1. Walther Bauersfeld, hemispherical dome using a system of metal bars in Jena, 1922

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Projecting stars, triangles and concrete

The Early History of Geodesics Domes, from Walter Bauersfeld to Richard Buckminster Fuller

Sometimes artefacts that had been designed with a scientific purpose turn into cultural icons that influence art and architecture, mainly because the viewer's relationship with the work and the very act of receiving it is quite different. In this way, the receiver extracts same of the properties of the original artefact and uses them in other prototype that appears in a completely different way to our eyes. This is the case with the first hemispherical dome using a system of metal bars connected by pin-joints (fig. 1) made by the Zeiss Company headquartered in Jena, Germany, designed by its chief engineer Walter Bauersfeld, and its reception some years later by the artistic and architectural avant-garde.

The Wonder of Jena

In 1913 the company Zeiss was entrusted by the Deutsches Museum in Munich with the construction of a projector that would reproduce the movements of the stars and planets on a hemispherical dome. From the very beginning, the nature of the assignment was going to change it into a cultural artefact. So far this kind of building was known as *Sternentheater* or *Sternenschau* [›Star Theatre‹ or ›Star Show‹]. They could accommodate few people, mainly due to the concept of the show. The planetarium, as known so far, was based on a fixed projector; the celestial dome was rotated to simulate both the movement of the

2. Walther Bauersfeld, Projector in the Zeiss Planetarium, 1926

stars as the earth. Such technique was applied in the so-called Atwood Celestial Sphere, designed by Wallace A. Atwood, director of the Museum of Science in Chicago. He designed in 1911 a spherical planetarium with a diameter of 4.57 meters, illuminated from the outside.[1] This type of planetarium could not accommodate a large audience. Since the projector is fixed, it involves a quite complex mechanism in order to rotate the dome to simulate the movements of stars, planets and the earth itself.

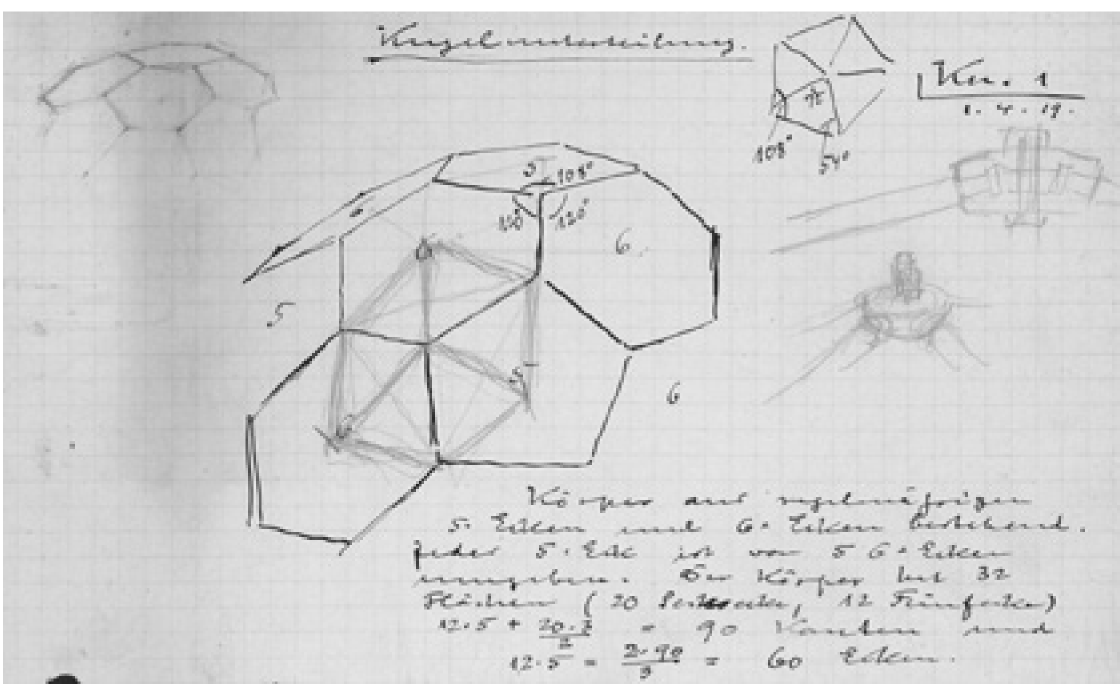
For the Munich dome, Bauersfeld flipped the concept, casting images from a mobile projector on a static surface. He designed a machine (fig. 2) that could rotate around its axis, casting images from 32 small projectors that reproduced the motions of the stars. The problem he faced was to divide the area of the projecting head into 32 flat surfaces for the individual projectors. The regular polygon with most faces is the icosahedron, with 20 triangular faces and 12 vertices. Bauersfeld truncated the vertices of the icosahedrons, getting a solid with 32 flat faces, in particular, 20 hexagons stemming from the original icosahedron and 12 pentagons resulting from the cutaway vertices. Also, a circumference of the same diameter can be inscribed in both the pentagonal and hexagonal faces. This principle simplifies the production and the placement of lenses, so it has been subsequently used by Zeiss and other companies.

Some documents in the Archiv Carl Zeiss called *Kugelunterteilung* show how Bauersfeld divided the sphere into 20 faces and later on, into 32 sections. This document, dated from 1st April 1919, has eight pages dealing with the division of the sphere, labelled as Ku1 through Ku8. In Ku1 (fig. 3) a note states: »Geometrical bodies consist of pentagons and hexagons. Every pentagon is surrounded by five hexagons. The figure hat 32 faces (20 hexagons and 12 pentagons), $12 \times 5 + 20 \times 3/2 = 90$ edges and $12 \times 5 = 2 \times 90/3 = 60$ vertices.«[2] In this way Bauersfeld invented the star projector.

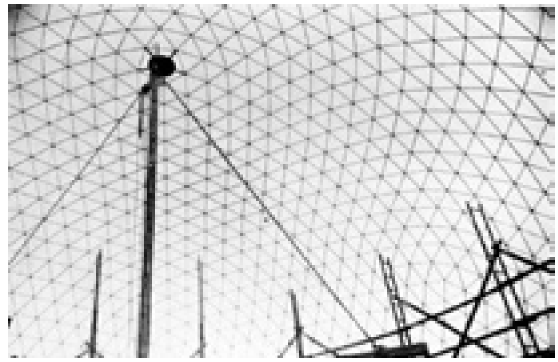
[1] Cf. Krausse 2006.

[2] »Körper aus regelmäßigen 5 Ecken und 6 Ecken bestehen. Jeder 5° Eck ist von 5 6° Ecken umgeben. Der Körper hat 32 Flächen (20 Sechsecke, 12 Fünfecke) $12 \times 5 + 20 \times 3/3 = 90$ Kanten und $12 \times 5 = 2 \times 90/3 = 60$ Ecken.« Bauersfeld 1919, 1.

3. Walther Bauersfeld, manuscript, Ku1 in Kugelunterteilung, 01.04.1919



4. Walther Bauersfeld, Planetarium in the Carl Zeiss factory in Jena, 1924



5. Walther Bauersfeld, hemispherical dome using a system of metal bars in Jena, 1922

The next problem that Bauersfeld had to solve was the construction of a hemispherical projecting surface where he could test the new projector. He needed a structure approximately 16 meters in diameter; it should resist inclement weather conditions for a couple of months without being neither too heavy nor too expensive. They decided to build it on the roof of the building number 11 of the Zeiss factory complex in Jena (fig. 4). At first, they had considered solving the problem with a cloth surface, such as the ones used in circus covers. They gave up this idea soon, since canvas, like all textile materials in the period, was very expensive due to high inflation. By contrast, steel, a German product, was relatively cheap; thus, they considered the possibility of constructing the hemisphere as a grid of metal rods.[3]

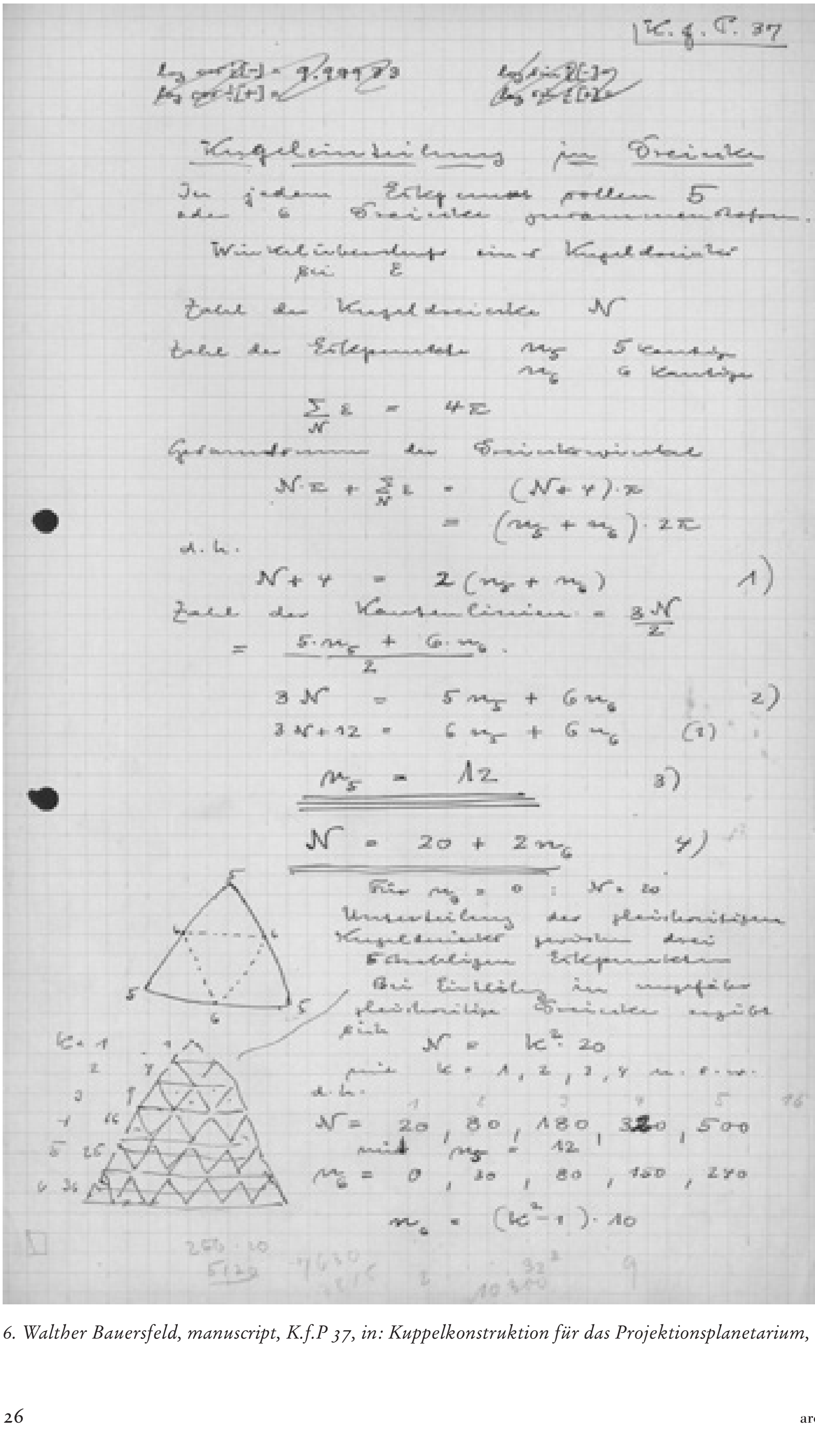
However, this construction system did not guarantee by itself a smooth surface in the inside nor the desired protection from the weather conditions. Technicians of the company Dyckerhoff and Widmann (DYWIDAG), which had already constructed other buildings in the complex of the Zeiss factory in Jena, suggested that the best solution was to project a thin concrete shell onto the hemispherical grid of metal rods, acting thus as a kind of formwork or centring.

In order to materialise the geometric form of the hemispherical metal bar frame, Bauersfeld used the same subdivision scheme he had devised for the surface of the projecting head, as two series of drawings known as Ku1 and Ku2 in the Zeiss archive shows (fig. 5). Reusing these ideas, Bauersfeld »calculated a spatial network construction in which the iron flat bars with a cross-section of 8 × 20 mm and a length of approx. 60 cm were held together at the intersections by specially developed node connections. The almost 4,000 bars with 50 different lengths [...] The complete network weighed only approx. 9 kg/qm including the projection surface.«[4]

However, Bauersfeld needed to divide the sphere into smaller parts in order to use more manageable bars in the construction of the hemispherical dome, rationalising the process in order to get smaller units. Thus, he began to project the icosahedron into the sphere, but he had 20 triangles that were still too big. He also knew that each of the 20 triangles of the spherical icosahedron could be divided into six equal triangles so that the geometrical figure would have a total number of 120 equal triangles. This implies that he already had a model where he could find out the lengths of the bars so that they will be equal in the 120 triangles. This triangle was named by Bauersfeld as *Charakteristisches Dreieck* [characteristic triangle].

3 Cf. Breidbach 2011, 57.

4 »Er berechnete eine räumliche Netzwerkkonstruktion, bei welcher die eisernen Flachstäbe mit 8 × 20 mm Querschnitt und ca. 60 cm Länge an den Kreuzungsstellen durch speziell entwickelte Knotenverbindungen zusammengehalten wurden. Die fast 4.000 Stäbe mit 50 verschiedenen Längen, bei Zeiss gefertigt, besaßen eine Genauigkeit von 1/20 mm ihrer Länge. Das komplette Netzwerk wog einschließlich Projektionsfläche nur ca. 9 kg/qm.« Kurze 2011, 65.



K.f.P. 37

Kugeleinteilung in Dreiecke

In jedem Eckpunkt sollen 5 oder 6 Dreiecke zusammenstoßen.

$N + 4 = 2(n_5 + n_6)$ 1)

$3N = 5n_5 + 6n_6$ 2)

$n_5 = 12$ 3)

$N = 20 + 2n_6$ 4)

Für $n_6 = 0$: $N = 20$

$N = k^2 \cdot 20$

$N = 20, 80, 180, 320, 500$

$n_6 = 0, 30, 80, 150, 240$

$n_6 = (k^2 - 1) \cdot 10$

6. Walther Bauersfeld, manuscript, K.f.P 37, in: Kuppelkonstruktion für das Projektionsplanetarium, 1922

Transcription of Fig. 6:

Division of the Sphere in triangles

In each vertex must concur 5 or 6 triangles
Count of angles excess in a spherical triangle
by Σ
Number of spherical triangles N
Number of vertices n_5 by pentagons
n_6 by hexagons

$$\sum_n E = 4\pi$$

Total Sum of the angles of a triangle

$$N\pi + \sum_n E = 4\pi = (N+4)\,\pi$$

$$= (n_5 + n_6)\, 2\Pi$$

i.e.

$$N + 4 = 2(n5 + n6) \qquad (1)$$

Number of edges = $3\frac{N}{2}$

$$3N = (5n_5 + 6n_6)/2 \qquad (2)$$

$$3n + 12 = 6n_5 + 6n_6 \qquad (1)$$

$$n_5 = 12 \qquad (3)$$

$$N = 20 + 2\,n_6 \qquad (4)$$

For $n_6 = 0$: N= 20
division of the equal spherical triangles with three vertices of a pentagons.
With the forward equal division of the spherical triangle's edge, it could be formulated:

$$N = K^2 \cdot 20$$

With K = 1, 2, 3, 4 and so on
i.e.

	1	2	3	4	5	16
N =	20,	80,	180,	320,	500	
n_6 =	0,	30,	80,	150,	240	

$$n_6 = (K^2 - 1)\, 10$$

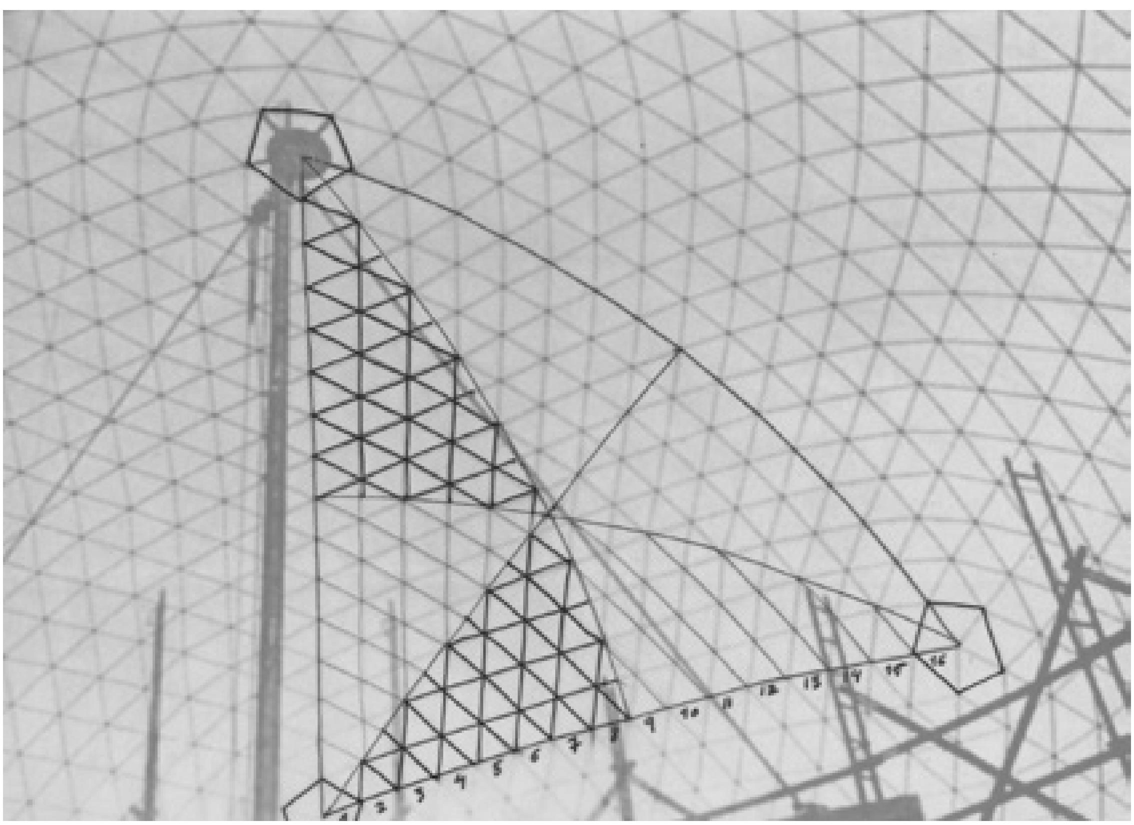
First of all, Bauersfeld calculated a mathematical formula to figure out how many triangles, pentagons and hexagons will appear when the spherical triangle of the icosahedron is divided k times. In this formula, N is the total number of triangles included in the entire sphere, while K is the number of divisions in each side of these spherical triangles. In this way, he could determine how many bars are needed to construct the entire hemispherical dome.

In document K.f.P 37 from the series BACZ 26025 in the Zeiss Archive, with the title *Kugeleinteilung in Dreiecken* [Division of the Sphere in triangles] (fig. 6), Bauersfeld mentions different parameters as number of vertices where five or six triangles concur and the number of edges, arriving at the result $N = 20 + 2n6$. If n6 – the number of vertices where six triangles concur – is equal to zero, we should have $N = 20$, that is, 20 triangles, and as Bauersfeld said »with the following division of the spherical triangle's edge into equal parts, it can be stated: $N = K^2\ 20$«.[5]

In this mathematical formula, N is the number of triangles in which the sphere is divided, K is the number of divisions of the spherical triangle's edge, and 20 is the number of spherical triangles in the sphere. The K concept introduced by Bauersfeld was to be used later on by other authors dealing with domes built with bars; for example, Richard Buckminster Fuller used the term ›frequency‹ with the same meaning. In this way, as the number of divisions of the spherical triangle increases, the shape of the dome approaches a perfect sphere more closely. We should remind that what Bauersfeld and the building engineers were trying to do was to approximate the shape of a sphere

5 Bauersfeld 1922a, Kuppelkonstruktion für das Projektionsplanetarium, K.f.P. 37.

7. Sketch showing the division of the spherical triangle on 5



through an icosahedron inscribed on it. The icosahedron should be divided again in order to get smaller triangles reducing the dimensions of the bars required to build the dome.

The next step is to find out the optimal relationship between the length of the bars and the factor K, that is, the number of parts in which each edge of a spherical triangle should be divided. In a sheet with the title K.f.P 38 it is written: *Relationship between the longitude l and the number of triangles N in average angles.*[6] The text hints that Bauersfeld was seeking relationships between these factors that he could use in order to change the weight of the construction or the numbers of bars. So he arrived at a mathematical formula with three terms, which he could change at will. L is related to the longitude of the bars, R is the radius of the sphere and K, as it is already known, is the total number of sections in which the icosahedrons edge's triangle is divided. In this way, he fixed the radius (R) and gave it a dimension of 8 meters. With this radius he got different results, from which he could choose different solutions. However, he went forward and decided to give to K the value 16 (fig. 7), so the results were those:

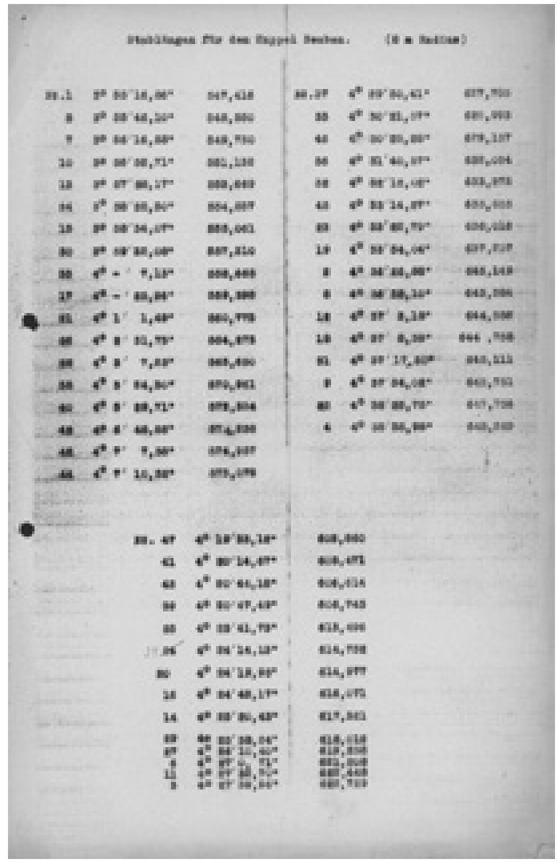
With R = 16 and K = 16, L will be equal to 0,6 in meters

Using the other mathematical formula
$N = K^2$ 20, $16^2 \times 20 = 5120$ triangles
Number of edges = 3/2 N = 7680 bars.

Anyhow, Bauersfeld was trying to build a hemispherical dome; thus he only had needed half this number of bars, that is 7680/2 = 3840. This is the same number mentioned by Kurze in the article mentioned earlier, where he defined the longitude of the bars as 60 cm what is 0,60 m.

Finally in the documents called *Rechnung der Stablangen für Kugelteilung* [Bar length calculations for the division of the sphere],[7] Bauersfeld computed the dimensions of the bars which were going to be used for the dome; as we had seen, the bars actually were used as a formwork for the concrete that was going to be projected on it. The document includes 31 pages where Bauersfeld performs the same geometrical calculations and trigonometrical relationships between the different parts in which the characteristic triangle is being divided. Let us remember that the characteristic triangle is one of the six equal triangles in which the spherical triangle could be divided and there are a total of 120 of them in the spherical icosahedron. Bauersfeld knew this fact and he also was aware of it and what is more important, having the length of the bars of one of these characteristic triangles could have the total dimensions of the bars of the hemispherical dome.

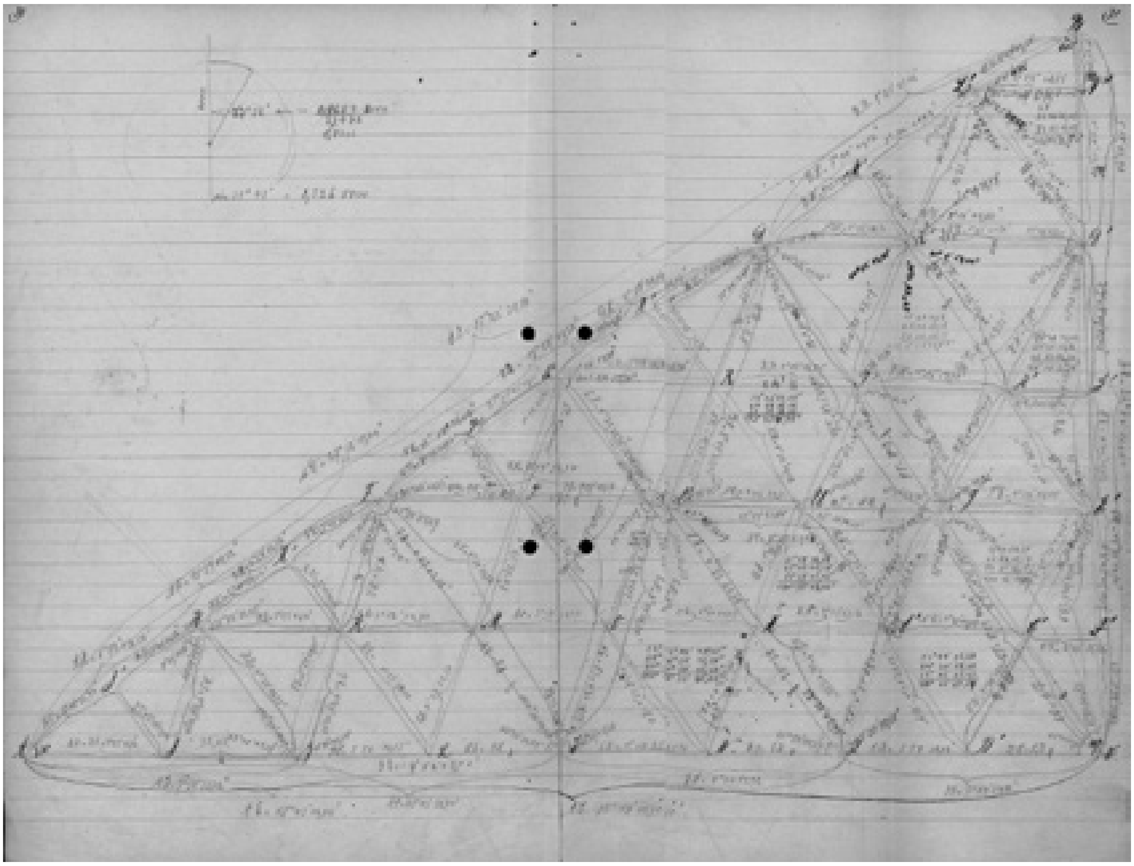
In the first 24 pages Bauersfeld divided the edge of the characteristic triangle into four parts and computed the distances in degrees; later on, he translated these



8. Walther Bauersfeld, manuscript, Stablängen für den Kuppel Neubau (8 m Radius), in: Kugelunterteilung-Rechnung der Stablängen für Kugelteilung, 1922

6 Bauersfeld 1922a, Kuppelkonstruktion für das Projektionsplanetarium, K.f.P. 38.

7 Bauersfeld 1922b.



9. Walther Bauersfeld, manuscript, Characteristic triangle, in: Kugelunterteilung-Rechnung der Stablängen für Kugelteilung, 1922

in mm in pages 25 to 27. In the page (fig. 8) named *Stablängen für den Kuppelneubau (8 m Radius)* [Bar's dimensions for the new dome (8 m radius)],[8] dimensions are written both in degrees and mm. In page 30 and 31 the characteristic triangle (fig. 9) is drawn, and all the distances are given. It should be notice that the characteristic triangle is being divided into 8 parts, that is, the frequency or the constant K is equal to 16, since the side of the characteristic triangle is the half the side of the spherical triangle. The drawing is a summary of the final dimensions of the bars used to build the 16-meters wide dome on top of the building number 11 of the Zeiss complex as centring for projected concrete.

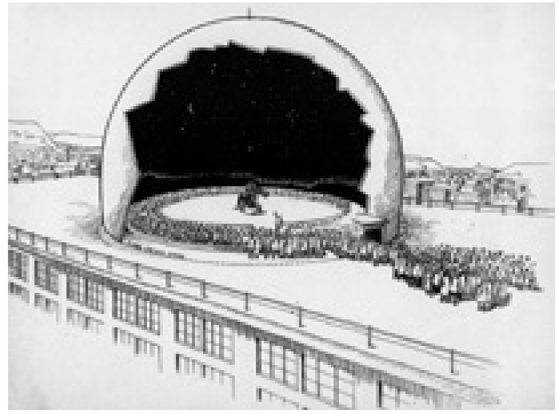
In order to build a shell with a thickness of three inches, that is, a thickness-diameter ratio similar to the shell of an egg, they used a sprayed concrete technique that had been recently invented and patented in the USA, using the frame as permanent centring. In order to assure a good execution of the inner projection surface, a 3 × 3 m wood formwork with a spherical curvature was used (fig. 10). After 24 hours, the formwork was removed, and concrete projection was resumed in order to finish the hemispherical dome shape, which included the metal bars grid within the concrete shell.

In August 1924 the hemispherical dome was finished; in two months 50.000 people visited the building to enjoy the Stars Theatre. The planetarium on the roof of the building of Zeiss (fig. 11) created such

8 Bauersfeld 1922b, Stablängen für den Kuppelneubau (8 m Radius).

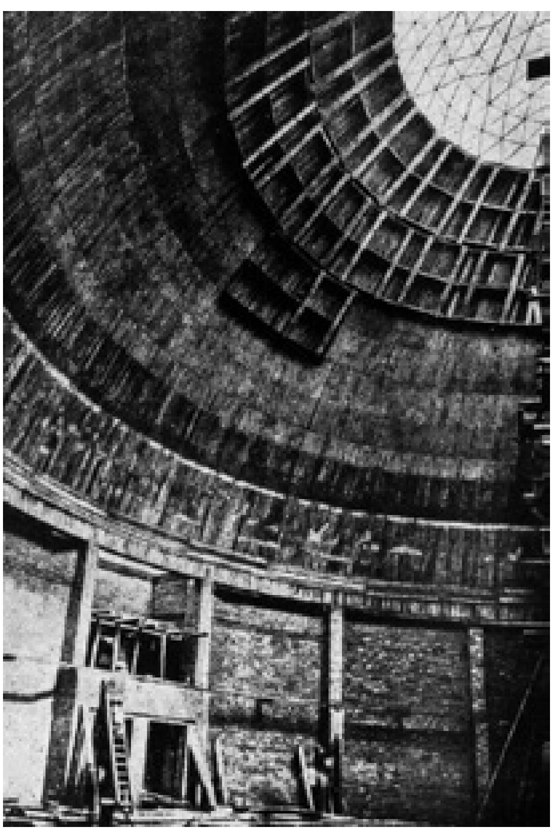
excitement that the works for a permanent building known as the Jena Planetarium began in the same year. It featured a dome 25 meters in diameter with a classical portico at the entrance. Due to the success of this pioneering show, from 1926 on, a series of planetariums were opened in Wuppertal-Barmen, Leipzig, Düsseldorf, Dresden and Berlin.

Zeiss were aware of the importance of the construction system used in Jena and, later on, in all the planetariums built by the company. In the beginning, the feature that got more attention was the thin concrete sheet implemented by Frank Dischinger at DYWIDAG. Later on, in 1922, Zeiss patented the system to build a reticular dome using metal bars (fig. 12) named *Verfahren zur Herstellung von Kuppeln und ähnlichen gekrümmten Flächen aus*



11. Drawing of Planetarium on top of the Zeiss company building, Jena, 1924

10. Wood formwork with spherical curvature in Carl Zeiss planetarium, Berlin, 1926



12. Carl Zeiss Company, Verfahren zur Herstellung von Kuppeln und ähnlichen gekrümmten Flächen aus Eisenbeton, Patent nº 415395, Berlin 1922

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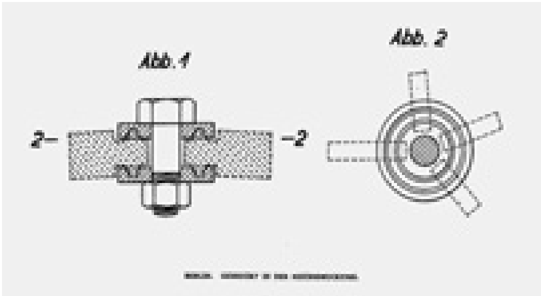
KLASSE 37a GRUPPE 2

Firma Carl Zeiss in Jena.



13. Carl Zeiss Company, detail in patent nº 420823, Knotenpunktverbindung für eiserne Netzwerke, 1922

Eisenbeton [Method for making domes and similar curved surfaces of reinforced concrete]. The memory stated, that »the new method consists in constructing a spatial network of iron bars in the roof cladding, supporting itself and part of the total intrinsic weight, and using lightweight formwork directly attached to the ironworks.«[9] This formwork should be positioned without introducing any tension that might deform the metal framework of bars. Also, no deformation was appreciated caused by bending stress, during the execution of the reticular frame. As mentioned above, the structural metal frame was seen as an auxiliary system to project the thin concrete shell and would be therefore hidden by it. There are no other data in the patent about how to build the reticular dome, or the way bars are joined to each other. It should be remarked again that the novelty of the method is that it is self-supporting and does not need any other auxiliary element to build the hemispherical dome, in fact, »the new method avoids the need for costly underpinning, which is replaced by the formwork mentioned above, and also virtually eliminates the stresses of the equipment, which would otherwise have to be taken into account when dimensioning the thickness of the individual parts.«[10]

Another patent granted to Zeiss and connected with the Jena dome deals with constructive aspects from a hemispherical reticular dome, specifically the knots joining the metal bars (fig. 13). With the name *Knotenpunktverbindung für eiserne Netzwerke,*[11] the constructive knot is patented, in the same date, i.e. 9th November 1922. The patent, which can be translated as ›Knots for a metal frame grid‹, describes a generic knot to join several bars; it is not specified how many bars meet at one knot. The joints are made with two metal round plates with grooves where the bars are inserted as Bauersfeld had already drawn in his notes (fig 14).

Once the bars are put into position, the knot would be closed by a threaded bolt, and the bars would be tightly joined with each other, since the node must be fully capable of transmitting forces arising from each bar. Bars with circular section have a slotted end that allows them to be inserted perfectly into the metal plates. Thus, the design of the system allows joining different numbers of rods at each knot, while the angles between bars and the metal plate may be different.

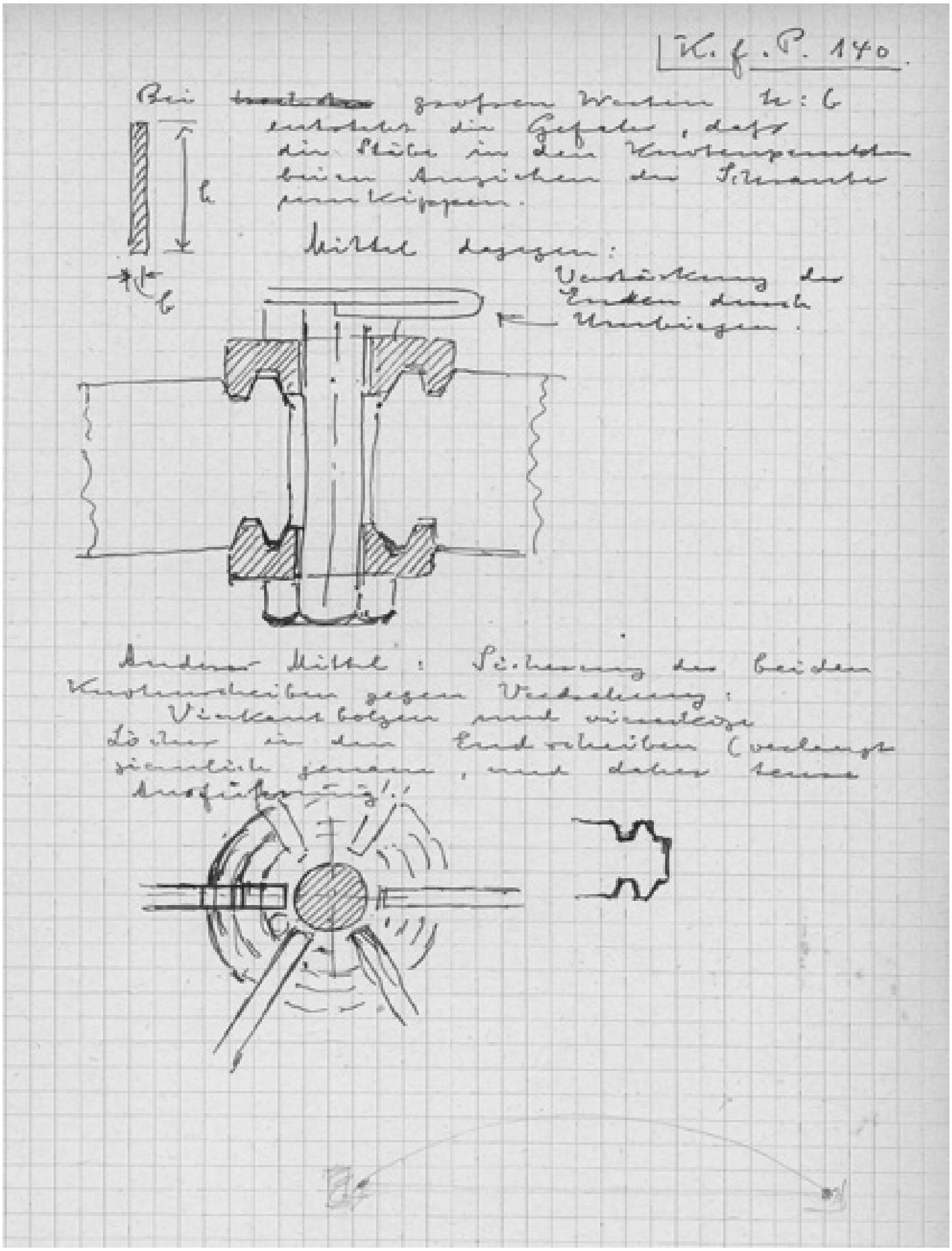
The claims supporting the patent filing are those: »1. Node connection for iron networks, in which the rods are held together by two lateral plates interspersed with screw bolts and plates and rods engage in one another with a groove and pin, characterized in that the grooves of the plates run round in a circular manner all around. 2. A node connection according to claim 1, characterized in that the wedge pins of the rods do not fill the wedge grooves of the plates to the bottom.«[12]

[9] »Das neue Verfahren besteht darin, dass ein sich selbst und ein Teil des Gesamteigengewichts tragendes, in der Dachhaut liegendes räumliches Netzwerk aus Eisenstäben aufgebaut und unter Verwendung leichter, unmittelbar an das Eisenwerk angehängter Schalungen, beispielsweise durch das Spritzverfahren, mit dem zur Erreichung der vollen Tragfähigkeit erforderlichen Betonmantel umhüllt wird.« Firma Carl Zeiss 1922a, 1.

[10] »Bei dem neuen Verfahren wird eine kostspielige Unterrüstung vermieden, an deren Stelle die erwähnten Schalungen treten, und es fallen auch die Ausrüstungsspannungen so gut wie vollständig weg, denen sonst bei der Bemessung der Stärke der Einzelteile Rechnung getragen werden muss«. Firma Carl Zeiss 1922a, 1.

[11] Firma Carl Zeiss 1922b, 1f.

[12] »1. Knotenpunktverbindung für eiserne Netzwerke, bei der die Stäbe durch zwei seitliche, von Schraubenbolzen durchsetzte Platten zusammengehalten werden und Platten und Stäbe mit Nut und Zapfen ineinandergreifen, dadurch gekennzeichnet, dass die Nuten der Platten kreisförmig ringsum laufen. 2. Knotenpunktverbindung nach Anspruch 1, dadurch gekennzeichnet, dass die Keilzapfen der Stäbe die Keilnuten der Platten nicht bis zum Grunde ausfüllen.« Firma Carl Zeiss 1922b, 2.



14. Walther Bauersfeld, Sketch, K:f.P 140, in: Kuppelkonstruktion für das Projektionsplanetarium, 1922

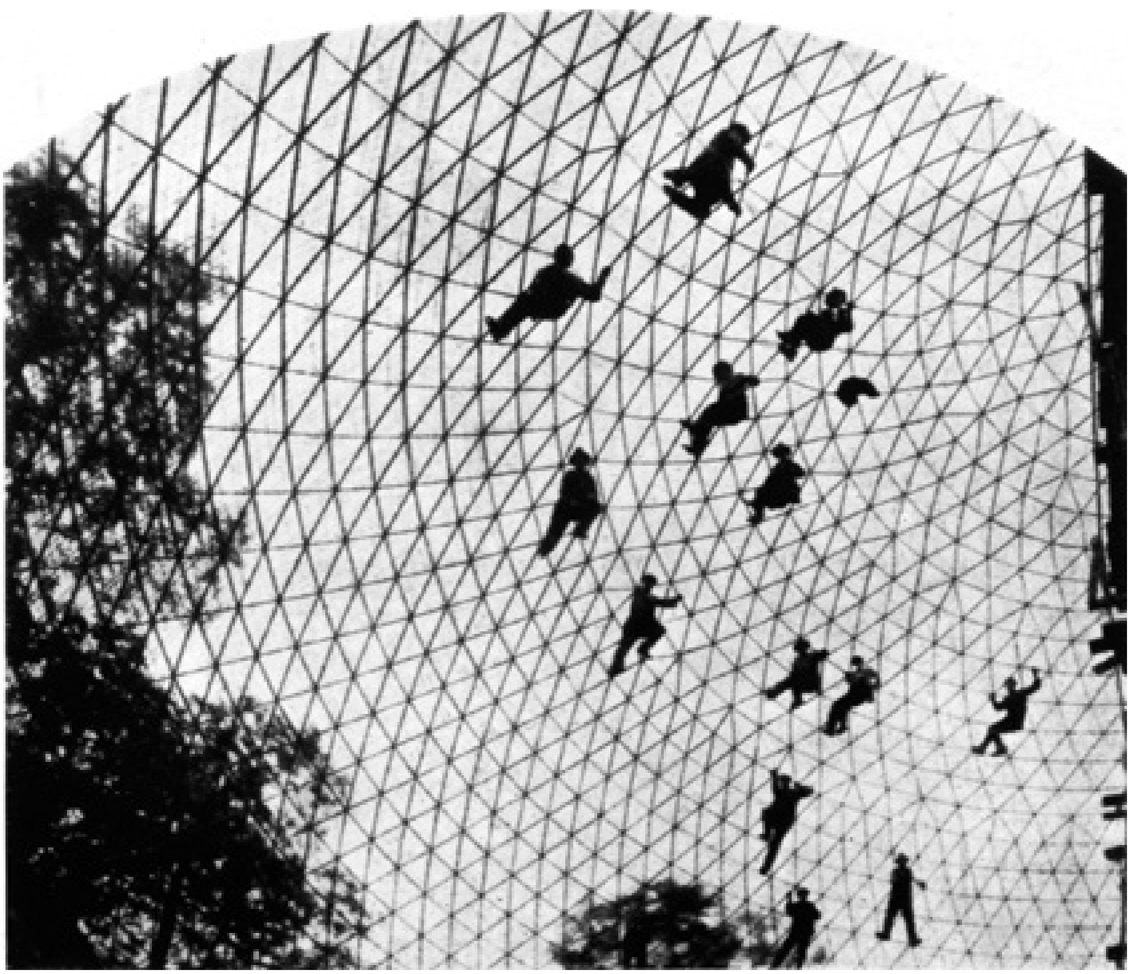
The hemispherical dome as an architectural paradigm in the thirties

The Berlin planetarium was photographed by László Moholy-Nagy, who included it in his well-known book *Von Material zu Architektur*.[13] Perhaps Moholy-Nagy was one of the first to recognise the impact of the metal bar reticular dome by itself. While the frame serves as permanent formwork, it also has a secondary function; in the words of Joachim Krausse; »That it could have or make a structural network was already known in a theoretical way, but here it is developed with a radical concept – a geometry based on great circles creating a tectonic frame. We are in the starting point of a paradigm, which was not recognised until the late twentieth century, that is, structural grids«.[14]

[13] Moholy-Nagy 1929.

[14] »Dass ein Netz ein Skelett vertreten oder ersetzen kann, ist zwar in der Theorie schon verbreitet gewesen, wird hier aber in bis dahin unbekannter Radikalität – nämlich einer neuen, aus Großkreisen entwickelten Geometrie – in greifbare Netzwerk-Tektonik umgesetzt. Kurz, wir befinden uns am baulichen Ausgangspunkt eines Paradigmas, das erst das 20. Jahrhundert als das ihm gemäße erkennen wird: das des Netzwerks«. Krausse 2006, 71.

15. Lázló Moholy-Nagy, Carl Zeiss Planetarium in Berlin, in: Von Material zu Architektur, 1929



As we have said, what turns a scientific artefact into an architectural icon is the influence of the position of the observer and how he or she is going to receive or perceive it. The students of the Bauhaus, who had visited the Jena Planetarium during construction accompanied by their teachers, including Mogoly-Nagy, Adolf Meyer and Walter Gropius, were utterly fascinated by the artefact, despite it was, in fact, a formwork made of metal bars that was going to be hidden after the concrete was projected on it, just the skeleton of a building. This concept had an important impact on architecture, like Krausse argued:

»The architects have observed natural structures as the physicians were finding new patterns using the new x-ray technique. Mies van der Rohe has reduced to skin and skeletons his work in the Friedrichstrasse. Behind the costume and the dress, the true and the construction courage is being sought. All of this is converged when using the x-rays as a theory in an ordinary conversation.«[15]

As X-Rays allowed to discover the inner structure of nature, students at Jena were dazzled by a building in skeletal form before concrete was projected. These rays had permitted scientists to observe how nature make its constructions and structures. Long before, a scientist who had worked in Jena, Ernst Haekel, had discovered the geometry of the radiolarian, a microscopic marine organism, which is about the same geometry that Bauersfeld used to shape the reticular dome using metal bars.

The photograph immortalised by Mogoly-Nagy (fig. 15) shows the construction of the planetarium Zeiss in Berlin, it was built by Bauersfeld although he used a different system. Anyhow, Mogoly-Nagy commented about it: »a new way of occupying the space: a group of people above a floating and transparent network, like aeroplane squadrons in the sky.«[16] What it is really impacting the viewer is the fact that he could watch the figures through the structures when he was staying at a lower level. There were no divisions between them, strengthening the illusion that the occupants are floating in space, as Krausse noticed too, when he said: »The transparent floating network allows people to fill the space freely, without contact with the ground, without any structural support. They are like tightrope walkers or flyers without any weight emerging in the space.«[17]

That is how Bauersfeld's artefact impacted strongly on the mind of Moholy-Nagy. He was not an architect, but he was deeply in touch with the profession; in his book *Von Material zu Architektur* he introduced concepts as light, energy, mass, volume and space through his experiments in photography and cinematography. These notions were actually extracted from different mathematical and physical fields. In these years many artists were influenced by Albert Einstein's theories around the fourth dimension. In Krausse's words »[…] some of the avant-garde artist as Naum Gabo, El Lissitzky, Adolf Meyer, Siegfried Ebeling, László Moholy-Nagy and lately mainly Buckminster Fuller had strongly believed in the relationships, similarities and performances between the new scientific revolution (through Planck, Einstein, Bohr etc.) and the change perceiving life and mainly the new way of understanding the profession in art and design fields.«[18]

For Moholy-Nagy, the new scientific discoveries were going to change our perception of the space, shifting the focus of architecture from static structures to dynamic ones. This involves movement relationships between the different spaces of a building, relating the outside closely with the inside, downstairs with upstairs, as well as connections between forces that are

15 »Die Architekten werfen Blicke auf Baukonstruktionen wie die moderne Kristallphysiker, die in den Interferenzmustern der Röntgenspektrographien Raumgitter entdecken. Mies van der Rohe reduziert den Bau mit seinem Hochhausproject an der Friedrichstrasse auf Haut-und-Knochen-Architektur. Hinter den Ver- und Umkleidungen wird die Wahrheit und Kühnheit der Konstruktion gesucht. All das fokussiert sich im umgangssprachlichen Ausdruck des Röntgenblicks.« Krausse 2006, 67.

16 »eine neue fase der Besitznahme von raum: eine menschenstaffel in schwebend durchsichtigem netz, wie eine flugzeugstaffel im äter.« Moholy-Nagy 1929, 235.

17 »Das schwebend durchsichtige Netz vermag die Menschen frei im Raum zu halten, ohne Bodenkontakt und ohne irgendeine Stütze. Wie Flieger oder Artisten scheinen die Menschen fast schwerelos im Raum zu agieren.« Krausse 2006, 71.

18 »[So …] glaubten einige der avantgardistischen Künstler und Gestalter, wie Naum Gabo, El Lissitzky, Adolf Meyer, Siegfried Ebeling, László Moholy-Nagy und später vor allem Buckminster Fuller an tieferliegende Beziehungen, Entsprechungen und Analogien zwischen der Revolution des wissenschaftlichen Weltbildes (durch Planck, Einstein, Bohr usw.) und der dramatischen Veränderung der sinnlich erfahrbaren Lebensumstände und besonders der auf Wahrnehmbarkeit gerichteten Praxis in Kunst und Gestaltung.« Krausse 2006, 73.

appearing as interactions of bodies. Plasticity among space, »since, in architecture not sculptural patterns, but spatial relations are the building elements, the inside of the building must be interconnected, and then connected with the outside by spatial divisions. The task is not completed with a single structure. The next stage will be space creation in all directions, space creation in a continuum. Boundaries become fluid, space is conceived as flowing-a countless succession of relationships.«[19]

The reception of the dome in the Avant-garde in the sixties through Richard Buckminster Fuller

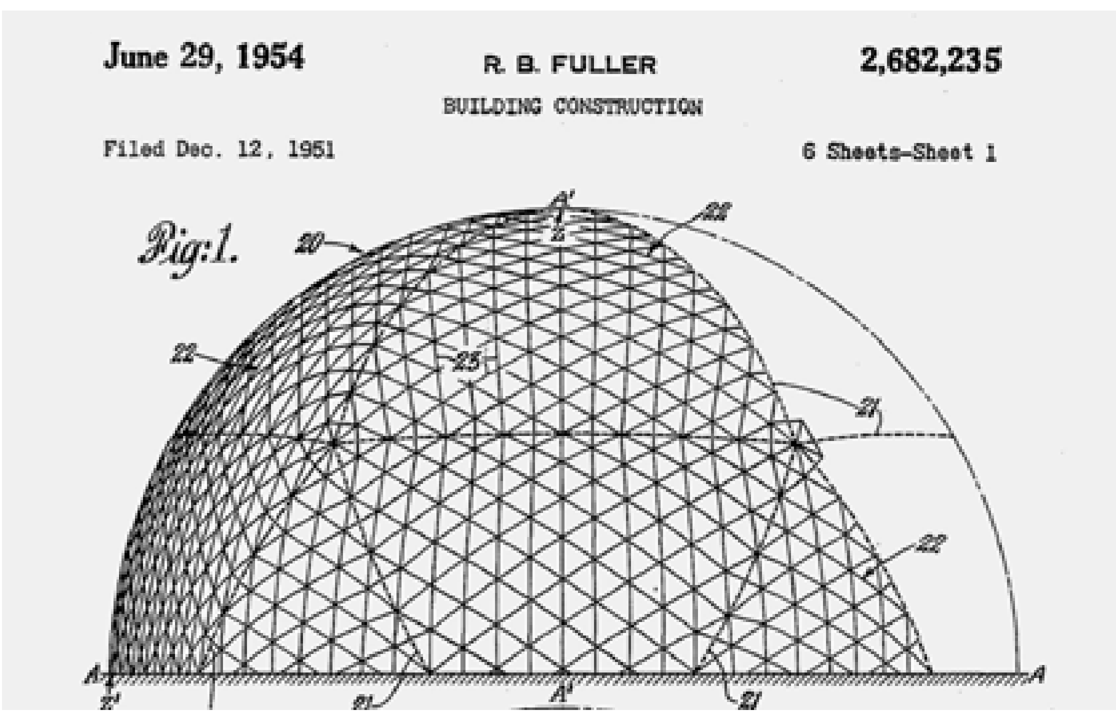
Bauersfeld and Zeiss were not aware of the importance of their invention. As Tony Rothman said in *Science a la Mode. Physical Fashions and Fictions* their patents are not very explicit nor too extensive.[20]

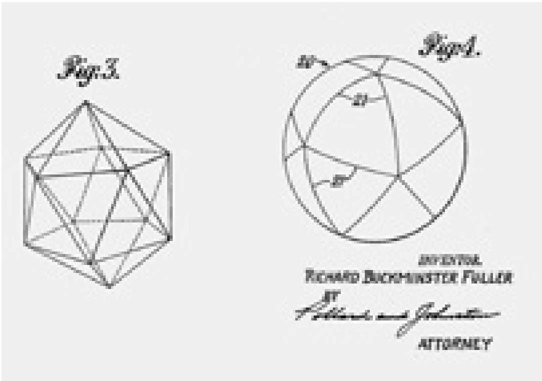
By contrast, the artefact had a major reception in the avant-garde architecture of the mid 20th century, through Richard Buckminster Fuller. Zeiss did not protect the triangulation system itself, but rather the concrete-projection system and the bar-joining knot. In the patents, the reticular metal structure had a secondary function, and it was referred only as a formwork helping as stress frame. The invention may be considered a form of serendipity, that is, the development of events by chance in a happy way. It was Fuller

[19] »[…] da bei der Architektur nicht plastische, bewegte Figurationen, sondern die räumlichen Lagerungen das Bauelement sind. So wird das Innere des Baus durch seine räumliche Gliederung in sich und mit dem Außen verbunden. Die Grenzen werden flüssig, der Raum wird im Fluge gefasst: gewaltige Zahl von Beziehungen.« Moholy-Nagy 1929, 222, cf. Moholy-Nagy 1947, 63.

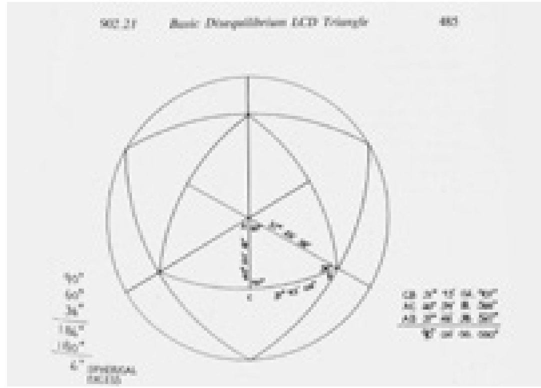
[20] »The language of the patent is not very precise but is clearly made out to the Zeiss Company of Jena and clearly refers to the technique used to build the Jena dome. To a logician it follows that the patent is for a geodesic dome. But law is not logic and I am not a lawyer; therefore, I will comment no further on the matter. The term ›geodesic‹ was applied to domes by Buckminster Fuller, who received a U.S. patent in 1954.« Rothman 1989, 59.

16. Richard Buckminster Fuller, Building Construction, Patent nº 2.682.235, 1954





17. Richard Buckminster Fuller, spherical icosahedrons, in: Building Construction, Patent nº 2.682.235, 1954



18. Richard Buckminster Fuller, LCD, in: Synergetics. Explorations in the Geometry of Thinking, New York 1975

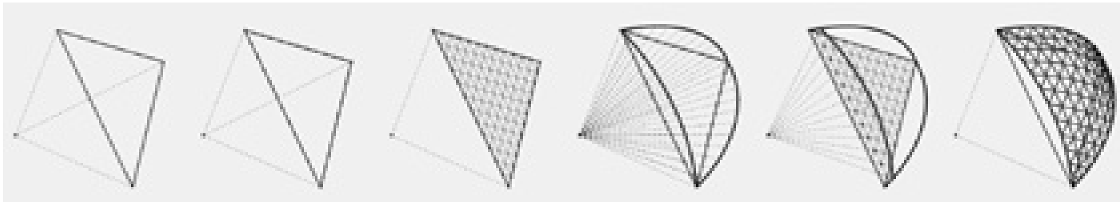
who took up the idea, making it one of the architectural paradigms of the 20^{th} century, turning a technical artefact into an architectural icon. In Krausse's words: »in some artefacts like the Planetarium, we can see a convergence of different independent fields like exacts sciences, technical inventions and artistic achievements, all of them finally coming together in a single theoretical discourse.«[21]

In 1948 Fuller began to teach at the Institute of Design in Chicago; that summer he was invited to give seminars at Black Mountain College in North Carolina, an innovative educational institution where John Cage and Merce Cunnigham taught seminars while Anni and Josef Albers brought the Bauhaus tradition to America. In summer 1948 he tried to build a dome made from aluminium strips with his students. This first attempt was unable to stand, so it was known as ›Supine Dome‹. Next year Fuller went back to Black Mountain. With the help of an engineering team, he tackled the construction of a geodesic dome using aluminium bars and vinyl sheets; it stayed erected until it collapsed in September.

Years later, Richard Buckminster Fuller patented an invention that had some points in common with the one from the Zeiss Company. Fuller used almost the same dimensions and the same system as Bauersfeld had employed to build the first planetarium on the top of the building 11 in the Jena factory. Rothman talked about the patent from Fuller too, which is called *Building Constructions* (fig. 16) and deals with ›Geodesic Domes‹, a term introduced by Fuller. He described the invention as a framework for enclosing space; materialised by a spherical form where the longitudinal centre lines of the structural elements lay in diametral or great circle planes. Several geometrical figures may be projected into the sphere and Fuller discussed this issue. He talked about the spherical tetrahedron, the spherical octahedron and his preferred solution, the regular icosahedron (fig. 17). All three share the same properties: »As we have learned, there are only three prime structural systems of Universe: tetrahedron, octahedron and icosahedrons. When they are projected onto the sphere, they produce the spherical tetrahedron, the spherical octahedron and the spherical icosahedron, all of those angles corners are much larger than their chordal, flat-faceted, polyhedral counterpart corners [...] they are projections outwardly onto a sphere of the original tetrahedron, octahedron, or icosahedrons, which as planar surfaces could be subdivided into high-frequency triangles without losing any of their fundamental similarities and symmetry.«[22]

[21] »In bestimmten Artefakten, wie das Planetarium eines ist, sehen wir eine Konvergenz des Denkens, das die unabhängigen Bereiche von exakten Wissenschaften, technischen Erfindungen und ästhetischen Innovationen einschließlich ihrer theoretischen Diskurse zusammenführt.« Krausse 2006, 78.

[22] Fuller 1975, 664.



19. Calvo, José. Projecting a triangle into a sphere.

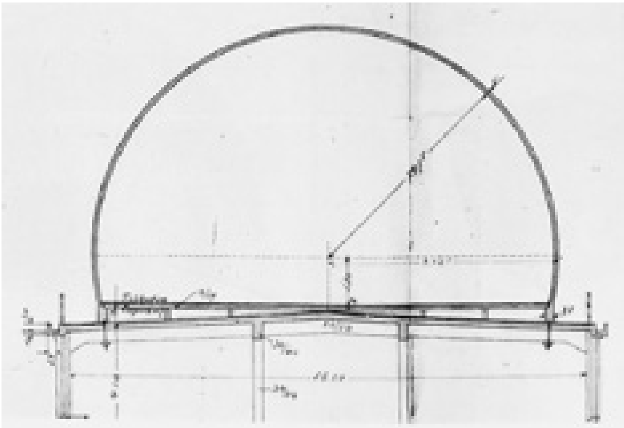
Fuller also knew too that each of the twenty equal spherical triangles might be modularly divided along its edges to generate individual bars; the numbers of them for each edge is dubbed ›Frequency‹ by Fuller. Also he called the process ›geodesic sphere triangulation‹ and defined it as »the high-frequency subdivision of the surface of the sphere beyond the icosahedron.«[23] He also was aware that each of these 20 triangles could be divided into six equal triangles; in fact, Bauersfeld had used a similar concept, giving it the name of »characteristic triangle«. Fuller defined it as spherical triangle LCD (fig. 18) which stands for Lower Common Denominator. Fuller projects the 20 triangles into the sphere in order to measure distances; also »the edges of each spherical triangle are modularly divided and are interconnected by the three-way great circle grids previously mentioned. These grids are formed of a series of struts each of which constitutes one side of one of the substantially equilateral triangles defined by the lines of the grid.«[24]

The language used by Fuller is not very specific; the patent uses term as ›approximate‹, ›substantially‹ or ›not precisely‹. This seems to arise from the fact that when the icosahedrons edge is projected into the sphere, and then the spherical icosahedron edges are divided into equal parts, three great circle lines will not concur in one point but two of them. It seems that Fuller used the same method as Bauersfeld did. First the icosahedron edge is divided in equal parts and then is projected into the sphere (fig. 19), giving as a result different bar lengths, as stated by Fuller, »in all of the form of framework I have described, the lengths of the individual struts are substantially equal, but not precisely so.«[25]

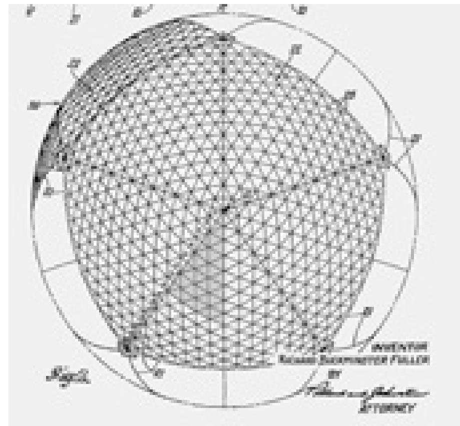
Notwithstanding that, in Fuller's prototype bars follow the great circle lines, that is, the geodesic lines of the sphere. Thus, the shorter path between two given points of the sphere is an arc of a great circle; in other words, the grid follows the most economical lines for energy to travel on the surface of the sphere. Thus load transmission is entirely optimised, so there is no waste of material or energy. In this way, nature is creating its own structures. With the projection of the icosahedron onto the sphere, Fuller achieved the geometrisation of the prototype. Frequency is the number of modules; when it reaches infinity, the modules will be points, and the spherical icosahedron will be a perfect sphere. Although in mathematics geodesics means the shortest distance between two points, the term comes actually from the Greeks words ›geo‹ meaning earth and ›dasia‹ standing for division. In this sense, geodesics is the science of the division or measure of the earth; we may surmise that Fuller wanted to build a prototype having the earth as a model. This fits well into his conceptions, considering the big enclosures to cover big cities that he designed or the metaphor having the earth as a spaceship in his publication *Operating manual for Spaceship Earth*.[26]

Such an interpretation of the earth as a model or prototype of the geodesic dome also connects Fuller with Bauersfeld, since the German engineer wanted to reproduce the sky, the celestial sphere in order to project the stars and planets on it. As Rothman said, Bauersfeld used the truncated icosahedron to approximate the geometric object to the sphere, while Fuller projected the icosahedron into the sphere, so it is referred to a two dimensional surface embedded into a three dimensional space: »The surface of a sphere is a two-dimensional manifold which lies in our or-

[23] Fuller 1975, 664.
[24] Fuller 1954, 2.
[25] Fuller 1954, 4.
[26] Fuller 1969.



20. Walther Bauersfeld, section of the dome with a radius of 8 meters, Carl Zeiss Archiv



21. Sketch showing the division of the Geodesic Dome from Fuller's patent called ›Building Construction‹

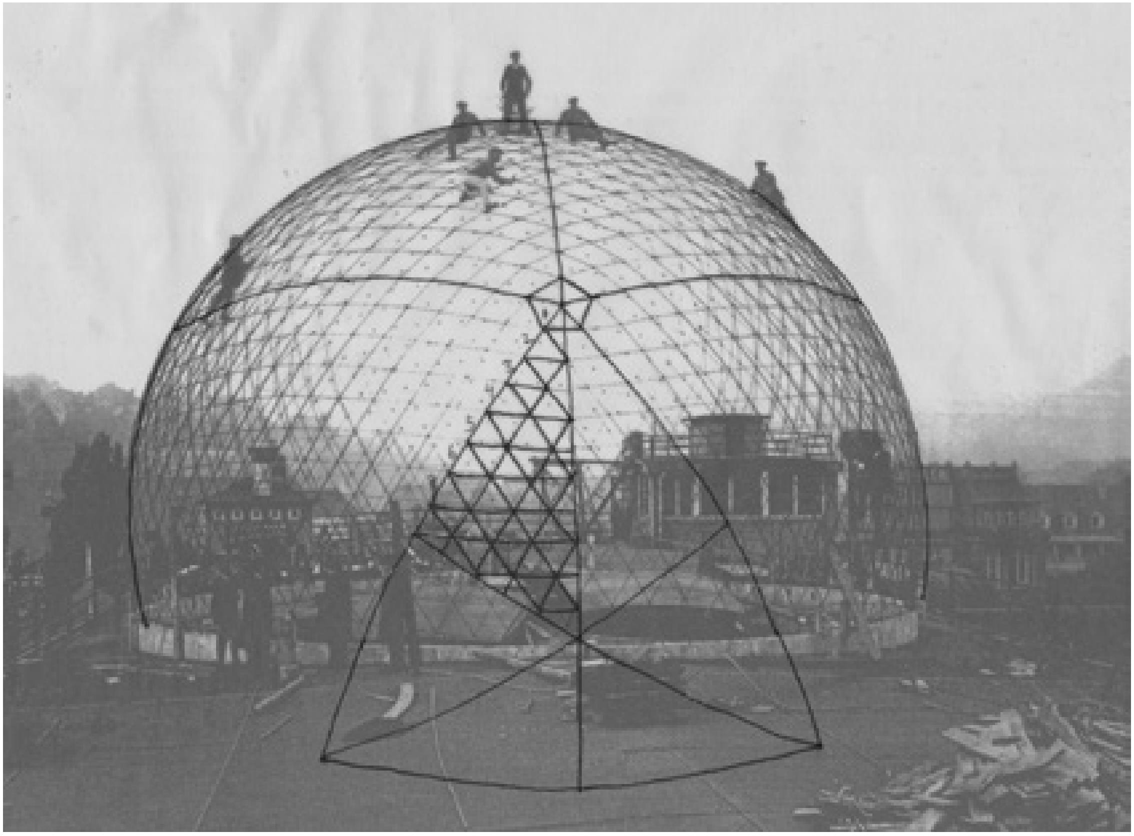
dinary three dimensional space. A geodesic dome is also a two-dimensional surface which is ›embedded‹ in three-dimensional space. The difference between the sphere and the dome is that the sphere's surface is curved but the dome is composed of Euclidean triangles. The approximation to the curvature comes at the joints between the triangles. Regge calculus extends this idea to spacetime. Spacetime may be viewed as our three-dimensional space moving through time. In others words, a three-dimensional manifold embedded in a four dimensional space.«[27]

Fuller achieved international recognition as the inventor of the geodesic dome, the prototype he patented with the name *Building construction* in 1954. In its summary he wrote »I have discovered how to do the job at around 0,78 lb per sq. ft. by constructing a frame of generally spherical form in which the main structural elements are interconnected in a geodesic pattern of approximate great circle arcs intersecting to form a three-way grid, and covering or lining this frame with a skin of plastic material.«[28]

Actually, this construction system is quite similar to the one devised by Bauersfeld. Both project the icosahedrons edge with their divisions into the sphere where the spherical triangles are placed as shown in figure 19. As stated above, the frequency is the number of modules in which this edge is being divided. In the Fuller's patent he decided to set the frequency at 16, »the number of modules into which each edge is divided is largely a matter of choice. In the framework of Figs 1,2,3 and 6, the number is 16.«[29]

Thus, Fuller used the same divisions that Bauersfeld had employed to shape the prototype on the top of the building 11 of the complex Zeiss in Jena and in the projector that he invented too. Besides, the diameter the Jena dome was 16 meter (fig. 20), while Fuller stated in his patent, »the framework construction illustrated in figs. 1 to 9 inclusive is representative of the best mode devised by me of carrying out my invention particularly as utilized in structures up to approximately 50 feet in diameter.«[30] 50 feet equal 15,24 meters, slightly shorter than the diameter that Bauersfeld used. Fuller's technical innovation was to lay the bars along the great circles of the sphere where the distances between two points are shorter, and energy travels in the more economical way, hence the name ›geodesic vaults‹. We may conclude that the geodesic dome that Fuller patented in 1954 (fig. 21) is the same one that Bauersfeld built 30 years before (fig. 22), using the same geometrical process and almost the same dimensions.

27 Rothman 1989, 72.
28 Fuller 1954, 1.
29 Fuller 1954, 3.
30 Fuller 1954, 2.



22. Sketch showing the division of the Characteristic Triangle of the hemispherical dome made by Walther Bauersfeld in 1922

The coincidences do not end here. Bauerfeld defined the characteristic triangle as one of the six triangles the icosahedron faces are divided into; as the icosahedron has 20 faces, there are 120 identical characteristic triangles. Richard Buckminster Fuller theorized about this triangle too. He dubbed it LCD what means Lower Common Denominator, or Fundamental Spherical Surface (fig. 23), as he said, »the largest number of equilateral triangles in a sphere is 20; the spherical icosahedron. Each of those 20 equilateral triangles may be subdivided equally into six right triangles by the perpendicular bisectors of those equiangular triangles.«[31] In this way, the length of the bars may be calculated for one of the characteristic triangles and extrapolated to the 119 other characteristic triangles. The ends of the bars results from the projection of the divisions of the characteristic triangles into the sphere; Bauersfeld calculated their different lengths painstakingly. All this is reflected in Bauersfeld's notes under the title *Rechnung der Stabl'ängen für Kugelteilung* [Calculations of the bar's lengths in the division of the sphere].[32] Later on, he computed bar lengths in mm in another document under the heading *Stabl'ängen für den Kuppel Neubau (8 m Radius)* [Bar's dimensions for the new dome (8 m radius)].[33]

Fuller did not write about the LCD in his patent called *Building construction* in 1954. However, in his book *Synergetics* he theorized widely about this

31 Fuller 1975, 480.

32 Bauersfeld 1922b, 29.

33 Bauersfeld 1922b.

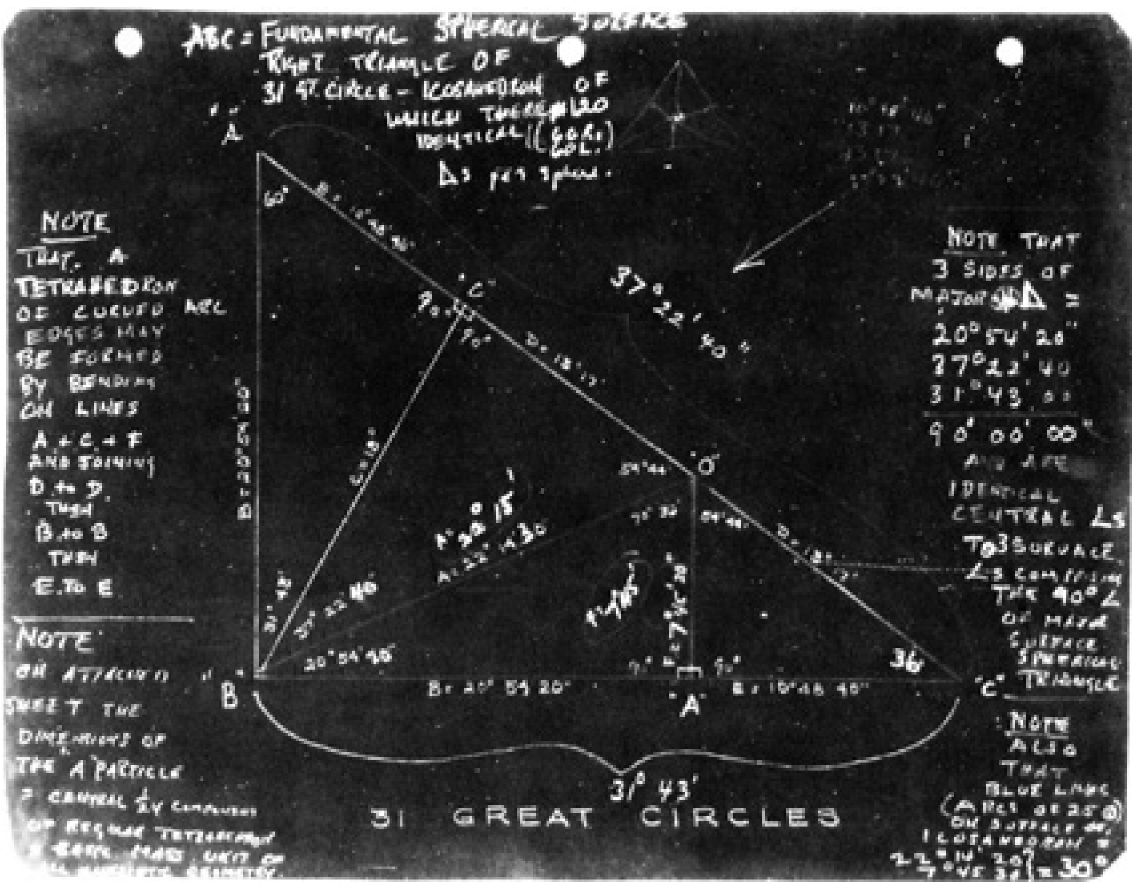
definition. In the chapter called *Moldeability* he defined it as follows: »The Basic Disequilibrium 120 LCD Spherical Triangle of synergetics is derived from 15-great-circle, symmetric, three-way grid of spherical icosahedron. It is the lowest common denominator of a sphere's surface, being precisely 1/120 of that surface as described by the icosahedron's 15 great circles. The trigonometric data for the Basic Disequilibrium LCD Triangle includes the data for the entire sphere and is the basis of the all geodesic dome calculations.«[34]

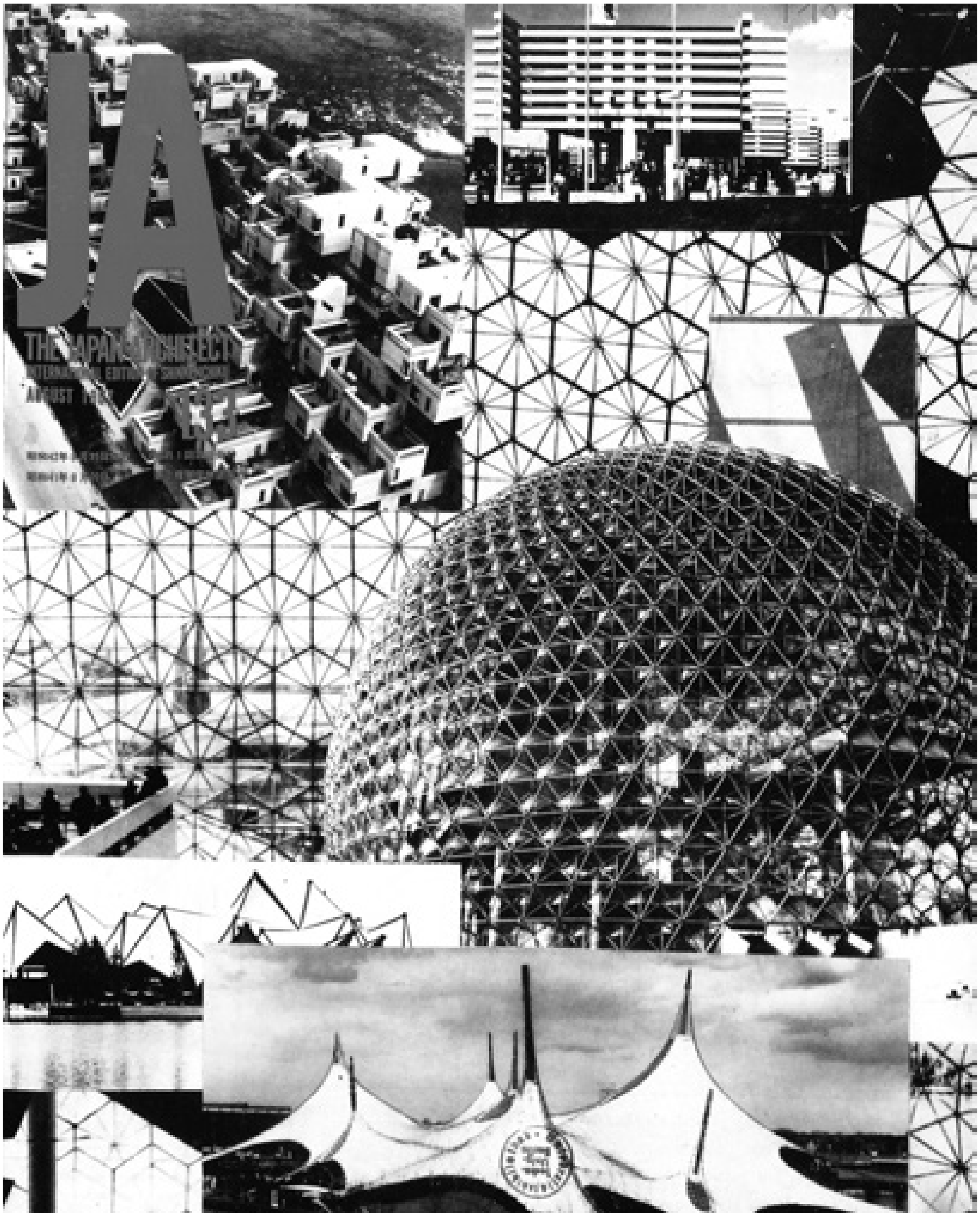
Fuller used the geodesic dome to explain the theory of *Synergetic*; the word combines the terms synergy and geometrical energy. Fuller combined the basic stability of the triangles with the optimal relationship between volume and surface in the sphere. As he said also, the bars are placed along the great circle lines, allowing the structure to work in the most economical way. Fuller tried to reproduces the coordinate axes used by nature, for example in the radiolarian, which shows similarities with the geodesic dome.

The prototype made by Fuller was to exert great influence in the younger generation of the architectural avant-garde (fig. 24) in the sixties; however, as we have seen, the basic ideas that led to the design of his geodesic domes had been conceived by Bauersfeld in the twenties. Anyway, its development offers a good example of a scientific artefact turning into a cultural and architectural icon. As Rothman said, »I hope the reader sees how the evolution of a few ideas-geodesics and limits – links such diverse fields as architecture

[34] Fuller 1975, 480.

23. Richard Buckminster Fuller, Fundamental Spherical Surface, in: The artifacts of Richard Buckminster Fuller





24. Richard Buckminster Fuller, Geodesic Dome, World Exposition in Montreal 1967, Magazine cover and cosmology. This is the way science works: the simplest ideas have the widest application. And it is entirely appropriate that the first architectural application of geodesic should be in a structure so intimately connected with cosmology where the concept of geodesic line is essential. I do not think it is coincidental. Neither am I surprised that Bauersfeld, a man trained in engineering and astronomy, thinking like the ancient Greeks about ways to divide the earth, became the inventor of the geodesic dome.«[35]

[35] Rothman 1989, 74.

Abstract

Sometimes scientific-technical objects can be given an extended meaning as cultural icons and be received in art and architecture. To this end, the object must be detached from its original context and viewed from different, new perspectives.

In 1922 Walter Bauersfeld constructed one of the first geodesic domes for testing projection devices in Jena. Walter Gropius and Lázló Moholy-Nagy were among the first to visit the Jena Planetarium; Moholy-Nagy received the dome in his book Von Material zu Architektur. Richard Buckminster Fuller further developed Bauersfeld's concept from the 1940s and patented the construction principle of a geodesic dome under the name Building Construction in 1954. His patent bears resemblances to the Bauersfeld Planetarium in Jena, which can be demonstrated by manuscripts by Bauersfeld from the Zeiss Archive in Jena. Fuller, on the other hand, also used the geodesic dome to explain his theory as Synergetic. The article traces the transformation of the technical object conceived by Bauersfeld via Moholy-Nagy and Fuller into a cultural icon of the 20th century.

Abstract

Manchmal können wissenschaftlich-technische Objekte eine erweiterte Bedeutung als kulturelle Ikonen erhalten und in Kunst und Architektur rezipiert werden. Dafür muss das Objekt aus seinem ursprünglichen Kontext gelöst und unter anderen, neuen Blickwinkeln betrachtet werden.

Im Jahr 1922 konstruierte Walter Bauersfeld in Jena eine der ersten geodätischen Kuppeln zum Testen von Projektionsgeräten. Walter Gropius und Lázló Moholy-Nagy gehörten zu den Ersten, die das Jenaer Planetarium besuchten; Moholy-Nagy rezipierte die Kuppel in seinem Buch Von Material zu Architektur. Richard Buckminster Fuller entwickelte das Konzept von Bauersfeld ab den 1940er Jahren weiter und ließ 1954 das Konstruktionsprinzip einer geodätischen Kuppel unter dem Namen Building Construction patentieren. Sein Patent weist Ähnlichkeiten mit dem Planetarium von Bauersfeld in Jena auf, was sich an Hand von Manuskripten von Bauersfeld aus dem Zeiss-Archiv in Jena nachweisen lässt. Fuller wiederum nutzte die geodätische Kuppel auch, um seine Theorie zur Synergetic zu erklären. Der Beitrag zeichnet den Wandel des von Bauersfeld erdachten technischen Objekts über Moholy-Nagy und Fuller zu einer kulturellen Ikone des 20. Jahrhunderts nach.

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Credits

Fig. 1–4, 6, 8, 9, 14, 20: Zeiss Archiv — **Fig. 5:** Krausse 2006, 63 — **Fig. 10:** Wermer 1953, 131 — **Fig. 11:** Hanisch/Bucher 2006, 100 — **Fig. 19:** José Calvo López