole system would be significantly larger than in classic structures in relation to material consumption. Fuller said that this spatial system was synergic in a way that its elements could not predict the behavior of the whole space grid.[26]

IV Utopian projects

Fuller wished to improve the quality of life of all humanity, which can be seen in his project Dome over Manhattan. (Fig. 6) This dome was supposed to have a radius of 2 km and to provide a stable climate for people living under the dome. Fuller stated that life under the dome would be much simpler: there would be no rain or snow, no snow removal, rain would be collected in the canal around the dome to be used as technical water and the height would be big enough so that people wouldn't even notice it. These ideas prove that Fuller was ahead of his time, because when they are analyzed with this time distance, we see that he thought about climate change, sustainable

[25] *Istorija moderne arhitekture: Antologija tekstova. Knj. 3, Tradicija modernizma i drugi modernizam*, ed. Miloš Perović (Beograd: Arhitektonski fakultet, 2005), 333.

[26] Fuller, *Inventions*, 167.

development, eco-consciousness and life economics. Fuller probably didn't perceive it like this, but his objects were sustainable.

What most scientists, architects and artists are still experimenting with is Fuller's idea of a city in the atmosphere. Since Geodesic Domes are getting more and more efficient in the sense of stability, and economically, if their diameter is increased, it encouraged the idea for the dome to fly. If one could make such climatic conditions that there is a difference in the heat of the outside and inside air, the dome would fly.

Fuller always said for himself that he was a man ahead of his time and that he designed for the future. He liked being called *comprehensive anticipatory design scientist* because he had a systematic approach to problems in the world guided by economy and efficiency. Fuller's ideas presented with the language of geometry never cease to inspire architects and scientist working in other fields. (Fig. 7)

Conclusion

The universality of geometry can be seen first and foremost not only in the use of geometrical language for presenting different concepts and ideas in architecture and art, but also in other sciences. With the examples given in this paper the relation between geometry and science, geometry and construction, and geometry as the way of (re)presentation is clearly visible. Through the analysis of philosophy and work of the architect Buckminster Fuller, the idea of the universality of geometrical language is confirmed on various levels.

The main characteristic of Fuller's work is the geometrical grid. Its triangular network emphasizes the existence of the joint as the element of three lines crossing. The chosen triangular grid element, Fuller explains with the term 'stability'. For him, stability is the one that came from the geometry of triangle as a stable form used in structural systems.

In his philosophical discourse he searches for the essence of the world on the macro level of the Universe. It must be emphasized that Fuller does not start designing from singular elements, but from the whole, slowly removing elements to get to the essence of structure. In that process, Fuller comes to the geometry of tetrahedron as the base of the Universe. He is interested in relations and invisible bonds in the world and gives them the name *synergy*. Using the language of geometry he analyzes relations between elements in different sciences. Looking at the structural elements of reality, he finds the regularities, which he then extracts to the surface. He considers it necessary to change the image of the world. Guided with new technologies and scientific development, during the course of his life, his ideas focus on the progress of humanity. They are based on the analyses of sciences like mathematics, physics, chemistry and quantum mechanics. His work shows constructions of reality through geometrical grid wishing to come closer to the universal – the essence of things.

Fuller has a specific approach to beauty. For him, beauty is what is universal and correct – the essence. When he starts working, he does not start with the form, but with the essence. Beauty is the final product. If the product is not beautiful then it is not correct, as Fuller points out.

All the ideas of universality, the essence of reality, metaphysical relation between elements are intriguing and contemplating. The author's clear and systematic procedures to get to the essence of the Universe can be seen with their deeper analysis. The universality of Fuller's domes is manifested through the unified space and the hierarchy of elements of equal importance, while their geometrical language completely matches his philosophy of the Universe.

(Re)creation of architectural space with geometrical language allows for its easier analyses, comprehension and viewing. By establishing proper, harmonic relationships, these spaces create a sense of comfort and calmness, and a pleasant emotion remains deeply engraved in the individual's memory.

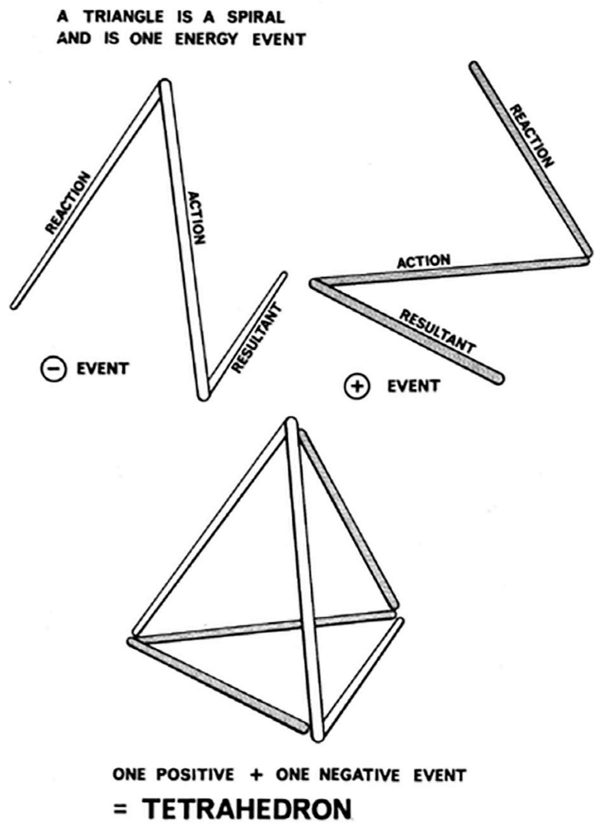

Fig. 1: Forming of tetrahedron. R. Buckminster Fuller and E. J. Applewhite. *Synergetics: Explorations in the Geometry of Thinking*. Sebastopol: Estate of R. Buckminster Fuller, 1997, Fig. 511.10

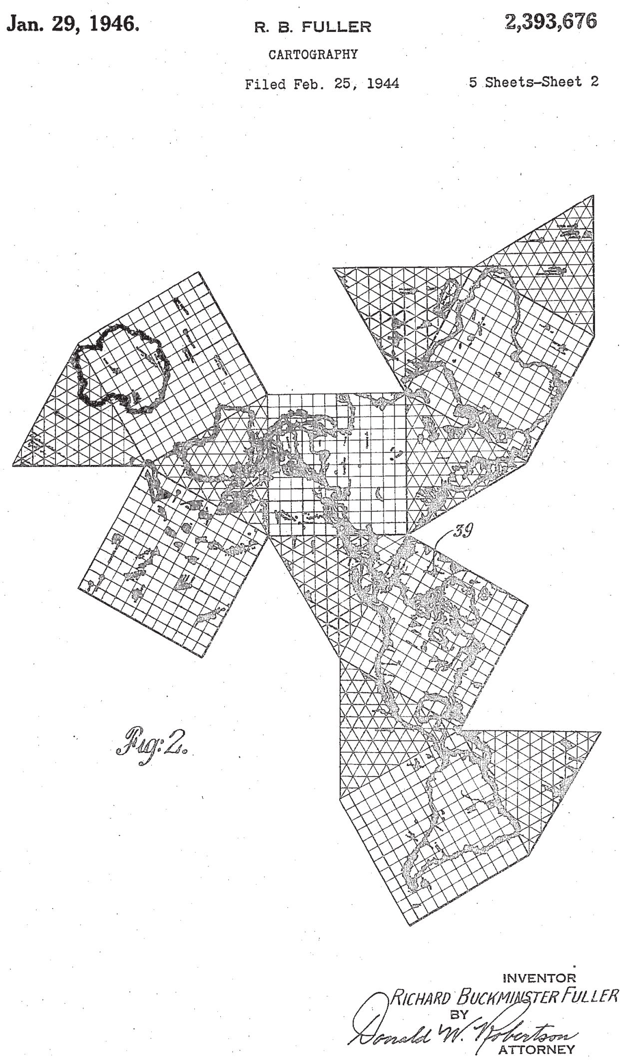

Fig. 2: Dymaxion map. https://patents.google.com/patent/US2393676A/en. Accessed June 13, 2018.

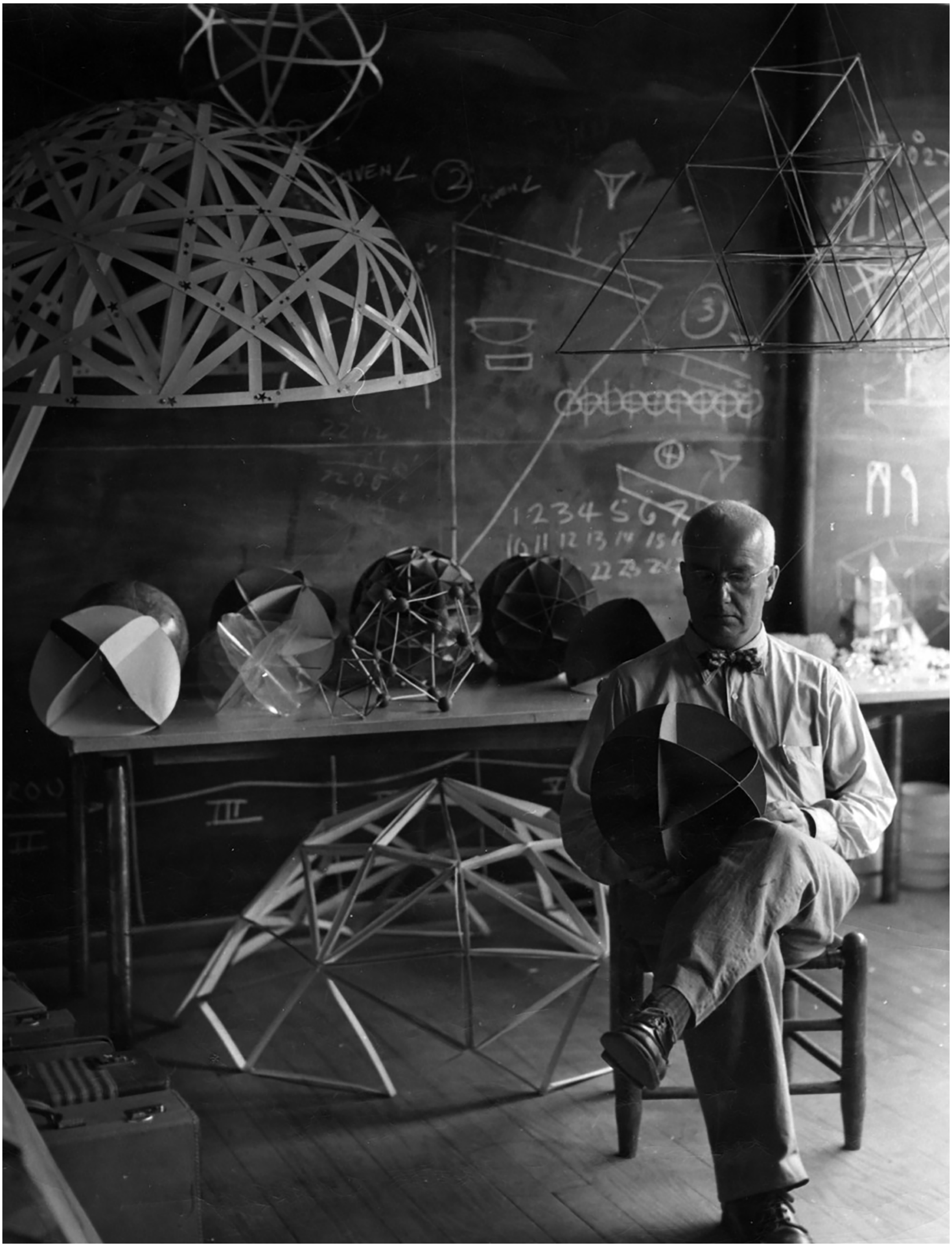

Fig. 3: Buckminster Fuller with his models.
https://d.lib.ncsu.edu/collections/catalog/0007123. Accessed June 13, 2018.

Fig. 4: Airlifting the Geodesic Dome.
https://i.pinimg.com/originals/da/32/f3/da32f37e598fd7ecf2650d178a333eeb.jpg. Accessed June 13, 2018.

Fig. 5: Design students in Fuller's class design a cotton mill.
https://d.lib.ncsu.edu/collections/catalog/0000102. Accessed June 13, 2018.

Fig. 6: Dome over Manhattan.
https://www.fastcodesign.com/3058386/how-buckminster-fuller-made-a-dome-over-manhattan-sound-sensible. Accessed June 13, 2018.

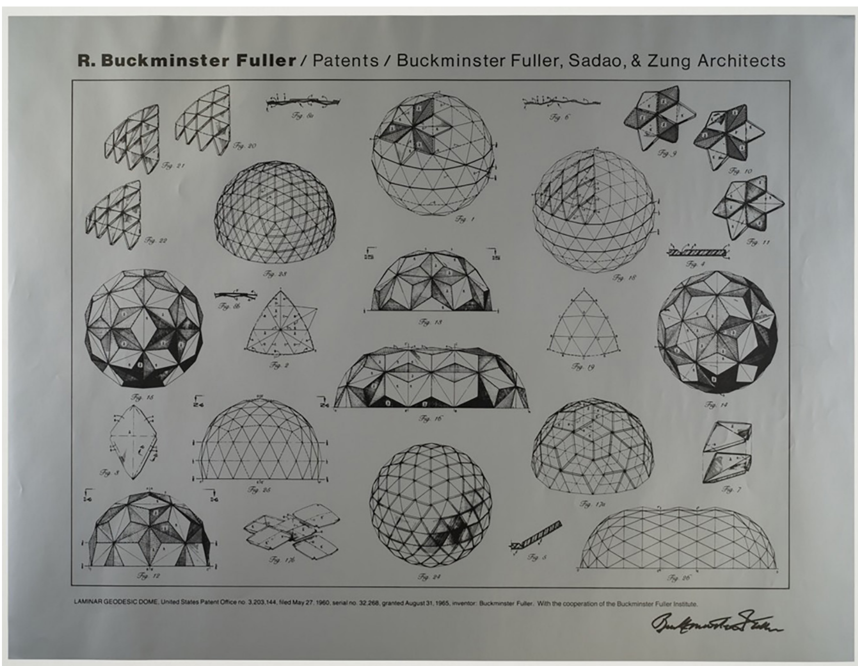

Fig. 7: Patents for Geodesic Domes.
https://d.lib.ncsu.edu/collections/catalog/rbc00004-001-ff0001-001-001_0001. Accessed June 13, 2018.

References

About Fuller, https://www.bfi.org/about-fuller. Accessed April 27, 2018.

Balz, Michael. "Phantasy in Space: On Human Feeling Between the Shapes of the World and How to Look on Natural Structures." In *An Anthology of Structural Morphology*, edited by Rene Motro, 109–16. Singapore: World Scientific Publishing, 2009.

Chilton, John. *Space Grid Structures*. Oxford: Architectural Press, 2000.

Frempton, Kenet. *Moderna arhitektura: Kritička istorija.* Beograd: Orion art, 2004.

Fuller, R. Buckminster. *Inventions. The Patented Works of R. Buckminster Fuller.* New York: St. Martin's Press, 1983.

Fuller, R. Buckminster and E. J. Applewhite. *Synergetics: Explorations in the Geometry of Thinking.* Sebastopol: Estate of R. Buckminster Fuller, 1997.

Georgijevski, Vladimir. *Lake metalne konstrukcije. Prostorni rešetkasti sistemi*. Beograd: Građevinska knjiga, 1990.

Gorman, Michael John. *Buckminster Fuller, Designing for Mobility.* Milano: Skira Editore S.p.A., 2005.

Hahn, Alexander J. *Mathematical Excursions to the World's Great Buildings.* Princeton: Princeton University Press, 2012.

Hearn, Fil, "Honest Structure as the Framework of Design." In *Ideas That Shaped Buildings*, 223–53. Cambridge: The MIT Press, 2003.

How Buckminster Fuller Made A Dome Over Manhattan Sound Sensible, https://www.fastcodesign.com/3058386/how-buckminster-fuller-made-a-dome-over-manhattan-sound-sensible. Accessed April 30, 2018.

Istorija moderne arhitekture: Antologija tekstova. Knj. 3, Tradicija modernizma i drugi modernizam, edited by Miloš Perović. Beograd: Arhitektonski fakultet, 2005.

Motro, Rene. "An Approach to Structural Morphology." In *An Anthology of Structural Morphology*, edited by Rene Motro, 15–31. Singapore: World Scientific Publishing, 2009.

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