Mathematics Behind the Cell Bubble Structure to Achieve Sustainability

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***Abstract*—"Today when architects calculate and exercise their thoughts, every thing turns into algorithms. Computation the writing and re-writing of code through simple rules, plays an ever-increasing role in architecture"**

Advanced calculation has given architects new innovative open doors with which to get to the geometrical space opened up by post seventeenth century mathematicians. A new wave of the relationship amongst science and space making is the consequence of this computerized advancement

This paper studies this new mathematical focus that showed the connection between complex structure and mathematics in design new forms.

This paper begins to execute parametric configuration system, to outline and upgrade the cell-like network structure for Bubble structure in the Water Cube in Beijing through giving description for a few parametric models of the Cell Structure Concept. These models will be investigated and assessed to explore an "ideal" structure by numerical examination for the structure. Initial step is creating Cell Structure modeling for hexagonal structure utilizing PC model "Grasshopper and Rhino-script". (By configuration of parameters) in which all unique components are described.

Finally, the paper will investigate the connection between producing this Cell matrix hexagonal structure and execute sustainable concepts to the outline structure framework of Energy Saving.

Keywords: Cell Structure, parametric Analysis, generative algorithms, Digital modeling.

I. INTRODUCTION

The idea of the structure is the normal structure of soap air pockets deciphered into compositional structure. The innovation and materials create energy efficient structure and ecologically friendly. (See Fig.1)

The paper makes a profound investigation for Water block structure as a Green Sustainable structure , this structure accomplish two primary feasible element Energy effectiveness by utilizing sunlight based vitality to warm the swimming pool and Water proficiency will be accomplished by water collecting, reusing, proficient filtration and backwash systems.

Fig. 1. Water Cube Green Structure

II. STRUCTURE OF BUBBLES

A foam structure is essentially an extensive accumulation of air pockets. The polyhedral structure of foam

The structure of air pockets comprise of hundred of single air pocket the connection between them manages strengths and vitality ,the problem reduces to finding the figure with the smallest surface area for the measure of air contained in the air pocket. What's more, if there are two air pockets touching, they meet and frame a dyad of air pockets. Furthermore, three air pockets meet, and they will constantly meet at 120 degrees. The more the air pockets, the more they are touched on various sides by different air pockets, shaping level countenances. (See Fig.2.) [1]

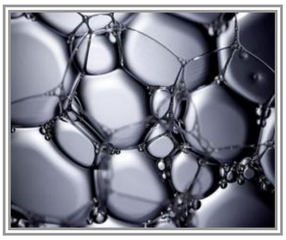

Fig. 2. Bubble Structure

A. Kelvin Solution: (in 1887)

Lord Kelvin found that 14-sided Polyhedron is the best answer for accomplish the base surface region on the structure, first Lord Look at boxes shapes for the segments spaces .Master Kelvin search for the state of structure that accomplish the minimum surface area on the structure .

The primary illustration ruler found is boxes shape for the allotments spaces, stacking boxes, one on top of each other, in all headings. Be that as it may, this arrangement doesn't give the base surface zone. Spheres aren't a conceivable answer, since they can't fill space with spheres — there will dependably be holes between the spheres.

the answer of Kelvin problem discovered it in nature Bubbles structures, segment space by taking the shape that minimizes surface region, So the state of air pocket take care of the issue and minimize surface range. Kelvin concentrated on air pockets name it as "tetrakai-decahedra." in his words, "a plane-faced isotropic tetrakai-decahedron." (These are truncated octahedral.) (Fig. 3)

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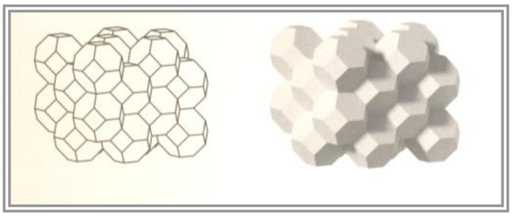

Fig. 3. . Kelvin Structure

B. Weaire-Phelan Solution:

Phelan began with the covalent bonding structure of clathrates compounds, in which the securities can be visualized as foam cells. The greater parts of rings of bonds on the sides of the confines are five fold, making pentagonal countenances. It is general gathering of two sorts of sporadic polyhedral cells with twelve and fourteen countenances, separately, consolidated in the proportion 2:6 in a rehashing unit of eight polyhedral. It ended up having a cell surface area for volume that was 0.3 per cent less than the admired guess of Kelvin. [2]

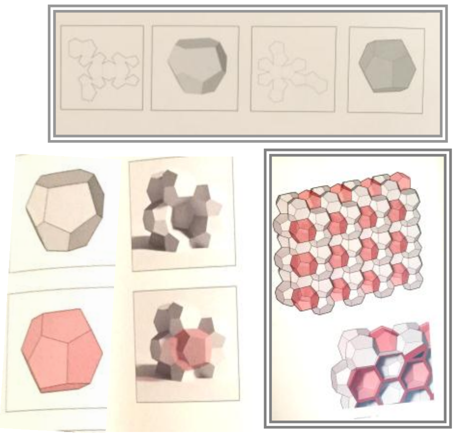

Fig. 4. Weaire-Phelan pressing: the 14-faced tetra decahedron, with its two hexagonal and 12 pentagonal faces (grey); the 12- pentagon-faced dodecahedron (pink); and the packing in which they fit together in unites of six and two, separately

C. Kelvin Structure and Weaire-Phelan Structure:

Century ago there is an answer for air pocket structure issue from the physicist ruler Kelvin:

Kelvin discovered that14-sided polyhedrons the best answer for foam structure to get equivalent volume between cells of air pocket structure with the minimum surface region, But in 1993, two physicists found a more proficient arrangement utilizing 12 and 14 sided polyhedrons. (See Fig.5)

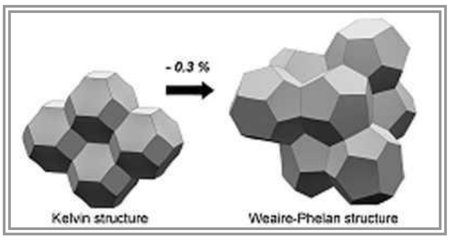

Fig. 5. Kelvin Structure and Weaire-Phelan Structure

III. BUBBLE STRUCTURE FEATURES:

Now the paper discusses the three main features found in bubble nature structure.

IV. RANDOM STRUCTURE:

The arrangement of polyhedral air pockets is consider an irregular structure since Foams develop with a specific end goal to minimize the surface region of the films between air pockets, which offers ascend to a specific widespread appropriation of polyhedron sizes and shapes, which is relied upon to happen for countless minimizing structures: polycrystalline metals, ferromagnetic areas, organic cells. (Fig.6.)

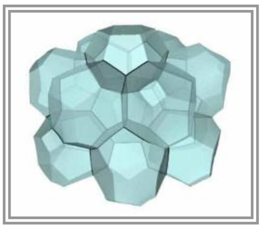

Fig. 6. .Kelvin Structure and Weaire-Phelan Structure

A. Complex cell structure:

By Aboav in 1970 gives his perception that for no less than one actually happening cell complex, rises with more than the normal number of faces had a tendency to be encompassed by rises with less than the normal number of appearances, and the other way around. A structure with the features outlined above a cell complex. (Fig.7)

Rather than setting up a connection between the quantity of faces of an air pocket and the total Gaussian shape contained in the appearances and the edges of that air pocket the investigation Explore the way of this relationship. In (Fig. 8), from this, the obvious requesting of the grains might be considered to emerge from variances in the Gaussian curvature and flow contained in little districts all through the cell complex.

Weaire's thinking is hence practically equivalent to the case that these variances are very little, or that natural foam is a surprisingly 'flat' structure. Our progressing research expects to keep on developing associations between the concentration of curvature and combinatorial properties of a cell complex.

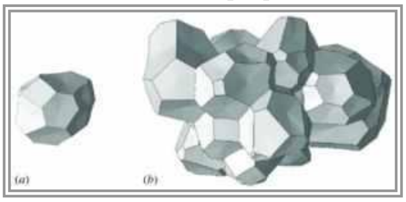

Fig. 7. Cell Complex Structure

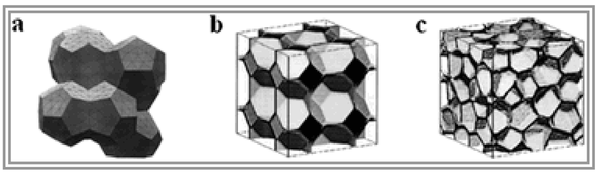

Fig. 8. Models for closed-cell cellular solids: (a) Weaire–Phelan model, (b) tetrakaidecahedral model, and (c) Voronoi tessellation model

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B. Cellular Solids:

Cell solids with closed cell structures have a place with an essential class of designing materials and highlight numerous appealing properties. As opposed to open-cell structures, closed-cell foams are described by non-interconnected cells, are denser and have a higher dimensional steadiness because of their auxiliary cell attributes. Further qualities incorporate high active energy absorption and low warm conductivity and in addition low density of which different engineering applications [3]

V. MATHEMATICAL IDEAS IN THE STRUCTURE :

A. Space filling and symmetry:

Space filling is truly about subdividing space in ways that leave as little as possible ,or nothing by any stretch of the imagination, unaccounted for, regardless of the fact that that subdivision proceeds to endlessness.

Symmetry takes on its most incorporating importance as opposed to only its most recognizable appearances in Euclidean geometry (mirror, rotational and translational symmetry) when size does not make a difference, when the same parts repeat, the same shape is found at numerous scales, and there are basic examples that take the stand concerning the more profound associations between things.

B. Mathematical challenge:

At the point when rearranging correspondingly measured coins on a table top, we can rapidly land at the triangular/hexagonal, two-dimensional example that covers the littlest part of the table; however it is not all that simple to demonstrate this is a general worldwide result. Here untruths the scientific test. Stacking oranges results in the elegant tetrahedral structures showed at a conventional greengrocer's

The cells of a structural space outline that give back and take into account the overhauling of vast, encased spaces, unrestricted by structural support, for example, those of the Water Cube for the 2008 Beijing Olymbics. In architectural design, there is a long tradition of harnessing relatively regular periodic packing regimes: orthogonal Structural Grids, repetitive space- frame units.

The part will examine design that can be known by their generators. An arrangement of focuses has an associated pattern of cells for which each point inside specific cell is more like one of the focuses than to whatever other point. This subdivision of space can be a two-dimensional net of polygons, or may complex spatial representation if it represents, for instance, the converging fields of gravitational fascination of neighboring items in space (, for example, the field of shapes that sand falls into around neighboring gaps made by tunneling crabs). [4]

Each point inside a given cell is not equal; there is a sense in which the points nearest to the cell limits are connected with with greater potential energy than those near the gravitational focal point of every cell. these patterns collectively belong to a theory of mathematical subdivision known as Voronoi patterns, for this situation, it is not the tilling or subdivision of repeating shape or gathering of shapes that is the issue, however the mapping of a distribution of points, to a subdivision of a two-dimensional surface or three dimensional space into contiguous cells related to those point sites. (Fig.9)

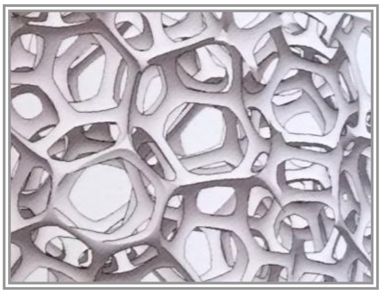

Fig. 9. Voronoi Patterns

VI. MATHEMATICAL ANALYSIS OF THE CELL STRUCTURE :

A. Cell Structure Generation :

Lord Kelvin suggested the conversation starter of how space could be divided into cells of equivalent volume and minimal surface area. This is comparable to asking what shape equal-sized soap bubbles would take in foam since actually expects shapes with minimal surface area. He He guessed that the arrangement was a cross section of truncated octahedra with somewhat bended hexagonal faces. The polyhedral version of this structure is known as the Kelvin structure. The physicists Denis Weaire and Robert Phelan connected a structure known from crystallography to the problem and found that the supposed Weaire-Phelan structure enhances the Kelvin structure. (Fig.10)

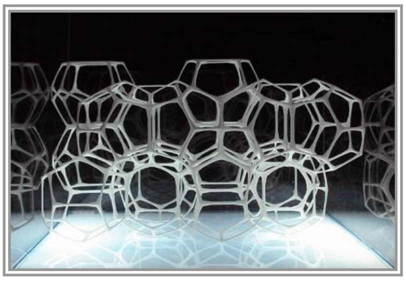

Fig. 10. Cell Structure Generation

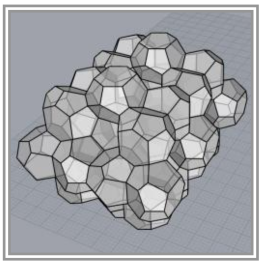

Fig. 11. Foam of equal bubble simualation structure

B. Cell of Hexagonal Structure Model:

Lets begin execution of parametric configuration recreation in this paper to create cell structure for bubble structure simulation on Grasshopper / Rhino .

We will audit the arrangement used to produce irregular tetrakaide cahedron , to draw the structure utilizing vertex facilitates extremely the Kelvin's tetrakaide cahedron. The

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soap structure hexagonal shape It can be created as polyhedra in Generative Components. Utilizing 20×10 for the underlying rhombus, begin with proportion 2/1 in diagonals then duplicate the rhombus by 10 (smaller of the diagonals) and rotate 90 degrees. a sequence to draw tetrakaidecahedron as basic as could be expected under the circumstances with just Euclidean constructions (no vertex coordinates). (Fig.11) [5]

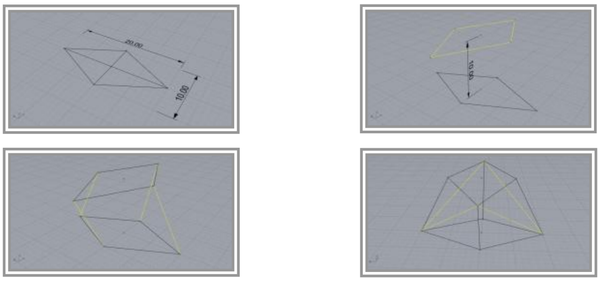

Fig. 12. Polyhedra in Generative component

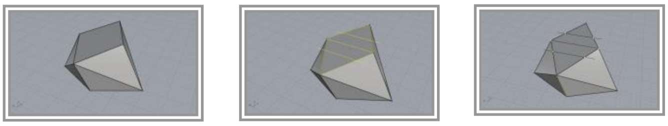

Fig. 13. Polyhedra in Generative component

- Connect the vertices of the two rhombi as appeared above, Also associate the vertices sideways to create equal triangles. Now, put triangle and quad appearances to make a 10 sided unpredictable polyhedron, as demonstrated as follows: (Fig.12)
- To make crossing points between the irregular hexagon of the polyhedral, Continue by drawing the short corner to corner of the rhombi and duplicate it 3.7 units (for 10) in both directions. Exchange the edge lengths at far corners of the rhombi. Put two spheres focused at far vertices of the rhombus, by indicating to the new (3.7) intersections keeping in mind the end goal to characterize radii. These radii will be exchanged this way; select the edges appeared above and cross the spheres to get those two points. (Fig.13)

These three points will be utilized to characterize cutting planes while trimming the 10 sided polyhedron. Now, cut the polyhedron utilizing those points as a part of a style that each of the four sharp corners of the rhombi will be trimmed.

Fig. 14. First Cut

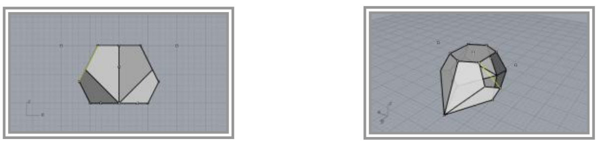

Fig. 15. Second cut. Just draw a line, get to a side viewport and trim the solid

Fig. 16. Third cut. This time, trimmed the rhombus below

Fig. 17. The fourth and final cut. Now cap the solid and finish the tetrakaidecahedron of a weaire-phelan solution

C. The Assembling Construction Solution:

weaire-phelan frameworks

The irregular dodecahedron, the 6 interpreting tetrakaidecahedra appropriately, they'll in the long run develop at unpredictable dodecahedron voids in the middle Strange patterns begin to rise with an inclined shape hub. (Fig.18) [5]

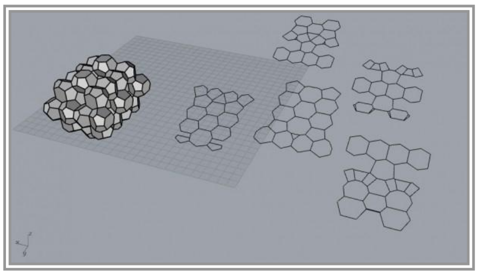

Fig. 18. assembling solution

VII. STRUCTURED GRID MODEL

"A mesh is considered to be a structured grid if the local organization of the grid points and the form of the grid cells do not depend on their position but are defined by a general rule. The connectivity of the grid is implicitly taken into account. – Liseikin, 1999"

A. Introduction

The network points were sorted out and recorded in a 2D cluster by grouping to make a standard for organized framework.

a) The network in the matrix

The network in the matrix changing the position of any framework point, Only the lattice cell will disfigure (cell-shape changed).

b) the primary outline variables in the structure matrix model:

- The normal network size
- The size of irregularity(The scale of randomness), which is defined by the range of the matrix point's development

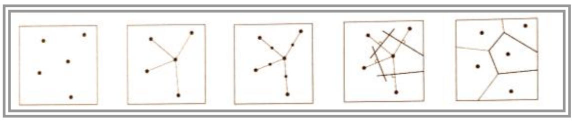

Fig. 19. Grid Points movemetnt

B. the advantages of structured grids

- *accurate and simple to excute.*
- *Parametric model can be easily handled and immediately actualized.*

produced by organized grid points and basic principles, the , the subsequent organized network models can be adjusted by changing size, and the margin of randomness - to get an unpredictable appearance. With this model, a progression of network sizes can be tried to give prescribed qualities to Bubble Cell structure (Fig.19).

a) Generate grid points:

The beginning stage of the organized network model was to create regular triangle grids; demonstrating steps:

1. Characterize diagram variable L as grid-size

2. Make cutting bends along surface

The division of the surface similarly into several horizontal regions (matrix Size. this pre-characterized grid-size was utilized to round up the quantity of division, and another size was recalculated:

Grid points produced along every divider were composed in number, as planning for organized grid generation.

- Triangle framework structure:

The hexagonal framework was relied on triangular grid (an organized matrix) Create triangle network (organized) was produced as 'intermediate' grid to make hexagon patterns.

b) Define new compomnent

Scripting is additionally good way for organized frameworks to create hexagonal example, however, to specifically characterize hexagonal matrices more sorted grid points (6 vertices in every hexagon) and the topology is more complex. The actualized arrangement was to characterize new components, hexagonal in-pack to triangle matrix, change the frameworks from triangles to hexagons, to improve the topology. [6]

3 elements were characterized to produce hexagon design: PtoH, Pto2H, and Ptohalf_H (from Points to Hexagon) (Fig.20).

In which, highlight Pto2H, and Ptohalf_H were utilized to finish the matrix close to the limits. (Note: the vertices must be chosen in arrangement, aside from the component 'PtoH' – there is no impact created by random interface vertices in light of the multi-symmetry.)

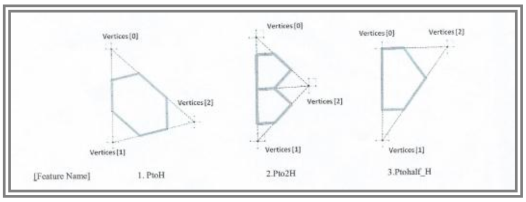

Fig. 20. *new components and the application in Cube Structure*

VIII. GRAPH VARIABLES

The parameters in the frameworks era are:

1. Grid size.
2. Grid association.
3. Grid shape.(Fig.21)

These items can be interpreted as diagram variables, which are defined and controlled in Generative Components:

1. L - The normal size of the triangular frameworks Corresponding size of the hexagonal grids is L/3

RSc – The scale of the randomness [in %] This variable was utilized to control the scope of irregularity to the grid point development. Every network point was given a stage size somewhere around 0 and RSc*L. [Random (0, RSc*L)]

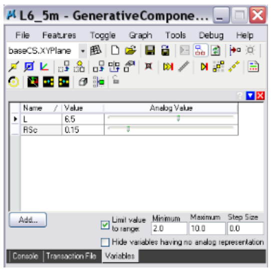

Fig. 21. *Graph Variables*

The network points are unequally distributed over the surface, when apply chart variable RSc (the Scale of irregularity) In the organized grid display, this outcomes in:

1. The lengths of the structure components and surfaces for the façade components have an extensive separation, which expand the many-sided quality of development innovation and expense.
2. Deformed cell components, in which some unfavorable nodal edges and cell shapes will happen. So it is not prescribed to apply large randomness scale (RSc), in case the hexagonal-cells deform too much.[6]

IX. STRUCTURE STEEL ANALYSIS:

A. Bubble Cluster:

In the Structure era method, several air pocket groups are joined by model of Weaire and Phelan to constitute a crystal, which is then turned and cut with horizontal and vertical planes. At that point the crystal cut is inside cut, taking into account the dimensional manages of the architectural program. And finally the solid model is changed over into a wire outline model, which lines relate to the individuals from the steel skeleton..(Fig.22-a)

Dissimilar to the conventional large span structures, with load bearing components generally organized according to a strict structural hierarchy, the spatial setup of bars and hubs of the air pocket structure, as resulting from the above era procedure is restrictive to any endeavor of an ordinate reading of the load bearing system: in the water cube 3D shape framework neither request components not a qualification amongst essential and optional components can be found. [7]

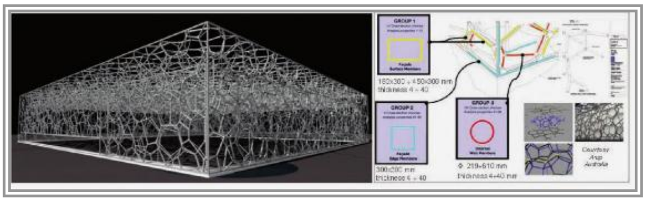

Fig. 22. Water cube:a)The wire frame model. b) the member cross sections

Turning out to be exceptionally prominent after the Beijing 2008 Olympics National Aquatics Centre's exterior (which is accepted to be a voronoi subdivision, as an epic misstep), Weaire-Phelan is an answer (again said to be the "best" arrangement, which is not yet demonstrated) of equivalent volumes with minimal surface area. This rapidly turned into a cult object for contemporary architectural geometry (this is right). In spite of the fact that it is accepted to be a structural solution, for architects, getting the attention with "adorable air pockets" appear to be the basic role of this structure.(Fig.22.)

Steel Frame:
The greatest difficulties of the Water Cube were structural design and manufacture. As a matter of first importance, it was expected to upgrade the general measurements of steel structure, additionally expected to satisfy the design requirement for the seismic situation of Beijing. [7]

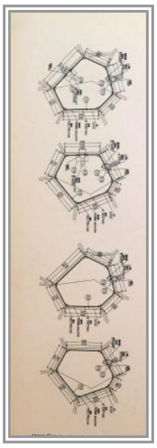

Fig. 23. Variables Dimensions of individual

X. ENERGY SAVING STRUCTURE CONCEPT:

The Water Cube is designed to be a Greenhouse. That's mean that this green house will achieve high levels of natural daylight into the building, and the building and the swimming pool passively heated by the power of the sun so the energy consumption of the building will be reduces to achieve sustainable structure concept.

Reduces the energy consumption to maximize energy efficiency this is the sustainable concept in the structure.
Arup has estimated that this sustainable concept has the potential to reduce the energy consumption of the leisure pool hall by 30 per cent, equivalent to covering the entire roof in photovoltaic panels.

This Sustainable concept reduces the energy consumption to maximize energy efficiency. [7]

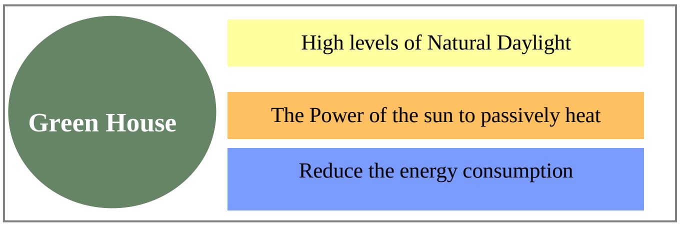

Fig. 24. Sustainability Concept in the Structure

CONCLUSION

The paper considers mathematical models of bubbles, foams and froths, as collections of surfaces which minimize area under volume constraints. The resulting surfaces have constant mean curvature and an invariant notion of equilibrium forces.
In This Paper, structured grid parametric model described:

- The main purpose to create the structured grid model was to have a parametric model which can be easily handled and quickly implemented and accurate model. With this model, a series of grid sizes can be tested to provide recommended values for the Bubble Cell structure.
- The connectivity rules were simple and organized the structured grid model was easy to be combined with some solutions for fabrication
- It was also used as the basic model in the member design experiment – assigning different profiles/cross sections to the structural elements; instead of applying various cell densities in the grid structure.
- The model various grid sizes can't be easily introduced or the grid cells will deform too much. To implement different cell-densities, unstructured grid model will be created in the following sections.

And finally the paper review this new program method to achieve sustainability concept for the structure and energy saving by using generative power and codes power as a new way for architect.

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