# Form-Optimizing Processes in Biological Structures. Self-generating structures in nature based on pneumatics

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*"If architects designed a building like a body, it would have a system of bones and muscles and tendons and a brain that knows how to respond. If a building could change its posture, tighten its muscles and brace itself against the wind, its structural mass could literally be cut in half."*

*Guy Nordenson, Ove Arup and Partners*

**Summary.** *This case study is an investigation of self-generating forms in nature based on pneumatic structures and their use in architectural theory. It focuses on the concept of self organization as a defining principle in nature and in particular, on the mathematical, geometrical and physical properties of bubble clusters and shows examples from nature, biology and engineering. Part of the research resulted in a series of digital models and renderings of different bubble clusters and there polyhedral configuration. Advanced structural design methods are already using systems based upon self-generated models rooted in biological and genetic forms. Engineers are able to input a series of variables into a computer program which in turn, derive a structure using a genetic algorithm resulting in the most efficient use of materials, etc. Numerous examples of such procedures already exist in nature today, in particular, biology. Blueprints for these forms are stored in the genetic code of the DNA*[1] *of all life forms. Until recent advances in computer technology, the ability to put such genetic algorithms to use has not been possible.*

[1] The DNA (deoxyribonucleic acid) is the carrier of our hereditary characteristics and that it is based on two strands twisted about one another forming a double helix. The strands consist of alternating carbohydrate and phosphate molecules. On each carbohydrate sits one of the four nitrogenous molecules **A**denine, **C**ytosine, **G**uanine and **T**hymine. A DNA strand can thus be compared with a long sentence (sequence) of code words, where each word consists of three letters that can be combined in many different ways, e.g. CAG, ACT. Each code word can be read by components inside the cell and translated into one of the twenty amino acids that build proteins. The three-dimensional structure, and hence the function, of the proteins is determined by the order in which the different amino acids are linked together according to the genetic code. (www.nobel.se/chemistry).



*E. Oñate and B. Kröplin (eds.), Textile Composites and Inflatable Structures*, 285–303.

**Key words:** Form-optimization, lightweight membrane-construction, radiolarian, genetic algorithm polyhedra

# 1 Introduction

The study of form-optimizing processes in biological structures has a long history starting with Frei Otto, Werner Nachtigall and followed by many researchers [2][3][4][10]. These researchers have outlined in a number of forms the mathematical relationships that control the overall geometry of polyhedral in biological structures [12]. The research centers on an investigation how optimizing processes in biological structures are possible starting points to generate optimized architectural forms and structures. For this particular study the bubble cluster based on the pneus was selected. The pneu is a system of construction comprising of a non-rigid envelope having a certain tensile strength, and an internal filling, which is in most cases pressurized. This system of construction can be translated into the architectural world in the form of pneumatic structures. This structural system, which can be found in many lightweight structures today, is based on the principals of those pneumatic structures found in nature.

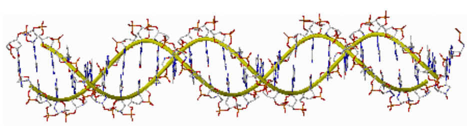


**Fig. 1.** DNA double helix

**Fig. 2.** DNA, the genetic code

# 2 Pneumatic Structures in Nature

One example of a pneumatic structure in nature is the soap bubble. In soap bubbles, growth is achieved through a system of division and inflation. This increased internal pressure encased in a reinforced membrane subject to tensile stress causes the bubble to grow in a process known as isomorphism or self-generation.

Free-floating bubbles collect and form dense clusters known as foam. If three bubbles are placed on a glass surface and a fourth is added, the fourth bubble will relocate to the top of the three bubbles to form the simplest three-dimensional cluster consisting of four bubbles. If further bubbles are added they will automatically form a foam structure. If the bubbles are of equal size the liquid edges of the foam are straight and of equal length and the angles of incidence at the nodal points are equal. The total structure forms a net of equal mesh size called the "basic net" (Fig. 13).

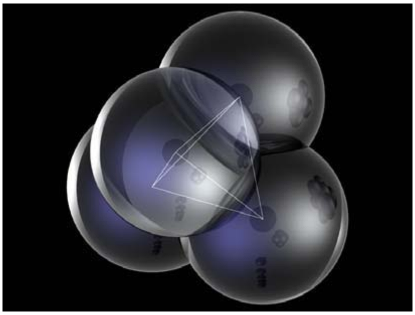


**Fig. 3.** Rendered computer model: Tetrahedron bubble structure

**Fig. 4.** Rendered computer model: Octahedron bubble structure

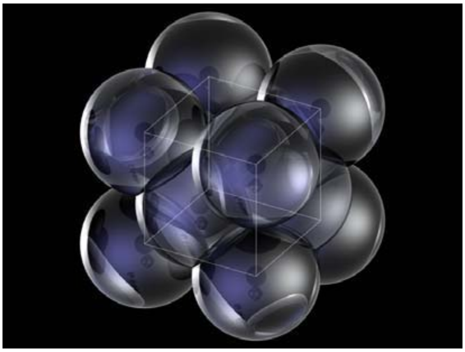


**Fig. 5.** Cube bubble structure

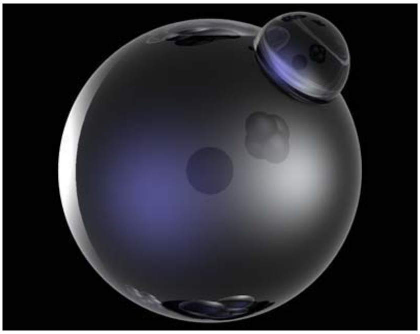


**Fig. 6.**

**Fig. 7.**

## 3 2-D Bubble Clusters

Net structures are formed through the solidification of a 2-D bubble cluster. Bubble clusters occur when bubbles are freely dispersed within a cell without touching each other. In the next phase, the bubbles are introduced to each other through points of contact and form patterns by agglomeration (Figs. 5–13). These patterns are based on geometric forms such as cubes, tetrahedrons and octahedron (Figs. 3–5). As solidification takes place, the membrane of the bubble dries out and the fiber net hardens (Fig. 12). The bubble membrane then dissipates and the net structure is left (Fig. 13).

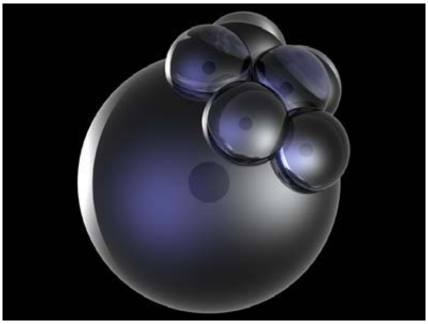


**Fig. 8.**

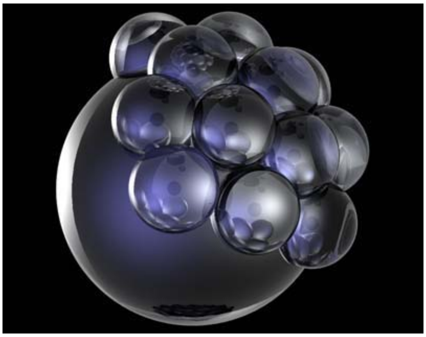


**Fig. 9.**

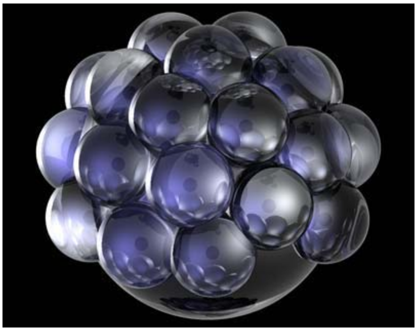


**Fig. 10.**

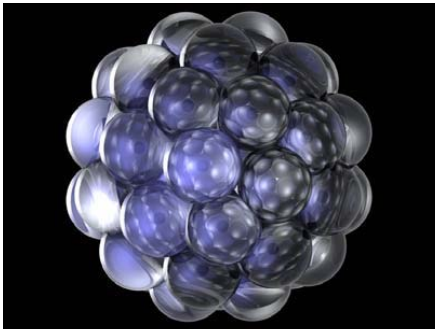


**Fig. 11.**

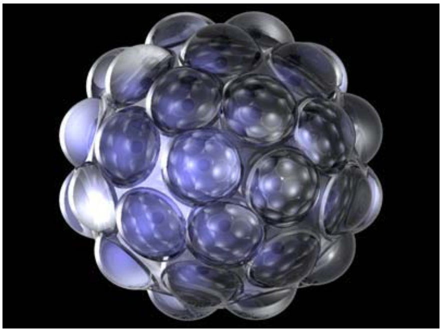


**Fig. 12.**

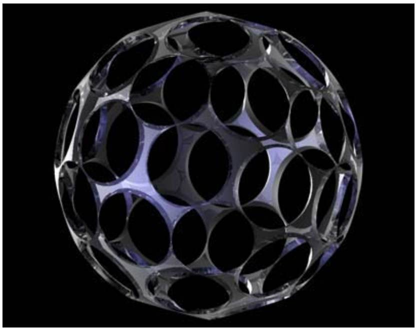


**Fig. 13.**

## 4 Mathematics/Geometry

*Closest packing*

One of the fundamental geometric principles that drives the repetitive, self-generating forms in nature is the notion of *closest packing* [1] of spheres. It is this, which defines the curvature of an insect's compound eye or creates the formwork to mold a radiolarian's skeletal structure.

As spheres are packed closely together, certain laws of physics cause geometric shapes to occur, such as hexagons. These polygons create repetitive surfaces among and around the spheres. In some cases, these surfaces find themselves useful for a number of functions, such as in an insect's eye. In other instances, these surfaces interlock together to create volumes, polygons create polyhedrons. These volumes may be used to serve a purpose.

Often times, it is not the surface or volume that is put to use in these systems. Quite likely, it is the edges along which these spheres meet that are of use to the organism. Once again, the radiolarian and diatom gather silicate deposits along the edges where the spheres meet around the outer surface. It is along these edges that a skeletal system is formed.

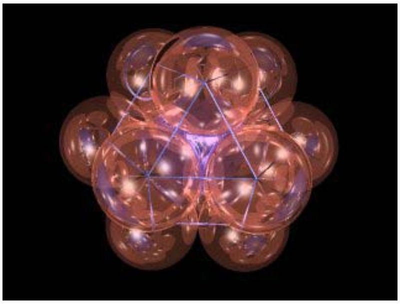


**Fig. 14.** Closest packing of spheres

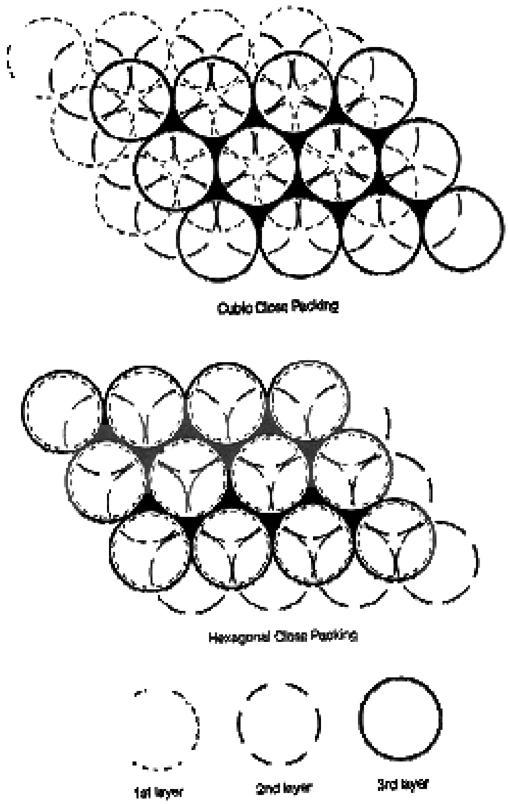



**Fig. 15.** Closest packing diagram

## Configuring and integrating form systems

One of the greatest advantages to geometric systems based on the closest packing model is the great variety of configurations from which to choose. Repetitive, self-generating form can be derived in the shape of hexagons, pentagons, and even triangles (Figs. 3–5). These can be arranged independently or between various types [1].

After a particular form is created, it, too, can be arranged with other similar forms to create even more shapes or, in terms of architecture, spaces. Some examples of this can be seen here (Fig. 16). Another important quality of these systems is the ability to obtain similar forms with varying degrees of complexity in terms of number of members, scale, etc. As you can see, very comparable forms can be achieved in different ways. The structural complexity of a geodesic dome is probably too complicated for that of a radiolarian's skeletal system. Yet, these two structures share obvious formal qualities with one another. At the same time, the mathematic and geometric basis from which both are derived are practically identical.

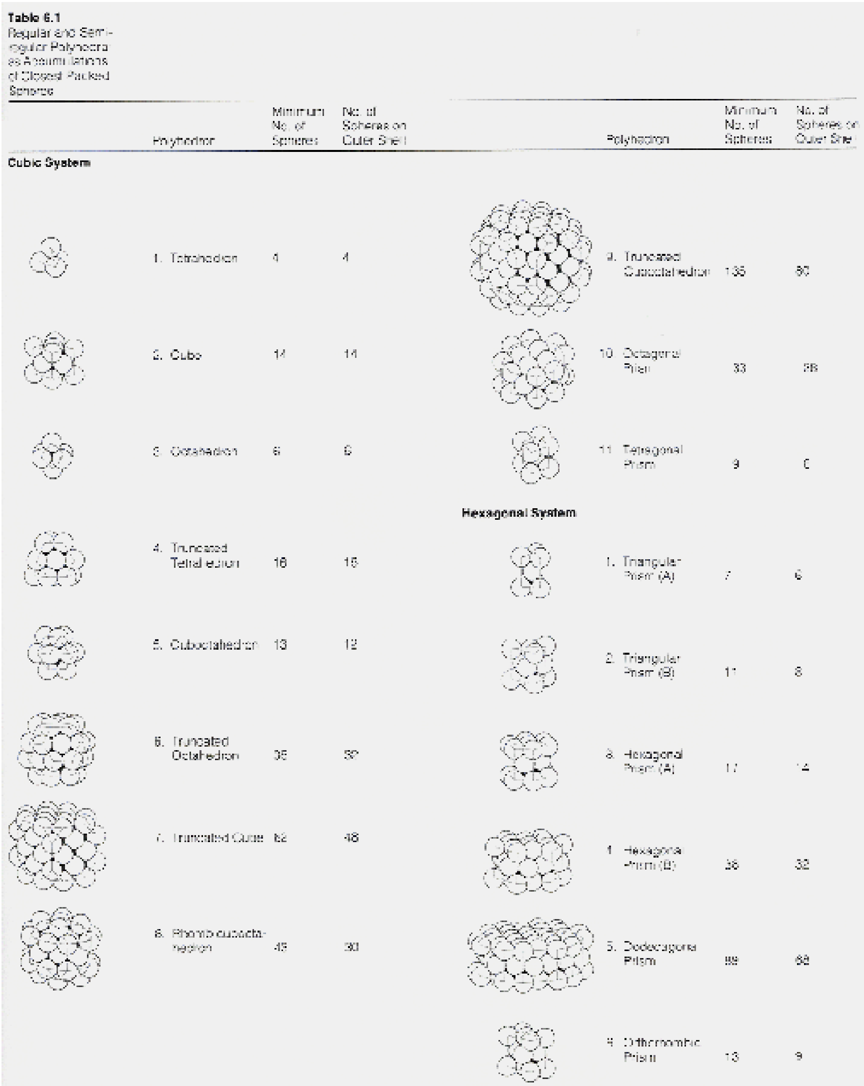


**Table 6.1** Regular and Semi-regular Polyhedra as Accumulations of Closest Packed Spheres

| Polyhedron | Minimum No. of Spheres | No. of Spheres on Outer Shell |
|---|---|---|
| **Cubic System** | | |
| 1. Tetrahedron | 4 | 4 |
| 2. Cube | 14 | 14 |
| 3. Octahedron | 6 | 6 |
| 4. Truncated Tetrahedron | 16 | 16 |
| 5. Cuboctahedron | 13 | 12 |
| 6. Truncated Octahedron | 38 | 32 |
| 7. Truncated Cube | 62 | 48 |
| 8. Rhombicuboctahedron | 45 | 30 |
| 9. Truncated Cuboctahedron | 135 | 80 |
| 10. Octagonal Prism | 33 | 28 |
| 11. Tetragonal Prism | 9 | 8 |
| **Hexagonal System** | | |
| 1. Triangular Prism (A) | 7 | 6 |
| 2. Triangular Prism (B) | 11 | 8 |
| 3. Hexagonal Prism (A) | 17 | 14 |
| 4. Hexagonal Prism (B) | 38 | 32 |
| 5. Dodecagonal Prism | 89 | 68 |
| 6. Orthorhombic Prism | 13 | 9 |

**Fig. 16.** Closest packing chart, Spheres as Morphological Units [4 Pearce pp57]

# 5 Structural Optimization in Engineering

## Genetic algorithms

In engineering fields, accomplishing an objective with a minimum of effort, either in terms of material, time or other expense, is a basic activity (Figs. 18, 19 and 20). For this reason it is easy to understand the interest designers have in different optimization techniques. Mathematical, as well as, model based tools have traditionally been

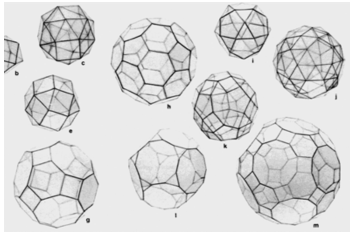


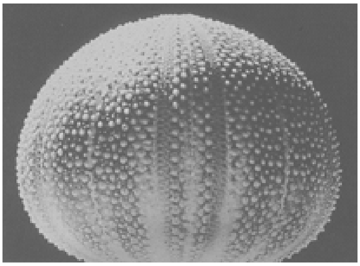
**Fig. 17.** Various geometric configurations

Here are a few varieties of geometric configurations that achieve similar overall results, spheres, while blending various geometric shapes together in a number of ways.

employed for such optimization. In recent times, mathematical methods executed on computers have become predominant. Unfortunately, computer derived solutions often obscure the range of possible solutions from the designer by only exhibiting a final, 'best' solution. Naturally, optimization methods can only respond to the objective parameters which are coded into the problem, and as a result, non-coded parameters, such as aesthetics, or context are left out of the optimization process, and ultimately left out of the final design solution.

Structural optimization in engineering takes natural constructions as an example. Similar to nature itself, computer-generated genetic algorithms[2] can be calculated using stated goals to achieve global optimization - the search strategy is, like in nature, goal-oriented. An evolutionary algorithm maintains a population of structures (usually randomly generated initially), that evolves according to rules of selection, recombination, mutation and survival, referred to as genetic operators. A shared 'environment' determines the fitness or performance of each individual in the population. The fittest individuals are more likely to be selected for reproduction (retention or duplication), while recombination and mutation modifies those individuals, yielding potentially superior ones. Using algorithms, mechanical selection, mutation and recombination improves generationally with a fixed parameter size and quality.

[2] A genetic algorithm generates each individual from some encoded form known as a 'chromosome' and it is these which are combined or mutated to breed new individuals. The basis for the optimization is a vast array of possible solutions (population), where every solution (individual) is defined through a particular parameter (chromosome). The individuals within a generation are in competition with one another (selection), in other words, the value (fitness) of the individual is what allows the survival of the parameter (gene) until the next generation. The results of this computer-supported process are automatically generated and optimized. Evolutionary computation is useful for optimization when other techniques such as gradient descent or direct, analytical discovery are not possible. Combinatory and real-valued function optimization in which the optimization surface or fitness landscape is 'rugged', possessing many locally optimal solutions, are well suited for evolutionary algorithms.



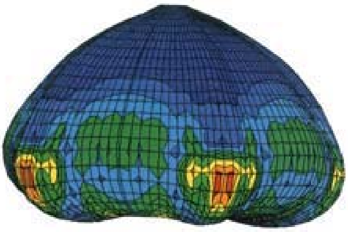


**Fig. 18.** Structure optimization in the shell structure of a sea urchin.

**Fig. 19.** Finite element analysis[3] of sea urchin shell, color coded stress analysis [15 *Process und Form*, K. Teichmann].

## Computer-compressed evolution

*Design space and finite elements*

Computer-compressed evolution follows the same construction principle that nature employs to promote for example the shell growth of a sea urchin (Figs. 18/19) or the silica structure of radiolarian (Figs. 23/25). Building material can be removed wherever there are no stresses, but additional material must be used where the stresses are greater. This is the simple principle that evolution has used for millions of years to produces weight optimized "components". Using computer programs based on computer-generated genetic algorithms like the SKO method[4], scientists are now able to simulate this evolution and compress it into a short time span [9].

In order to simulate lightweight engineering strategy according to nature's guidelines, scientists using the SKO method must first define a virtual design space, which represents the outermost parameters of the component being developed. To subdivide this design space into many small individual parts, the finite elements, a grid is applied. If now a virtually external load applied, the computer calculates the resulting force exerted on every one of the finite elements. The FE model shows exactly where there is no load stress on a component and in turn shows where it is possible to make savings with regard to the materials used. On the other hand, for areas that bear heavy stress the simulation program indicates the need to reinforce the construction material. Like nature the computer let repeat this "finite element cycle" several times. As a result, they can refine a component repeatedly until the optimal form –one that evenly distributes the stresses within a component– is found.

[3] The finite-element-method is a procedure used to solve structural-mechanical calculations with precedence given to the three-dimensionality of the system. As a result, the construction is broken into discreet elements - Finite Elements (FE – such as columns, beams, plates, shells, etc. characterized by the individual connections (discreet points) where they are combined with one another.

[4] The DaimlerChrysler Reaserch Center Ulm and Uni Karlsruhe, Prof. Claus Mattheck, in Germany developed the SKO method (Soft Kill Option). The method is based on the idea that is it only possible to achieve a combination of the lightweight and maximum strength in a design when the stresses are constant over the structure's entire surface area, ensuring that no area is under- or overstressed.

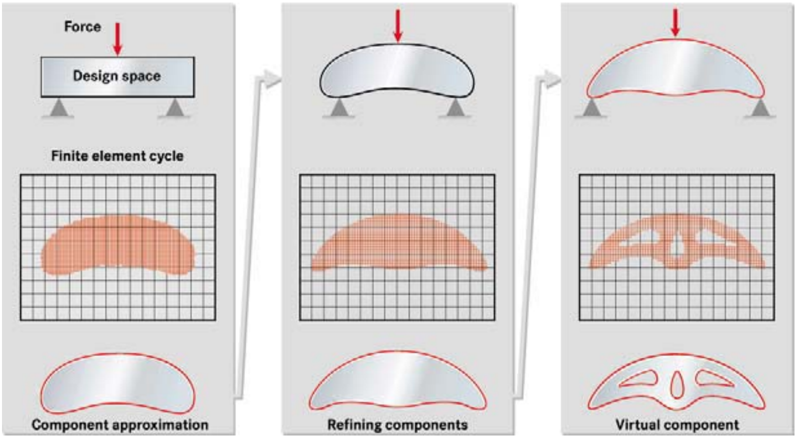



**Fig. 20.** SKO method (Soft Kill Option). [9 HIGHTECH REPORT 1/2003, pp60-63]

## 6 Biological Models

### *Radiolarians*

A number of self-generated, biological models based on the bubble cluster theory exist. One of the best examples of this is the Radiolarian. Radiolarians are single-celled, marine organisms. These microscopic creatures extract silica from their environment to create a skeleton. Highly articulated geometric patterns define the usually spherically shaped structures. The resulting form resembles that of a dome.

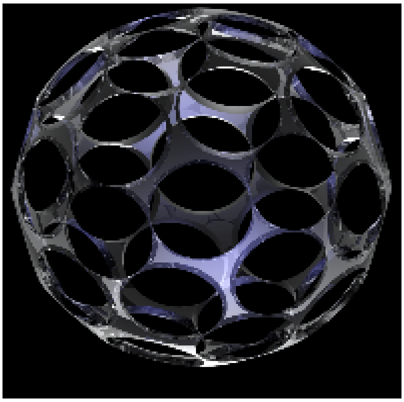


**Fig. 21.** Computer generated spherical cluster skeleton based on the bubble clusters theory (Figs. 6–13)

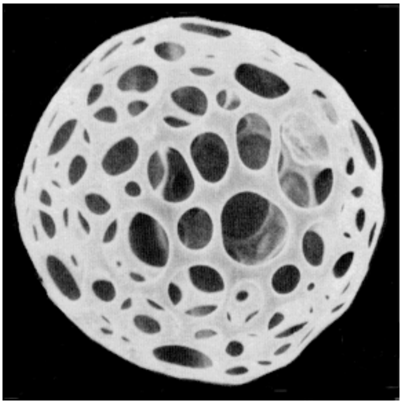


**Fig. 22.** Fossilized skeleton Radiolarian [6]

The process carried out to produce such as resulting structure is a relatively simple one. A great number of vesicles, tiny sacs of fluid, are created. These bubbles are essentially tiny versions of the larger soon-to-be cell (Figs. 6–13). They are the common modules for the cell. As the vesicles begin to pack closely together in a radiating pattern, the resulting form is a spherical mass, the cell. The unique geometry of the cell's surface, as produced by the closely packed bubbles, is the formwork for a skeleton [4].

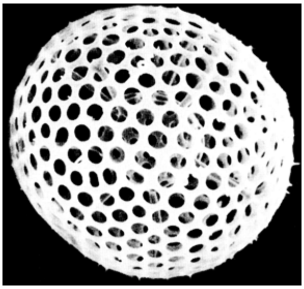


**Fig. 23.**

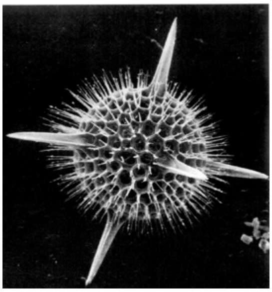


**Fig. 24.**

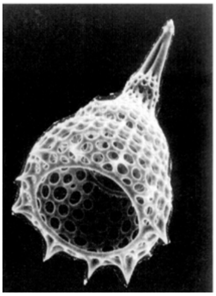


**Fig. 25.**

Radiolarian and fossilized skeleton [5][6]

Within the crevasses formed at the edges where the bubbles contact one another, silica particles settle and join together. The geometry created by the bubble connections allows the silica to form a series of interconnected members of similar size and shape. The result is a complex-looking skeletal structure made up of a great number of simple, relatively similar members.

To create such a seemingly complex system for so simple an organism, it is necessary to build upon highly efficient mathematic and geometric principles. These principles are embedded in the genetic code of the radiolarian, and similar life forms.

### *Diatoms*

A number of diatoms share similar characteristics with their single-cell cousin, the radiolarian. Some of these include: radial form and a ridged skeletal structure. The skeletal structure of a diatom is not necessarily spherical, but it is radial. Tiny bubbles radiate in a closely packed form to create the cell shape. This bubble form is decrypted as a "foam-raft". Once this occurs, silicate deposits meet along the bubble edges to form the skeleton. This material forms what can be considered actually a "glass" skeleton.

Variations of diatoms are numerous. Not all diatoms are perfectly round in configuration. For instance, some are actually triangular in shape. These diatoms still adhere to the closest packing principles, just a different version than most. Other types of diatoms are oblong in shape. Instead of a repetition of similarly shaped spheres, or bubbles, these adaptations pack together larger, tubular forms to create their skeletons.

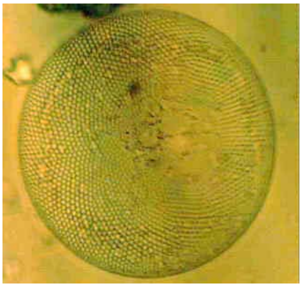


**Fig. 26.**

**Fig. 27.**

Diatom cells

Diatoms, and radiolarians alike, are chief examples of highly efficient structural systems with simple enough geometries for organisms with limited genetic information storage capabilities.

### *Cork cells/honeycomb*

Cork cells and honeycomb structures are prime examples of minimalist, self-repeating structures. Both rely on simple members to shape themselves along with a certain rigidity and efficiency of space within its structure.

**Fig. 28.** Honeycomb

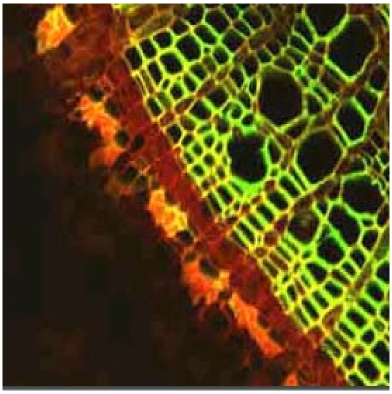


**Fig. 29.** Cork cells

The structure of cork cells is the purely biological representation of a honeycomb structure. The cells are roughly hexagonal and do adhere to the closest packing rule of geometry [4, Pearce pp16]. Cork cells, however, are not entirely uniform. Honeycomb, while not biological in nature, is created by biological creatures and is rooted in genetic information stored within these beings. Its purpose is quite functional, in that, it stores honey for food. The most efficient way to contain the honey in relatively small compartments is in a hexagonally shaped container. This simple shape is quite important for a number of reasons.

First of all, a great number of honeycomb cells are necessary to store the food. A hexagon is made up of six sides of identical length. This makes the construction process easier on the bees as only one dimension of material is necessary. Second, due to equal member size as well as a number of possible orientations, the hexagons fit together very easily. This is important because many bees work at the same time from different places and, therefore, need to be able to connect the structure with little effort.

### *Insect compound eye*

One of the most recognizable examples of closely packed systems is that of the compound eye (Figs. 30-31) found on most insects.

Many characteristics of insects, most often the ability to fly, facilitate the need for a relatively large eye with maximum surface area and range of view. To fulfill these needs in such a small creature, a simple method of order is necessary to construct such a complex system. Naturally, a highly repetitive organization was used. A tightly packed network of smaller, hexagonally shaped eyes is wrapped around the curvature of the larger, whole eye, which bulges from the insect head.

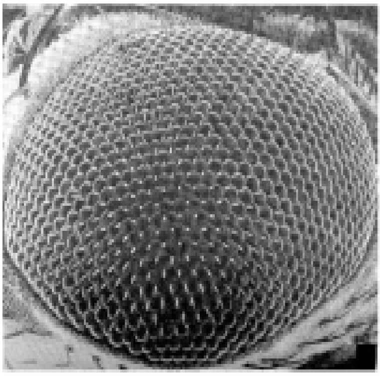


**Fig. 30.** Compound eye

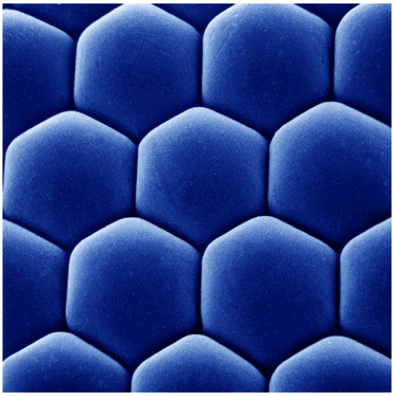


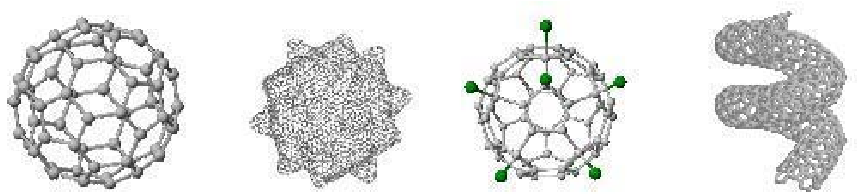
**Fig. 31.** Detail of insect compound eye

The flexibility of the hexagonally shaped eye units allows this to easily be achieved. Permitting the blanket of eyes to be wrapped in any direction on the insect's head gives it a view toward most any angle possible, which is necessary for such erratic flight patterns. Compound eye configurations can vary from species to species, but the hexagonal sheet configuration is the most common.

### *Fullerene*[5]

The smallest known and just recently discovered structures based on the principles of self generation, closest packaging and polyhedral are the fullerene[6]. Fullerenes (Figs. 32–33) were first discovered in 1985 when the soccer ball shaped C60 (Buckminsterfullerene) was synthesized. The novel phase of carbon was named after the engineer and architect Richard Buckminster Fuller (1895-1985) as the molecules share the architecture of his geodesic domes. Fullerenes are ranging in size from 20 to over 500 carbon atoms.

The carbon atoms in C60 are arranged in a geometric shape consisting of 12 pentagons and 20 hexagons. Other spherical fullerenes (collectively known as buckyballs) were subsequently synthesized with a different number of hexagonal faces. The smallest possible fullerene is the dodecahedral C20, a shape consisting of 12 pentagonal faces and no hexagonal faces [7]. Larger, fullerenes have been found to exist in nature [8]. Nanotubes, nanohorns and buckybowls are other examples of fullerenes [14].



**Figs. 32–33.**

Different models of fullerenes. Fullerene Research Centre, [14 University of Sussex www.susx.ac.uk] Left to right: C60, C60-, Exohedral Fullerene Compounds C60, Cl6, Nanotubes

## 7 Architectural Applications

*commonsense nature - producing maximum effect with minimum resources*

### *Structural configurations*

Just as volumetric and formal configurations are quite various, so, too, are the structural configurations of closest packed organizations. Structures with the qualities of domes are not the only forms that can be used and turned into a building. Variations in the manner in which the polygons go together can create long- spanning tubular structures and volumes. The blending of these various methods of employing the system can be seen here.

**5** Definition: A class of cage-like carbon compounds composed of fused, pentagonal and/or hexagonal $sp^2$ carbon rings.

6 In 1996 Prof. Sir Harold Kroto was jointly awarded the Nobel Lauriate for chemistry for discovering the fullerenes. Fullerenes are large carbon-cage molecules. By far the most common one is $C_{60}$ –also called a "buckyball", other relatively common ones are $C_{70}$, $C_{76}$, and $C_{84}$.

**Fig. 34.** Polyhedral structure Eden Project, Cornwall, GB, Nicholas Grimshaw Architects

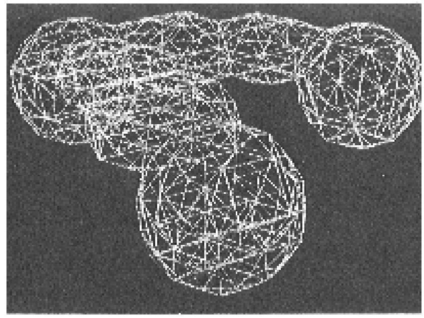
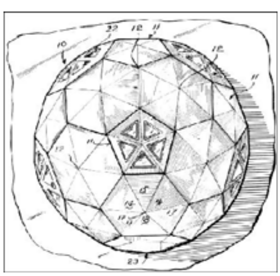


**Fig. 35.** Structural system by B. Fuller

The basic way to derive these structural schemes is to place relatively thin, load carrying members along the edges where the polygons meet. When configured correctly, these are the points at which forces naturally occur. Based upon the geometries of that form, it is likely that a highly efficient system is the result. One of the greatest benefits of this type of structural design is the relatively small number of member sizes. When multiple polygon geometries are involved, other members and connection types are necessary, but all can be accounted for in the initial design.

***Fuller′s geodesicpatent***

Applying the science of self-generation to architecture has yet to be fully realized. Attributes of biological examples, like the radiolarian, do currently exist in structures like Buckminster Fuller's geodesic dome. Fuller recognized the closest packing of spheres phenomena in nature and used it as a model for his dome based on those mathematical principles. One of the most revolutionary innovations Fuller developed with his geodesic system was the repeated use of highly efficient, similar members. This allowed for the self- generating/repeating method of construction already in use by nature.



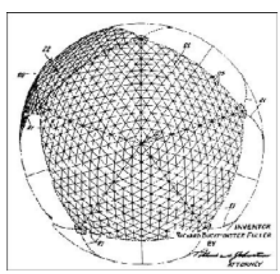


**Fig. 36.** Geodesic sphere

**Figs. 37-38.** Fuller's geodesic patent drawing

To take Fuller's discoveries one-step further using today's technology, it is possible to generate structural optimized structures in a computer by using for example the SKO method to create not just a representation of a biological form, but tu reproduce the evolutionary steps taken to make a structural system most efficient.

## *Eden Project, Cornwall, GB*, Nicholas Grimshaw Architects

A recent example for polyhedral structures in architecture is the Eden project completed in 2001 by Nicholas Grimshaw. The Eden project is a botanical garden and education centre within a former china clay quarry. The construction of enormous greenhouses (biomes) created a sheltered micro-climate and enable large numbers of the world's tropical and Mediterranean species to be represented within the plantings. The building foundations follow the complex contours of the pit and support the lightweight tubular steel geodesic domes which are interlinked with arches. The largest of these domes is 100m across and 45m high internally.



**Figs. 39-40.** *Eden Project, Cornwall, GB*, Nicholas Grimshaw Architects, Anthony Hunt Associates engineers, structure: MERO Membrane ETFE-Pillows diameter 9 m, Dimensions: 15 590m$^2$, 100m $\times$ 220 m height 55 [www.anthonyhuntassociates.co.uk]

The Lightweight ETFE foil pillows form the cladding system between the dome members with panels up to 11m diameter providing maximum light and UV transmission. These hexagon shaped bubbles were used as they can settle perfectly on to any shaped surface.

The Biomes' steelwork is extremely light and is anchored into the foundations with 12-metre long steel ground anchors. The design comprised a two-layer steel curved space frame, the hex-tri-hex, with an outer layer of hexagons (the largest 11m across), plus the occasional pentagon, and an inner layer of hexagons and triangles (resembling huge stars) all bolted together like a giant Meccano[7] kit. Each component was individually numbered, fitting into its own spot in the structure and nowhere else.

[7] Meccano is a metal construction set consisting of nuts, bolts, strips, girders, brackets, wheels, axles, motors, gears and pulleys, Patented in 1901 by Frank Hornby of Liverpool, England.

**Figs. 41-43.** The transparent foil 'windows', made of 3 layers of ETFE (ethylenetetrafluoroethylene-copolymer), form inflated 2- metre-deep pillows. ETFE has a lifespan of over 25 years, transmits UV light, is non-stick, self-cleaning and weighs less than 1the equivalent area of glass and has a great stress redundancy. [www.anthonyhuntassociates.co.uk]

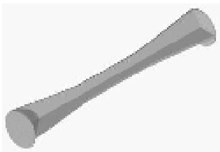
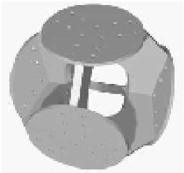
### *National Swimming Centre Beijing Olympics 2008*, *Peking* (*CN*) PTW, Sydney & China State Construction Engineering Corporation, Peking & Ove Arup Pty Ltd., Beijing, London

The winning project for the international design competition' National Swimming Centre Beijing Olympics 2008' by the Australian architectural firm of PTW is an other example for the efficient combination of polyhedral structures with ETFE cushions. The design, called 'Watercube' is a simple and concise square form that ultimately uses the water bubble theory, the natural formation of soap bubbles, to create the structure and building cladding. The structure system, a space frame, is based on polyhedral cells in different dimensions, the most effective sub-division of three dimensional structures. It is also based on the way that structure in nature tiles spaces. The building's skin, made from ETFE, has been designed to react specifically to lighting and projection.

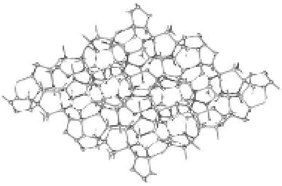
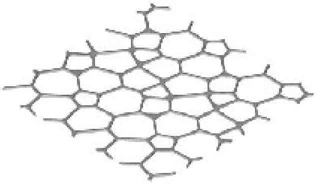
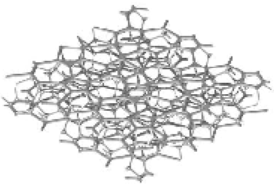
**Figs. 44-46.** The Rendering, model and structure model shows the three dimensional arrangement of the polyhedral structure, a common natural pattern seen in water bobbles and organic cells. The building envelope acts as an very efficient green house where90area. [Ove Arup Pty Ltd, www.ptw.com.au]

### Construction and Internal structure

The internal structure within the depth of the roof and walls is highly repetitive. There are three different nodes and four different members. These elements can be cast, rolled or fabricated in different ways [13, Ove Arup Pty Ltd].


**Figs. 47-49.** The members are fabricated from three plates with circular end plates. The nodes are simple steel fabrications with circular plates for the end plates on the members and corresponding holes to receive the bolts. These two elements are simply bolted together to form an assembly. The assemblies are bolted together to form the space frame. [Ove Arup Pty Ltd]

**Figs. 50-52.** From left to right: polyhedral space frame, flat face structure, combination of both. The face structure comprises a flat web of rectangular box sections either welded or bolted together on site. The face structure is added to the top and bottom of the space frame to compete the structure. [Ove Arup Plt ltd]

## 8 Intelligent Structures and Materials

*Self-organization as the defining principle of nature*

Polyhedral structures based on the bubble principal are perfect study models for self-generating structures in nature because of there relatively simple physical and morphological principles and geometries. Self- organization it the defining principle of nature. It defines things as simple as a raindrop or as complex as living cell - simply a result of physical laws or directives that are implicit in the material itself. It is a process by which atoms, molecules, molecular structures and constructive elements create ordered and functional entities.

Engineers are using this concept already successful for optimization processes in a white range of applications starting in mechanical-, medicine-, air and space engineering. Architects are only one step away adopting the same technique for designing in a macro scale buildings and structures. Material scientists[8] are already designing and producing new materials or smart materials in a Micro scale using the self organizing principles. In the future, the material engineers will develop constructions out of self-structuring materials that consciously use the principles of

[8] Saarbrückener Institut für Neuer Materialien [INM], Frauenhofer Institute für Fertigungsmechanik und Angewandte Forschung, Bremen

self-organization, creating not only materials with brand new properties but also inspiring architects to define their constructions in a more intelligent way.

At its best, intelligent structures and materials will influence the entire philosophy of construction. Engineers will no longer ensure safety through quantity of material and cost. Simple structural analysis will no longer suffice; instead, self-organizing structures will define the new construction principles.

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University of Tennessee, College of Architecture and Design Research Grand.

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