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# CONSTRUCTING SYMMETRIC BAMBOO DOMES AND BAMBOO SPHERES. THE SHAPE OF FULLERENES C60 AND C80 AS A TEMPLATE FOR DOMES

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Phenomena Exhibition, Visual Mathematics Section, Zurcher Forum Publishers, Zurich (1986).
Symmetry Exhibition, Mathildenhohe, Eduard Roether Publishers, Darmstadt (1986).
Heureka Swiss Science Exhibition, Visual Mathematics Section, Zurcher Forum Publishers, Zurich (1991).
Buckminster Fuller Exhibition, Your Private Sky, Museum of Design Zurich, Lars Muller Publishers (1999).

**Abstract:** *Since more than 20 years I have built many bamboo domes and bamboo spheres of various sizes in countries like Switzerland, Germany, Japan, Singapore, and the USA. As I have never written a paper on the subject, I will take this chance now to write how a bamboo dome or bamboo sphere is constructed. In honour of my teacher Buckminster Fuller, I used to call a bamboo sphere a BBBB, which stands for Big Bamboo Bucky Ball. The name Bucky ball or fullerene is the scientific expression for a carbon molecule. Most of the first bamboo domes or bamboo spheres are based on the soccer ball, consisting of 12 pentagons and 20 hexagons, which for stability reason are constructed not from polygons, but from bamboo-star-elements. In 2019 during a workshop my students assembled a bamboo dome and inserted instead of five pentagonal-star-elements another row of five hexagonal-star-elements. By this mistake a C80 bamboo dome was born! It uses five hexagonal-bamboo-stars more than a C60. To build a C60 dome we need a total of 240 struts to construct 6 pentagonal- and 15 hexagonal-bamboo-stars. To build a C80 dome we need a total of 300 bamboo struts to construct the 6 pentagonal- and the 20 hexagonal-bamboo-stars. Because it is more time consuming to mark all the bamboo-struts and prepare all the flat bamboo-star-elements, than the dome assembly on the site, the transportation of these large bamboo-star-elements was often a problem. We managed to solve this problem by making the bamboo-stars transformable into hyperboloid-like-bamboo-bundles.*

Keywords: Geodesic Domes; Bamboo; Lightweight Structures; Fullerenes and Bucky Balls; Buckminster Fuller.

## INTRODUCTION

It is about 50 years since the geodesic dome boom started in the innovative 1960's and 1970's. The American architect Buckminster Fuller was the driving force behind this movement (Fuller, 1975, p.701-704). As a joke he used to say that to live in a dome feels nice, because we human anyhow live each one of us in its own dome inside our skull! This paper is to show that nowadays domes are still attractive, implying a futuristic image. Most geodesic domes are based on an icosahedron or triacontahedron, whose edges are divided in equal parts, forming different types of triangles asFigure 1. The larger a dome, the higher the frequency, avoiding large strut length. The world's biggest geodesic domes are the Montreal biosphere and the Epcot-dome in Florida, both a 32-frequency icosahedron. Bamboo struts (Tonkin poles) as a building material for domes are available from natural bamboo forests or in do-it-yourself stores at reasonable prices. The basic type is green bamboo and slightly more expensive is the black bamboo or tiger bamboo (Phyllostachys nigra), which is harder and more durable. As connectors we use tree-fix rubbers, which are available in gardening centres as Figure 4. This way to build bamboo structures is safe, because there are no metal parts like wire used. If we use a unit polygonal edge-length to make the bamboo-stars forming hexagons, octagons, decagons, and dodecagons etc, we can build any shape of dome or Archimedean solid. This idea was born during a bamboo-workshop with French architect Jean Baudoin (Baudoin., 2009, p.1). The basic bamboo dome is based on the 32-faced truncated icosahedron, the shape of a fullerene C60, called a Bucky ball (Robert *et al.*, 1996). The novel idea at the second part of this paper is that if we use the shape of a fullerene C80, which is a 42-faced truncated triacontahedron as a template, we can build much larger domes with the same unit edge length as Figure 2. The hexagons are slightly flattened, because they are based on the Golden rhombuses of a triacontahedron, with angles of approximate 116.5 degrees (Cundy, 1961, p.121). The diameter of the C80 fullerene is about 117% larger than the C60 fullerene. The fullerene C80 has a belt of 10 hexagons in a row around its equators.

*Figure 1* A 6-frequency icosahedral paper dome designed by the author for Swiss Pack Expo Basel 1971. Note that the distance between two centres of the pentagonal stars is divided into 6 edges i.e., 6-frequency. Diameter 8m, height 5m.

*Figure 2* Paper models of fullerene C60 and C80 built with the same edge length. Note the C80 is made of non-regular hexagons and larger in size. The black pentagonal faces are purposely omitted and just left as empty space.

## BAMBOO DOMES BASED ON THE SYMMETRICAL SHAPE OF FULLERENE C60

For a classic bamboo dome, the template of a truncated icosahedron is used, consisting of 12 pentagons and 20 hexagons, equivalent to the shape of a fullerene C60 or Bucky ball (Schwabe and Ishiguro, 2006, p.138-139). For dome builders there are two ways to dissect a sphere; that is into a hemisphere or in most cases into a so called 5/8 dome, which uses of the total of 32 faces only 21 faces (Kahn, 1971, p. 4). It is necessary to build a dome not with pentagons and hexagons, but with pentagrams and hexagrams, that means rigid star-polygons, forming twin-pentagrams and twin-hexagrams, thereby receiving strong overlapping connections between all the bamboo-star-elements as Figure 3. The dome above is made of 240 bamboos with an equal strut length to form 6 decagonal and 15 dodecagonal bamboo stars. The bamboo stars are woven up and down, which gives additional strength and by doing so, even thick bamboo struts will fit neatly on top of each other as Figure 5. Note that a left-handed pentagram comes on top of a right-handed pentagram and a right-handed hexagram on top of a left-handed hexagram as Figure 3. By using a 2-m unit-strut length we get a dome diameter of 5.5m and if we use a 3-m unit-struth length the diameter is approximate 8m.

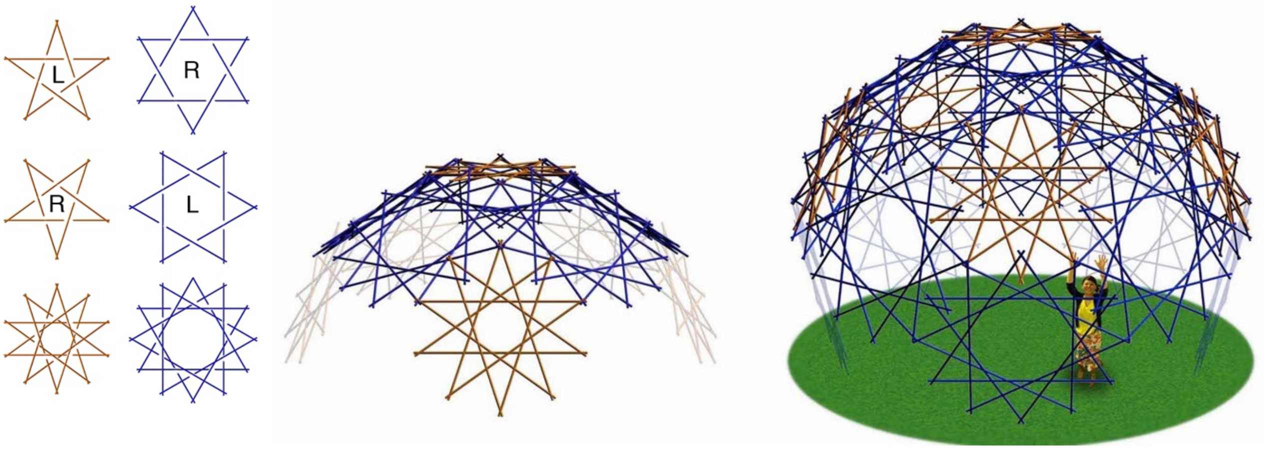

*Figure 3* The construction of a bamboo dome using two types of left- and right-handed woven twin-star shaped bamboo elements. The dome is built from top part to downwards. (Drawing courtesy of Saori Nakajima, Tama Art University Tokyo).

*Figure 4* Lashing technique of the bamboo struts using rubber connectors. For a 5/8 dome we need 800 pcs. connectors. The mushroom-like rubber head is pulled and wrapped twice around the bamboo, then secured by hooking into the tale.

*Figure 5* This bamboo dome is strong enough to climb on.
Hart&Demaine 2008. Seto Inland Sea 2012 (photos by author)

## A NEW TYPE OF BAMBOO DOME BASED ON THE SHAPE OF FULLERENE C80

The main reason to use a fullerene C80 as a template is that by using the same unit strut length, we can get a much larger dome. A fullerene C80 has 10 faces more than a fullerene C60. We adapted a different weaving method to make bamboo stars with wider openings. Note that the dodecagonal bamboo-star consists of three bamboo squares! The C80 fullerene has 42 faces and is called a truncated triacontahedron or chamfered dodecahedron or a Goldberg polyhedron. To use the fullerene C80 as a template to construct a bamboo dome, suits the flexibility of bamboo very well as it can adjust and accommodate the slightly deviation of the hexagons from regularity. Note that the connection between a decahedral- and dodecahedral-star is only approximative as Figure 6. The units are designed to be folded up into hyperboloid-like bamboo bundles and vice versa (Hilbert, 1952, pp.16-17), and therefore packed in a small space, easy transported, and in a short time assembled to a dome.

By using 2-m strut length, the star elements are 2.8m in diameter which makes them impractical to transport as they would fit only in a wing trailer. The new practical design to fold them up into bundles makes them easily transportable in any station wagon. Note that to make the 26 double stars we need double the number of struts: in total 600 struts and 1600 rubber connectors. By using 2-m unit-struts we get a dome diameter of 8m. If we use 3-m unit-struts we get diameter of 12m and if we use 5-m struts, we would get a diameter of 20m! For convenient reasons we used a unit-strut length for most of the domes. Mathematically a pentagonal-strut is approximative 92% shorter than a hexagonal-strut, but we adjusted those by leaving the pentagonal bamboo-ends slightly sticking out as Figure 7.

I could imagine that the famous light weight architect and Pritzker prize winner Frei Otto would have been delighted to see this filigree bamboo dome constructions as in Figure 8 (Otto, 1990, frontpage). Buckminster Fuller named the view through a dome grid "My Private Sky" (Krausse, 1990, p.330). Of the total 32 faces if a fullerene C60 sphere we used 21 faces to make a 5/8 dome. 32: 21 = 1.523. Of the total of 42 faces of a fullerene C80 sphere we used 26 star-shaped faces to build our 5/8 dome. 42 : 26 = 1.615 which is surprisingly close to the Golden ratio of 1.618!

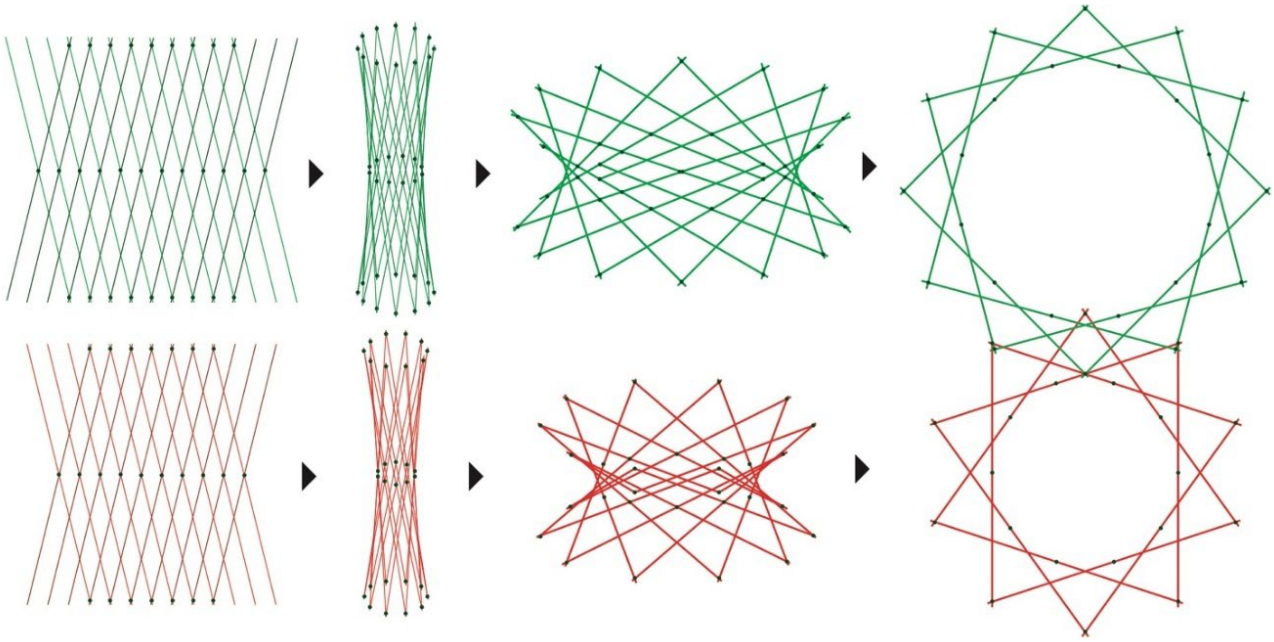

*Figure 6* The arrangement of the bamboo struts to make the new type of bamboo stars. On the top left, the pattern how to overlay the 24 struts and below the 20 struts to form hyperboloid-like bamboo bundles, convenient for transportation. The bundles unfold into a twelve-folded, and below into a ten-folded bamboo-star, the elements to assemble the dome.

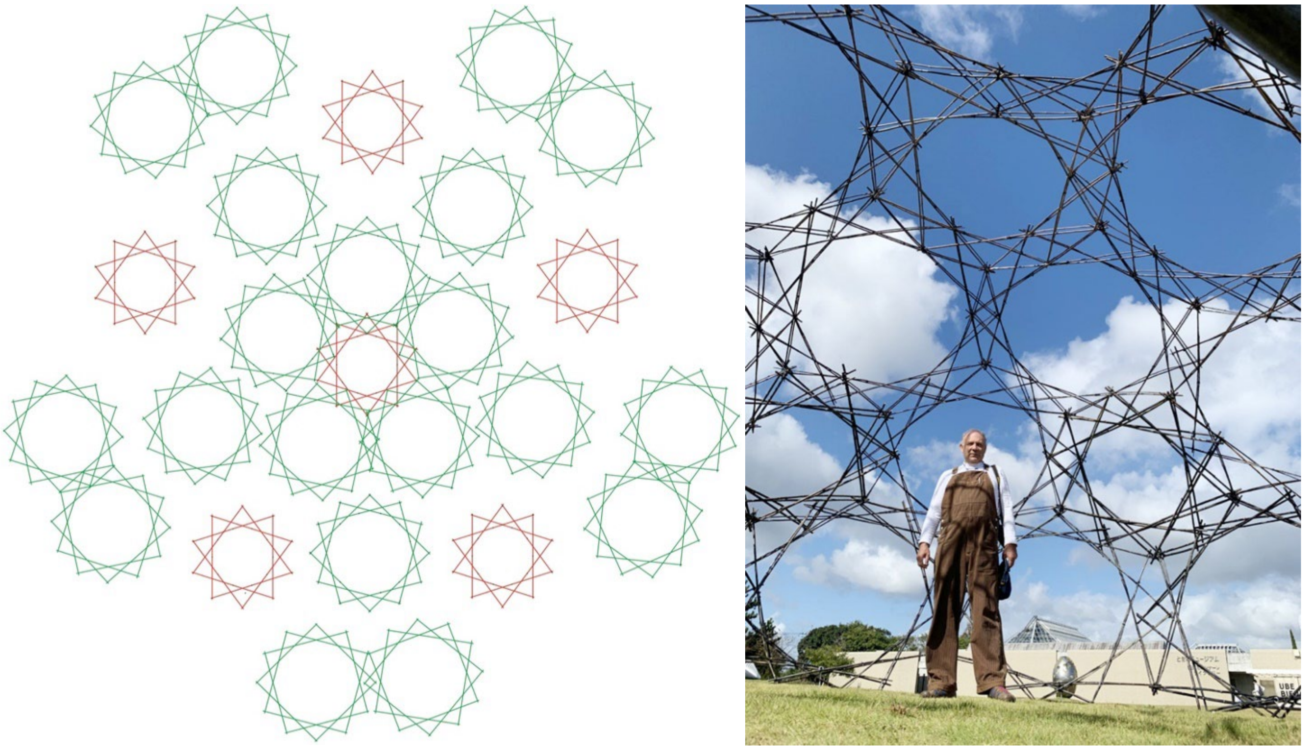

*Figure 7* On the left the assembly-diagram of a fullerene C80 bamboo dome made from 6 decagonal and 20 dodecagonal stars. Note that all the bamboo-stars are double layered and made from 600 bamboo struts of 2-m. Assembled in half a day to a dome with a diameter of 8m and a height of 5m and a weight of 100 Kg. Ube Sculpture Biennale Japan 2021.

*Figure 8* Fisheye view of a fullerene C60 dome. Snow crystal like fullerene C80 dome. Filigree like a giant Radiolaria; the top section of a fullerene C80 bamboo dome using the new weaving-method with big openings to see the open sky.

## CONCLUSION

The use of the shape of a fullerene C80 as a template, with a unit size bamboo-strut, gives us larger and stabler 5/8-bamboo-domes, because the ten bamboo-star elements at the bottom can be securely fixed to the ground as Figure 9. A fullerene C60 dome in comparison is rather unstable because it touches the ground only on five delicate points as Figure 3. The innovative way to fold the bamboo-stars into compact hyperboloid-like bundles, makes them well-suited for transportation to the construction site, where they are unfolded and assembled into a big bamboo dome in a short time.

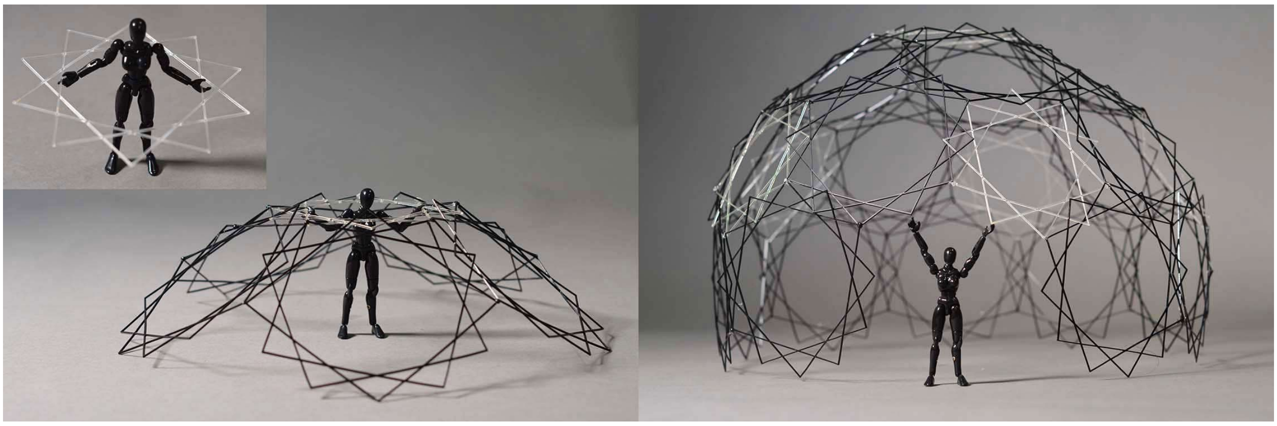

*Figure 9* Left side: Starting with the top centre decagonal star, where on its edges five dodecagonal stars are attached to. Right side: The 5/8 dome is built from the top downwards and there is no need for a crane or scaffolding! The row of the 10 dodecagonal stars is standing all on the ground and one is left empty for the entrance. Model size M = 1 : 200.

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### Caspar SCHWABE

Caspar Schwabe was born 1953 in Zurich, Switzerland. He was involved in numerous interdisciplinary science and art exhibition. Since 1995 he is honorary member of SIS-Symmetry: art and science. His “Kinematic Serendipity” performance of flexing mathematical models was shown at numerous exhibitions and conferences all over the world. He was one of the creators of the legendary Phenomena 1984 exhibition in Zurich. He was a member of the first Symmetry exhibition in Mathildenhöhe Darmstadt 1986, the Swiss science expo Eureka 1991 in Zurich and the travelling exhibition My private Sky on Buckminster Fuller 1999. For the Swiss pavilion in Lisbon Expo 1998, he created a 4-d cube as water tesseract. Currently he is professor at the graduate school in Kobe Design University in Japan.