TRANSFORMATION IN NATURE

Integrating biomimetic design into
New Pavilion Design in Seismic Groningen

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TRANSFORMATION IN NATURE

This is my research paper for graduation project in Architecture Engineering Studio of TU Delft University Faculty of Architecture and Built Environment. The paper is intended to search for biomimetic solutions to design a new construction method in seismic Groningen. This paper acts as the preparation and preliminary research to facilitate my latter design. I would like to give thanks to my architecture mentor for his enlightening guidance and patient teaching, also my research mentor ir. P. Jennen for his adequate help.

Yonghui Huang/ 4502914

CONTENTS:

GENERAL OVERVIEW

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Keywords:
seismic approaches, biomimetic morphology, lightweight structure, responsive skin application

The over-exploited oil production induces the mild but frequent earthquakes in Groningen. Most constructions in Groningen are brittle unreinforced masonry structure, which are suffering different degrees of damage. The architects and engineers are collaborating to find solutions to retrofit and stabilize the existing constructions. On the other hand, Holland's State Foresty Commission is starting a "reforest program" to increase the forest coverage rate. Based on those double backgrounds in Groningen, this paper is to find the biomimetic solutions to approach the seismic architecture design.

The research method is via literature study, case studies and physical experiments to finally find a suitable construction way.

In the previous chapter, the research is about the basic knowledge on seismic design principles, toolbox and constraints. The second chapter is to research the biomimetic structure, which is divided into three steps. firstly, I try to collect and categorize biology-inspired cases and their counterparts in architecture applications in the general way. Secondly, more deeper research and analysis will be conducted on Frei Otto 's natural construction and lightweight design because of Frei's excellent precedence in natural construction. Thirdly, regarding a more sustainable material choice, timber spine structure and detail components are in the consideration. Final chapter relates with the technical parts, the responsive skin design, which is another use of bionics influencing the interior environments.

In the conclusion part, I will discuss about the integration of the tensile structure and timber construction, applying it into a new type of construction method which is prepared for the latter design part.

1. INTRODUCTION

1. INTRODUCTION

1.0 TITLE
TRANSFORMATION IN NATURE

"Being an integral part of nature ourselves, we shall never be able to talk about it from the outside but only from the inside."

Architects and builders have always drawn inspiration from nature. Countless analogies can be found in the architecture of all ages. The examination and application of nature's materials, the interrelation of the edifice with the environment, all these aspects have been considered by builders at all times.

Figure1

1. INTRODUCTION

1.1 PROBLEM STATEMENT

The Groningen is facing a continuous and potential danger of the frequent earthquake these years due to over-exploitation of the oil in the underground soil layer. Most buildings in threatened areas by earthquake are masonry construction. Although very few constructions really collapse, It has been accumulated that quite a few buildings in Groningen are in different extents of the damage. The engineers attempt to stabilize the existing structure with the technical and engineering solutions, which always lacks consideration of the aesthetic value and functionality. Beyond providing decent retrofit to the existing constructions, architects should prepare for the new construction methods and design. The collaboration between the architects and engineers should not only take account for the structure strengthening stability , but also offer more value on the social, economical, sustainable aspects.

In terms of economical and social aspect Groningen has abundant of undiscovered landscape resource value in farmland. People are losing interest of the rural landscape and rural life style. Furthermore, the city is facing the challenge of population shrinkage. Less and less people are willing to live in this area. Thirdly, the start is made by HOLLAND'S STATE FORESTY COMMISSION to regrow the forest canopy in heavily exploited and densely populated areas called "Reforestation Program". How to bring the value back to the rural life stimulating the village vitality, at the same time with responding to the appeal of the reforestation plan?

1.1 PERSONAL FASCINATION

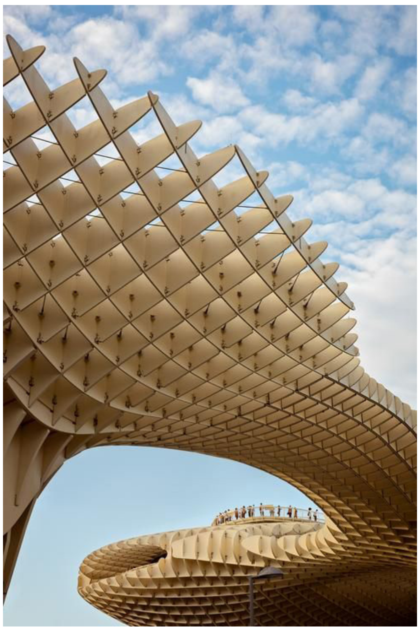


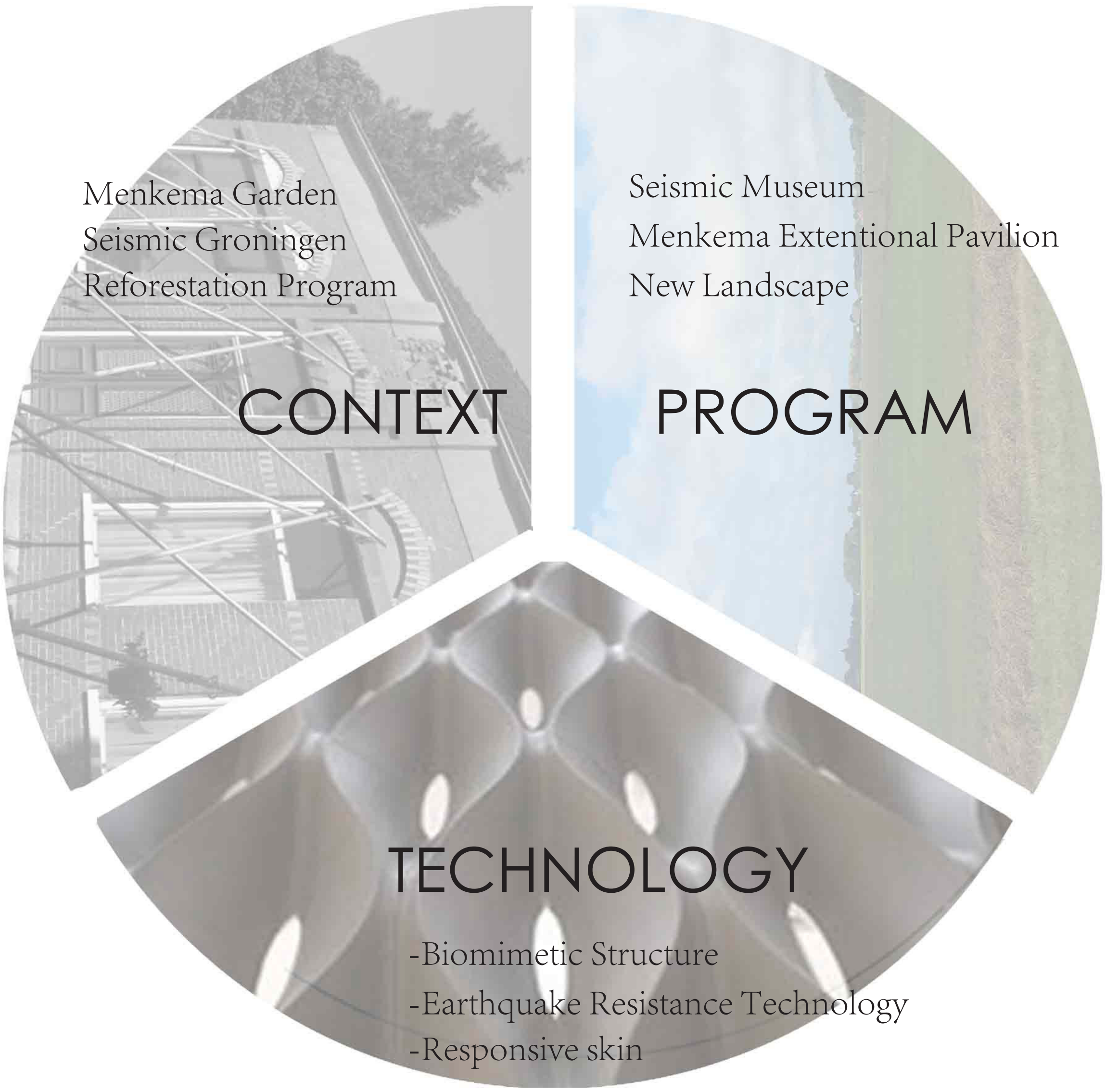
Figure2

Through the study on the space formation and structure design, I am aware of structure acting an essential role in the space formation. In the seismic architecture design, the structure can be either passively utilized as an approach to strengthen the structure stability regardless of the aesthetics and function, or can be integrated with the space formation and architecture morphology. The role of the architect is to understand the interactive relationship between space and structure provoking the creative inspirations on the new construction method and material use.

The topic of this research paper is set upon the biomimetic structure and natural form finding with the purpose of reinterpreting the man made landscape morphology. On the other hand, this biology-inspired approach should also be beneficial to the seismic proof design. The interest of biomimetic structure oriented to the application of the spine structure as pretension and compression structure, with light weight timber as material choice.

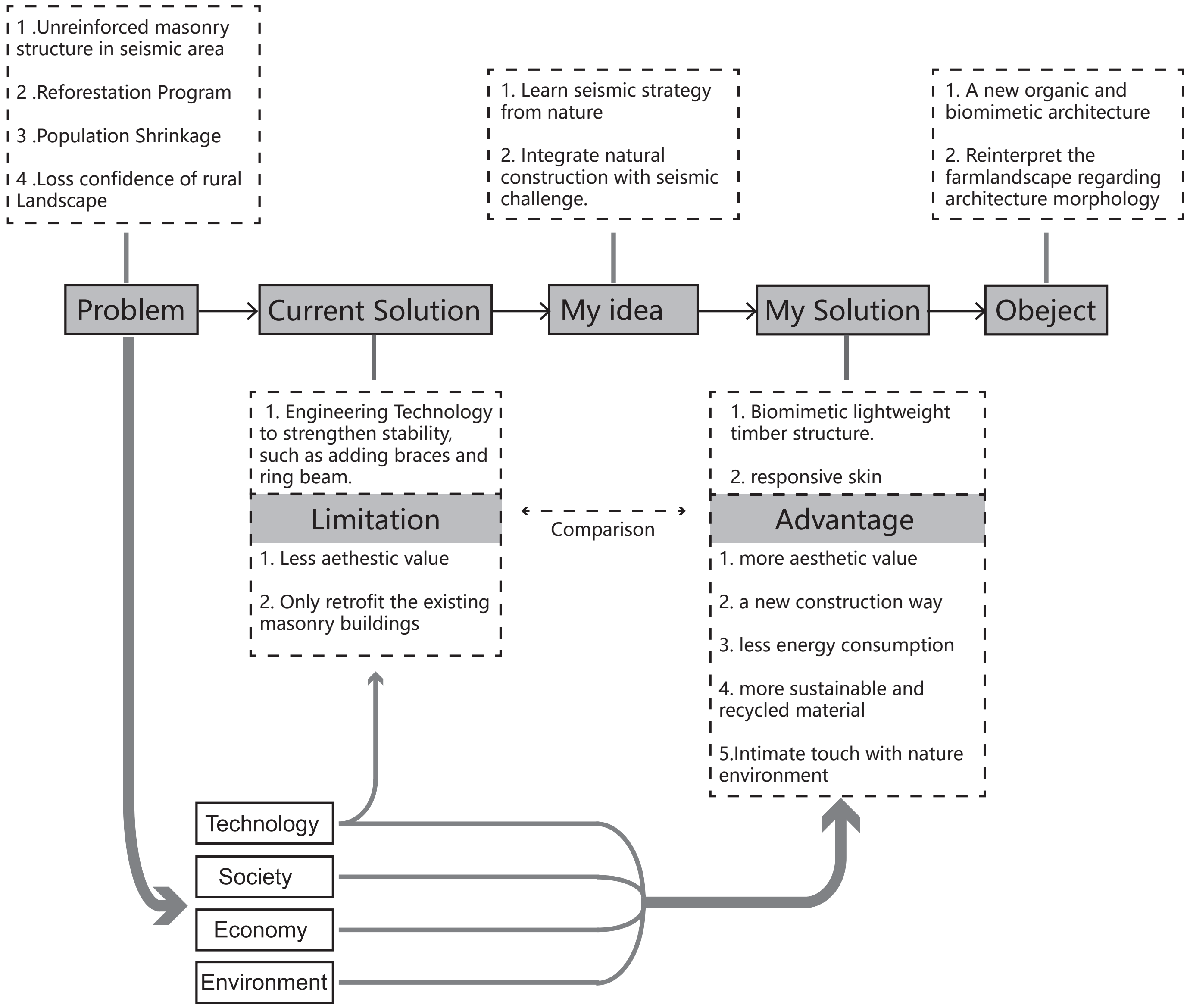
1. INTRODUCTION

1.2 Diagram



1. INTRODUCTION

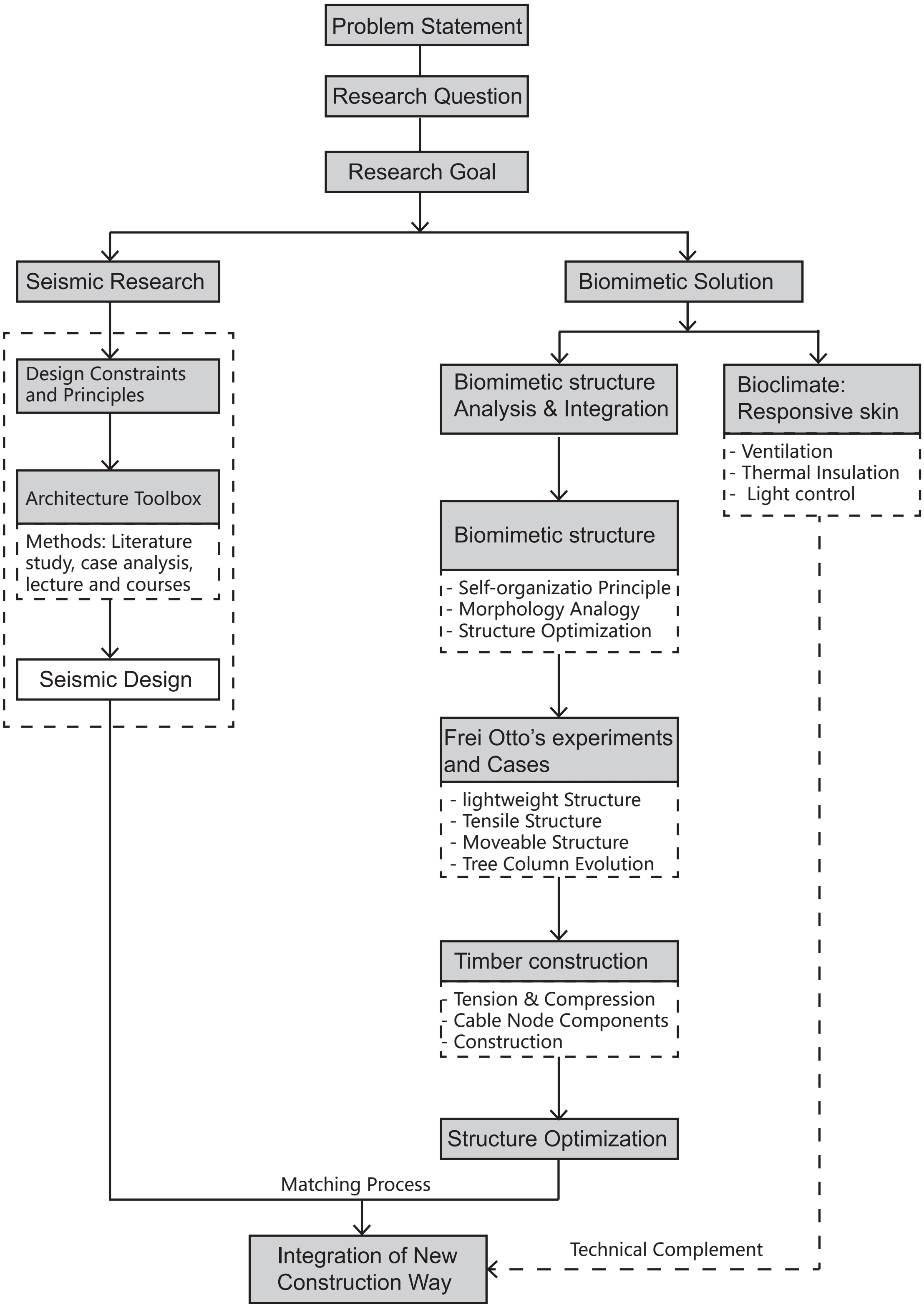
1.2 Diagram & Scheme Of Research



1. INTRODUCTION

1.2 Diagram & Scheme Of Research

The research consists of seismic proof constraints and bio-mimetic application. The overall research scheme is from the general to specific and design oriented.



1. INTRODUCTION

1.3 Research & Design

RESEARCH QUESTION:
"How to adopt a biomimetic strategy for the seismic Groningen, taking the landscape, context, technology into account?"

The research will be spilt up into three parts, seismic design research, biomimetic structure research, bioclimate technology research.

seismic design research
-1.what constraints the architecture design should comform to in seismic region?
-2. what kind of the architecture approaches could contribute to the seismic resistance design?

Biomimetic structure research
-1.what kind of biology-inspired structure in general architecture applications?
-2. which structure type could better match with the anti-seismic principle?

Bioclimate technology research
-1. what kind of interactive skin technology could be integrated into the museum design?
-2. How to attached into the new structure in an appropriate way?


Figure3. British Museum Glazed Toroid

DESIGN QUESTION:
"Can I design a bio-morphological Museum in Seismic Groningen reinterpretating the local nature landscape?"

-1.How to create a new inspirational structure with the knowledge of biomimetic research and timber construction?

-2.How to integrate the responsive skin technology into the museum design creating a charming space atmosphere?

1. INTRODUCTION

1.4 Site & Context

Uithuizen in farming landscape

Garden zone in the village

Figure 4. Site

Figure 5 Farmland Landscape

Figure 6 Artifical Landscape

The site is located in the south of the Menkenma garden in Uithuizen, surrounding with abundant high trees in three faces, the southern orientation is towards the broad farmland, which is a great horizontal landscape scenery (figure 5).

The Menkenma garden is designed by Allert Meijer in 16th century. "The gardens are marked by a clear cut, orderly and symmetrical layout with principal axis and a transverse axis which intersect at the center of the house. The style proclaims "man, the master of nature."

Does rationality can really conquer and control the nature? Whether the 16th centuries' notion of relationship between human and nature is one subjected to the other one? This is one question that I try to respond in this design.

Thereby, how to reinterpret the position of the man made design in in front of nature?

Program & New landscape

My ambition is to design a bio-morphological seismic museum. The form of the Museum will be distinctly different from the existing strictly organized garden, with suggesting the human's creativity will be an imitation of the natural creation rather than conqueror. The design itself will be a new interpretation of the nature just like the artificial landscape (figure 6). The other goal of the design is to attract the development of the tourism industry and revitalize the local community life.

2. METHODOLOGY

2. METHODOLOGY

2.0 Design oriented Research

1. Research Process

The research is a process of seizing knowledge from abroad to specific range to find answer to the question. Based on my design object attempting to design seismic resistant, bio-inspired timber construction. I correspondingly concentrate my research topics into three aspects below, seismic design principles, biomimetic structure, and timber constructions. Consequently, the research provides me with three structure proposals, which can be fitted with the site and architecture concepts.

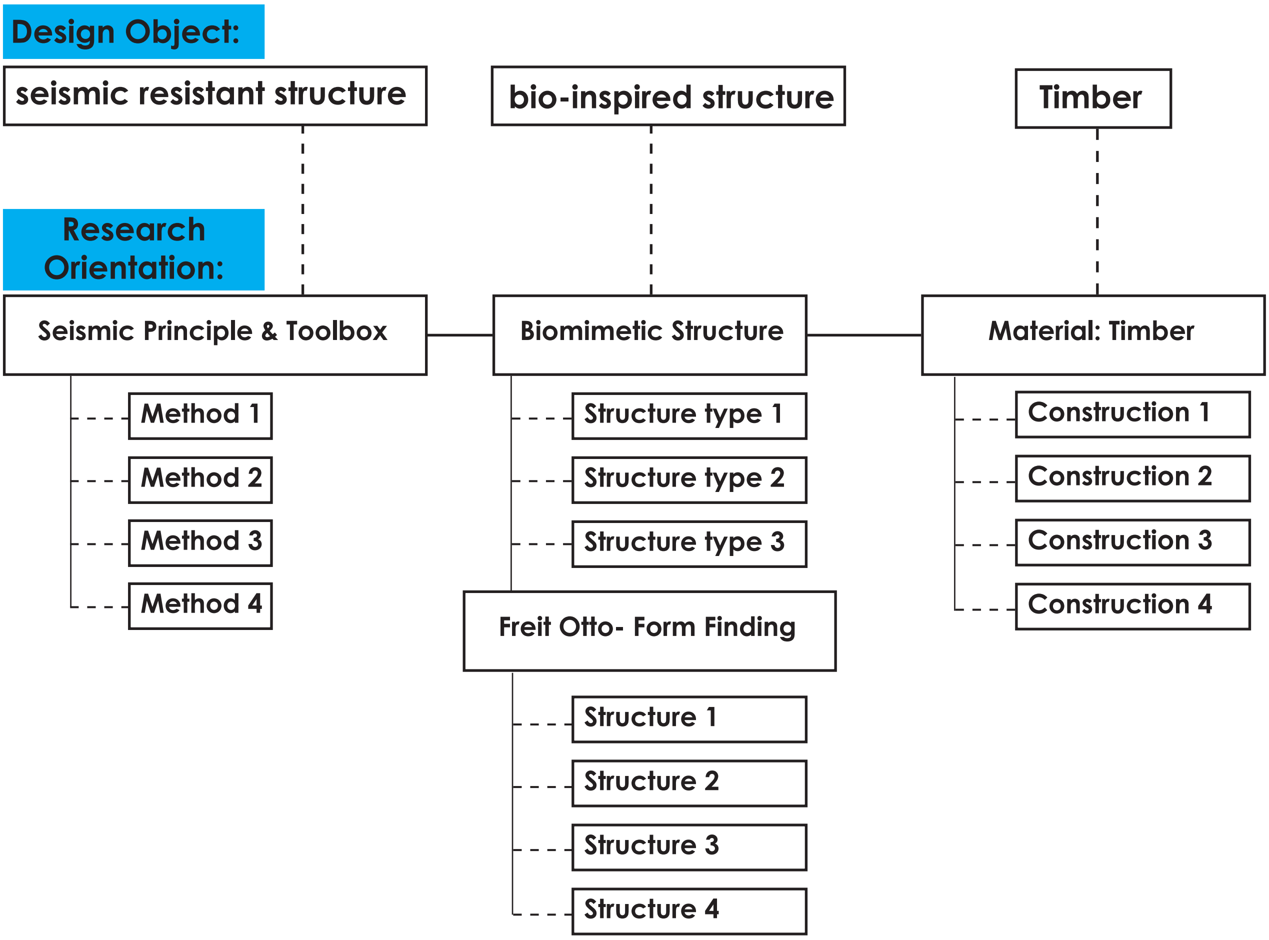


Figure 7. Design oriented research

2. METHODOLOGY

2.2 Literature study & Case study

1. Literature review

literature review is executed in order to gain understanding of the biomimetic application in architecture, the seismic situation in Groningen ,the seismic design principles, and the timber construction in complex shape.

2. Site visit

During the research, the site visit was finished. The visit is an experience of sensing the site atmosphere, which set the major tone of the design, the environment-friendly construction in the forest with a humble figure. At the same time, the visit was focused on the in-depth conversation with local people to find out what is the potential need for local people.

3. Socio-environment analysis

Through the literature study, the demographic statistics of this area, the reforestation program executed by Holland's state foresty commission became the challenge and opportunity for me to start the design task.

4. Case study

with respect to the specific analogy with the living, the case studies are involved in every biomimetic applications.

5.Course and conferences

The seismic design course by Emily is given, addressing the earthquake hazard, dynamics of structure, basic design principles about seismic resistant construction.

Figure 8. site photos

3. SEISMIC PRINCIPLES IN ARCHITECTURE

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3.0 Nature & Seismic-resisting Principles

-Nature of Seismic force

Seismic force is inertia force. The inertia force generated by earthquake transfers from the foundation to the whole structure.

"As the ground under a building shakes sideways, horizontal accelerations transfer up through the superstructure of the building and generate Inertia forces through it." [1]

With the increasing height of the building stories, the more inertia force the building would need to bear. Unlike the wind loading, the peak earthquake force only lasts for just fractions of seconds. The earthquake force is coming from various directions, both vertical and horizontal directions.

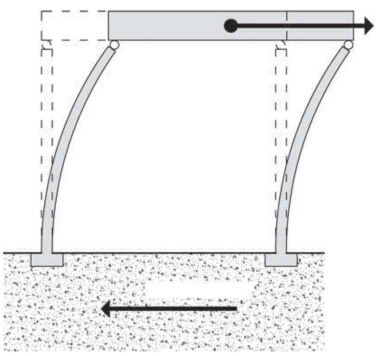


Figure 9. An inertia force is induced when experiencing acceleration at its base.

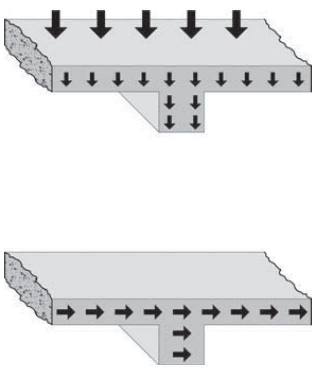


Figure 10, An area of concret floor showing the diffirence between gravity forces and horizontal forces

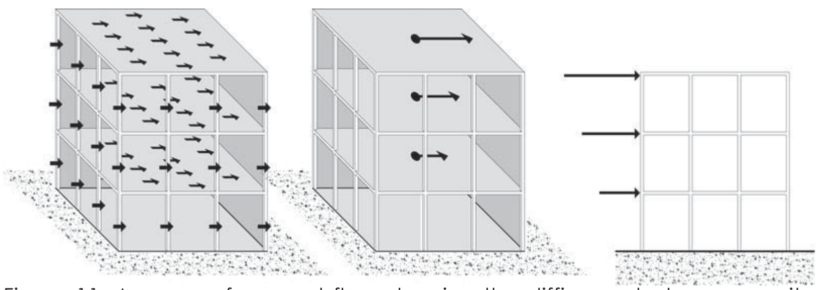


Figure 11. An area of concret floor showing the diffirence between gravity forces and horizontal forces

1.Seismic Design Architecture.2 How Buildings Resist Earthquakes.P16

3. SEISMIC PRINCIPLES IN ARCHITECTURE

3.0 Nature & Seismic-resisting Principles

-Factors Affecting the severity of Seismic force

1. Building weight

The single most important factor affecting the inertia force in a building is its weight. According to Newton's Second Law of Motion, F=M x a. The heavier an object is, the greater the inertia force for a certain level of acceleration and the longer natural period lasts. If there is no mass, there is no inertial force. Accelerations generated by the seismic waves in the ground are transmitted through the vibrating structure to the masses at various levels, thereby generating the so-called horizontal seismic forces. The light-weight construction reduces the potential architectural impact of the requirements of seismic structure.

2. Resisting Seismic Force: Strength and Stiffness

Every building requires sufficient structural strength to resist the bending moments and shear forces by the earthquake. The building with shear wall resist inertia forces in both orthogonal directions and the wall forces, bending moment. (Figure 12)

Stiffness is almost as important as strength. The stiffness of a structure could prevent deflection of the structure member. Stiffness is proportional to the inertia of a member.(Figure 13) Different stiffness of the member should be proportioned to the

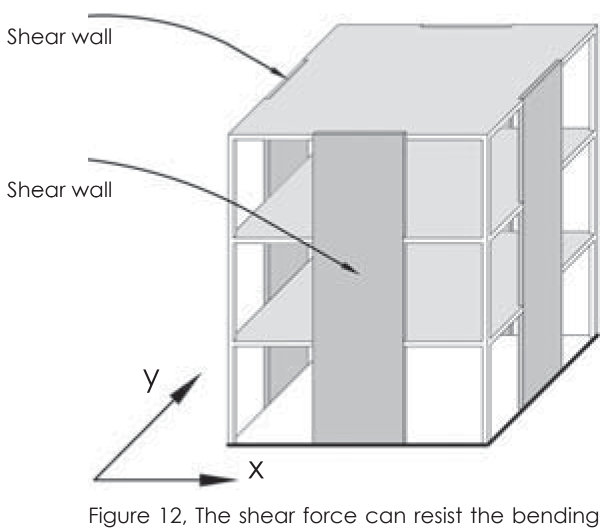


Figure 12, The shear force can resist the bending moment, wall force and "Xy" directional force.

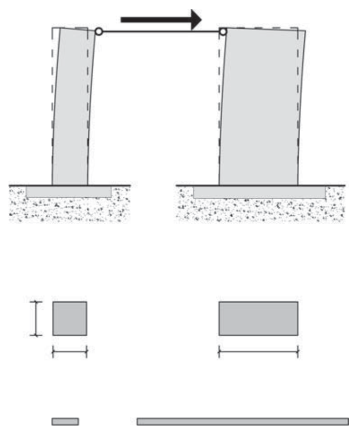


Figure 13, The wall with different stiffness in plan resists different proportion of the inertia force

3. SEISMIC PRINCIPLES IN ARCHITECTURE

3.0 Nature & Seismic-resisting

-Factors Affecting the severity of Seismic force

3. Ductility

Depending upon the degree of ductility, a structure possesses the design seismic force can be reduced to approximately as little as one sixth of an equivalent non-ductile structure. The ductile (and brittle) performance means the extent a structure reaches its maximum elastic limit and then deforms. For example, the glass is very brittle with low ductility, which is easily to breakdown when being impacted by some forces.

4. Torsion

Building torsion occurs either where structural elements are not positioned symmetrically in plan or where the centre of rigidity or resistance (CoR) does not coincide with the CoM. (figure15) A picture shows the deeper right-hand columns are increased in the y direction and resi

5. Force Paths

A force path describes how forces within a structure is resisted by certain elements and transferred to others. Every structural elements and connections not only should be strong and stiff enough to withstand the forces acting within them, but also transfer the force to other members. (see figure 16) The wall is required sufficient bending and shear strength to resist their own inertia force, half of the force is transferred the roof and the foundations separately. During the earthquake, the shake takes place in x, y, and other directions simultaneously, the force paths are activated simultaneously, thereby adequate force paths are provided as much as possible, the danger of damage and death would be minimized in the largest extent.

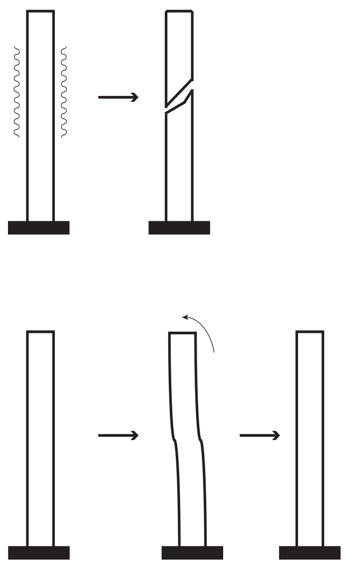


Figure 14, The different ductility of structure responds to the seismic force

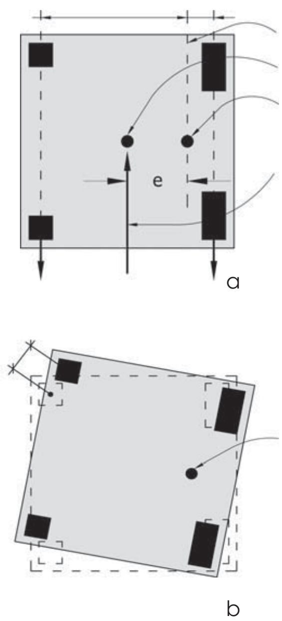


Figure 15,a.deeper right-hand columns resist more force than left-hand columns. b. Twisting at roof level about the CoR

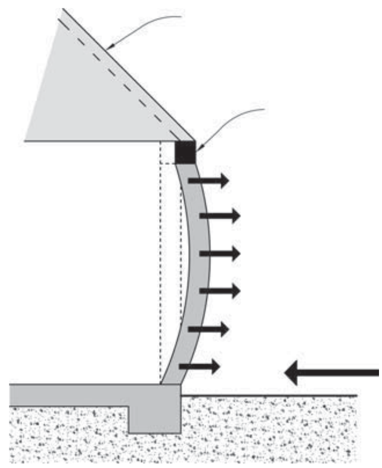


Figure 16 - Load path in building

3. SEISMIC PRINCIPLES IN ARCHITECTURE

3.1 Toolboxs for seismic design

There are two distinct ways for the anti-seismic measures. One is resistant method including traditional architecture strategies: plan and vertical elevation configuration, material property such as stiffness and strength, connection members and so on. The other one is responsive method. By means of adding damper and other mechanical installation, the buildings can dissipate the energy generated by earthquake.

-1. Principles for new buildings: Choice of material
There are mainly four types of traditional materials in the application of the seismic architecture design. Each material has its limitation and application range. The common used material are steel, reinforced concrete, reinforced masonry, confined masonry, un-reinforced masonry, wood and cable net etc....The key indexes for material choice are **high damping capacity** and **limited mass.**

In terms of damping capacity of the material, the wood, cable net and steel are always the material advised, which absorb the seismic energy much more than infilled masonry construction. It is favorable to use materials with high ductility and damping capacity.

In terms of mass and weight, the timber and cable net, transparent envelope are almost the representation of the lightweight material, which at the largest extent save material and reduce inertia force generated by earthquake.

Of course there are also many specific solutions corresponding to the other material like steel, reinforced masonry and concrete constructions in the process of seismic-resisting design, like ring beam, shear wall, brace and so on. This can be achieved by adding extra lateral load resisting system to stabilize the structure. However, it is always beneficial to the latter design development when choosing with better material performance at first step.

Figure 17, timber frame structure with glass facade

Figure 18, timber frame structure with fiber skin

3. SEISMIC PRINCIPLES IN ARCHITECTURE

3.1 Toolboxs for seismic design

-1. Building configuration - Regularity in plan

Building should have a simple geometrical shape in plan, such as rectangular or circular plan. If the building is too long(in one direction) or too large in plan, it is likely to be damaged during the earthquake. The arrangement of L, H, V, Y or H shapes in plan (figure 19) is unfavorable because the wings tend to vibrate in the event of an earthquake. The advised solution for the necessary complex form is to break up the building into several simple segments with proper separation joints, thereby each segementation behaves as individual units under an earthquake.

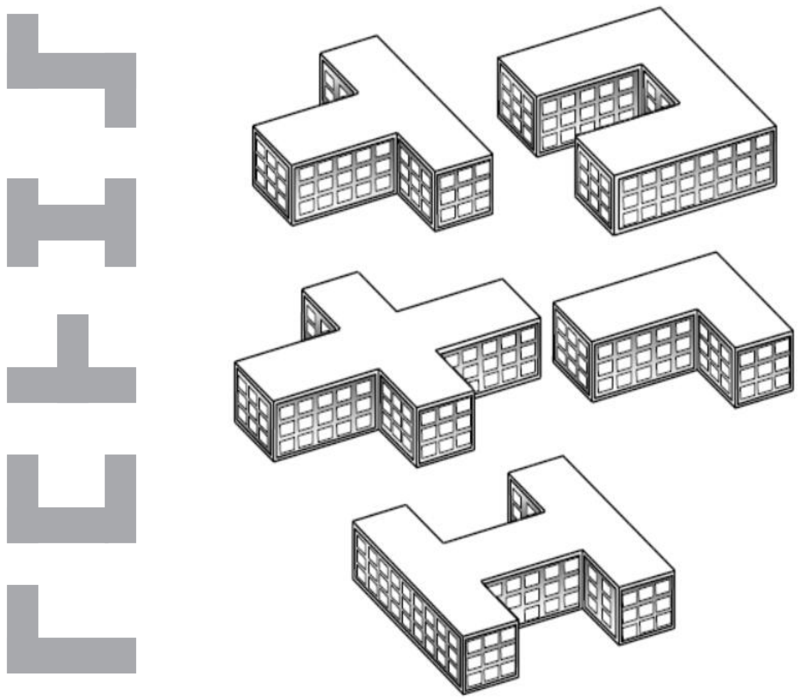


Figure 19. "U", "H", "L", "T" and "anchor" shaped plan arrangement of building is unfavourable

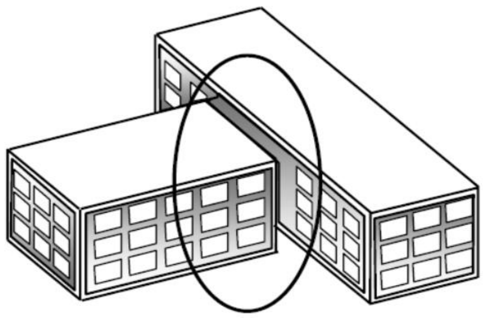


Figure 20. building with seperate joint in its wings is unfavourable

3. SEISMIC PRINCIPLES IN ARCHITECTURE

3.1 Toolboxs for seismic design

-2. Building configuration - Regularity in elevation

Building should not only be simple in plan but also in elevation. The structure components like walls and columns should continue uninterrupted from top to bottom to ensure the load path going through the easiest and shortest way. Secondly, Building with many setbacks or overhanging projections perform poorly in terms of seismic resistance. Thirdly, the case that columns are in the ground floor with the high-floor load bearing walls supported on it is inadvisable, just like the villa savoye. Finally large cut off in the wall should be avoided due to the load bearing role and strengthen of the wall would be weaken.

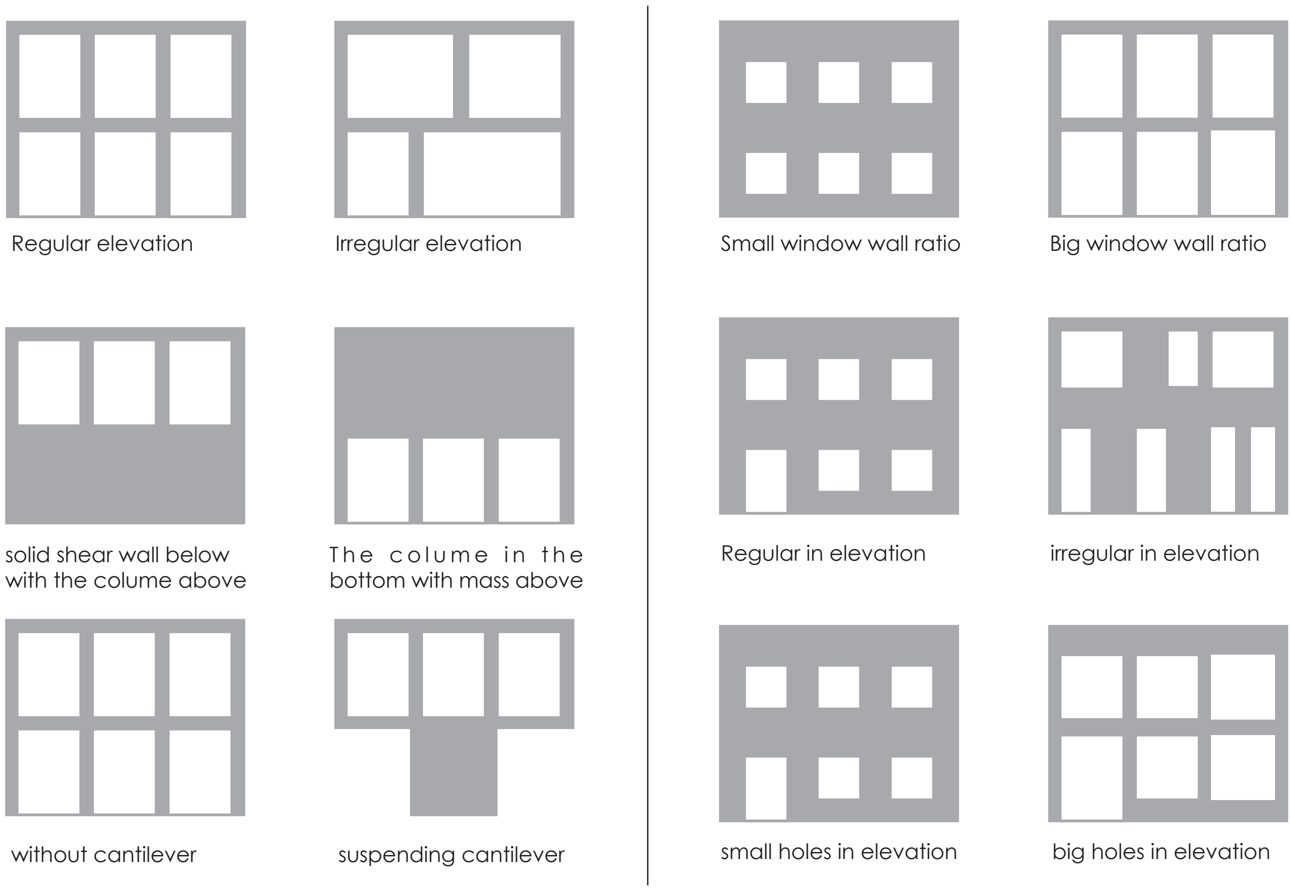


Figure 21. Left favourable ---- Right unfavourable   Left favourable ---- Right unfavourable

3. SEISMIC PRINCIPLES IN ARCHITECTURE

3.1 Toolboxs for seismic design

-3. Load Paths Transfer:
There is an important principle adopted in the seismic resistant design of framed buildings:

Soil must be stronger than foundations; Foundation must be stronger than columns; columns must be stronger than beams. [2]

To ensure that forces are safely transmitted from beam to columns, from columns to foundations, and form foundation to soil, the connections at the beam-column joints, column-foundation joints and foundation-soil interface should have the required strength. (figure 22)

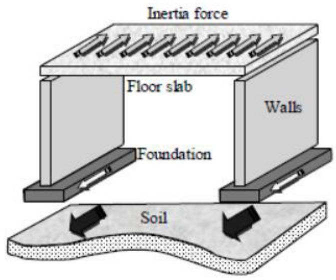


Figure 22 - Load path tranferring

8 storey concrete construction can choose various types of structure, such as shear wall structure, moment frames. While the more strict rules required by the earthquake, the more thicker and heavier section through the columns and beams. (figure 23) Right pictures are the case about combination of the structure.

two-way moment frame integrate with gravity only columns in the construction design.

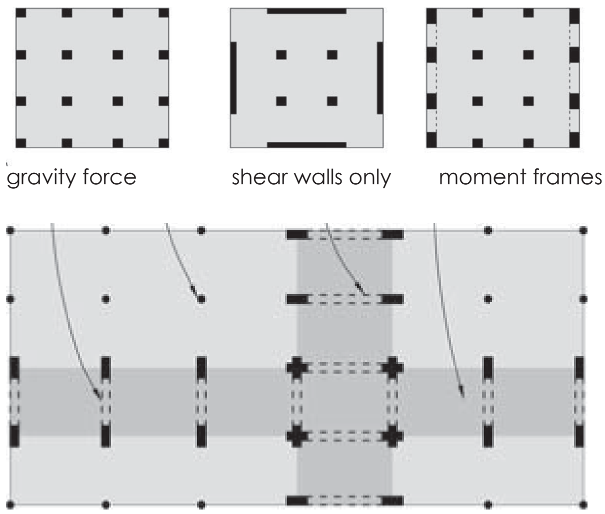


Figure 23 - Two-way moment frame resisting inertia force whose strucrually symmetrical layout integrate with gravity only columns.

Redundancy:
Sometimes an alternative structure can be inserted into main structure for the construction in case of the main structure is broken down during the earthquake.

2.Seismic Design Architecture.2 How Buildings Resist Earthquakes.

3. SEISMIC PRINCIPLES IN ARCHITECTURE

3.1 Toolboxs for seismic design

-4. Horizontal structure:
diaphragms, bone beam, collector

The floor slab not only resist vertical gravity but also resist horizontal inertia force, therefore the slab is called diaphragms. the structure wall provides force in y direction parallel to seismic inertia force. (figure 22)

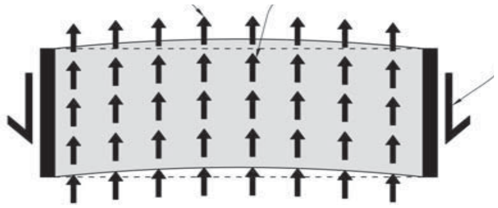


Figure 24. plan of inertial force in diaphragm

The strong and ductile details connecting walls and diaphragms are necessary. Diaphragm provides both tension stress and compression stress.

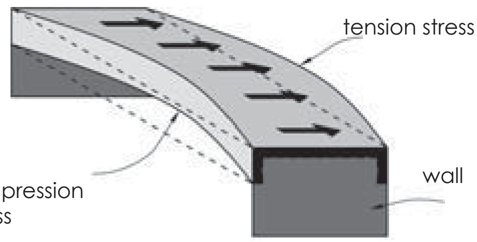


Figure 25. connection of diaphragm and wall

If in the plan arrangement an exterior wall is curved, a bond beam can use the rounded geometry to transfer forces primarily by arch-action. The bond act as a rounded portal frame resisting the earthquake force in horizontal direction.

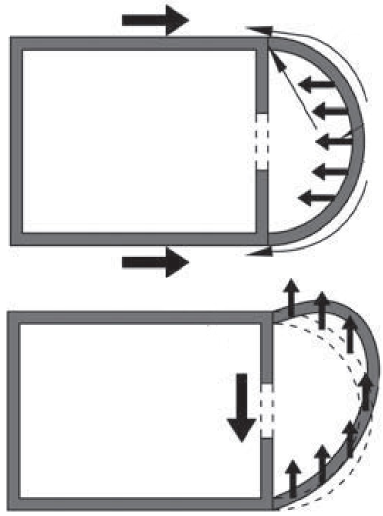


Figure 26. bond acting as arch

The seismic force is parallel to y direction of shear wall. Short wall in x direction as collector members would effectively resist the inertial force.

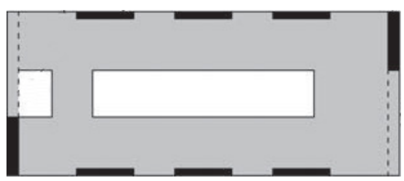


Figure 27. collector members in x direction are needed to transfer y direction force to shear force.

3. SEISMIC PRINCIPLES IN ARCHITECTURE

3.1 Toolboxs for seismic design

-5. Vertical structure: shear walls, brace, moment frames

Bending moments cause tension and compression forces at each end of a wall.
Specific Methods: Some walls become thicker at their ends specifically in cross-sectional area which is necessary to accommodate the vertical tension reinforcement and is also effective to prevent the ends of walls buckling in compression.

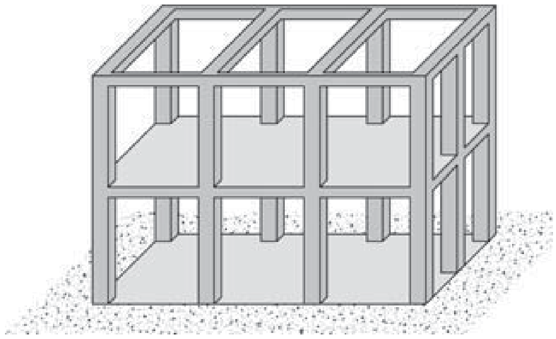


Figure 27. Moment frames

Shear walls are structural walls designed to resist horizontal force.
Reason: Their inherent stiffness minimizes horizontal interstorey deflections and consequently earthquake damage to structural and non-structural elements. The shear strength of reinforced concrete walls is provided by a combination of the concrete strength and horizontal reinforcing bars that act as shear reinforcement.

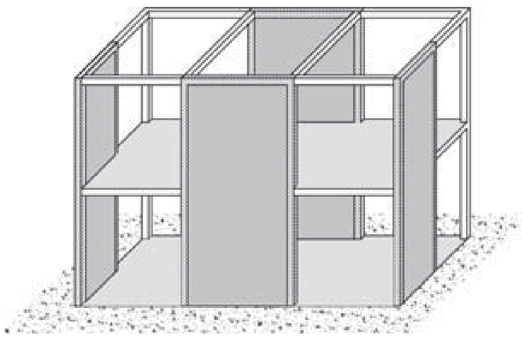


Figure 28. shear walls

The braced frame is the least common vertical seismic resisting system from an international perspective. it is used extensively in some lacking finance supported countries.
Specific Methods: achieving the necessary connection strengthens with bolts or other stiff fasten devices is necessary for wood bracing. Connection details are stronger than the tensile strength of a brace. Compression braces absorb very little earthquake energy. Ductility improves if approximately the same number of braces in tension and compression are in each line of framing. Ductile fuses can also be inserted absorb inelastic axial deformations.

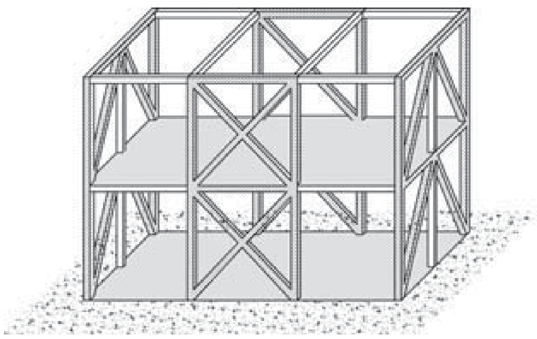


Figure 29. Brace and chord

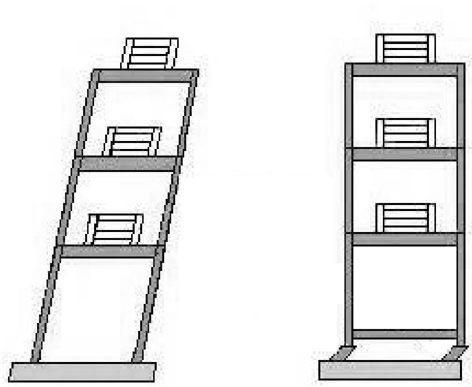
3. SEISMIC PRINCIPLES IN ARCHITECTURE

3.1 Toolboxs for seismic design

-6. Reduce demand

Instead of strengthening the existing structure, another measure is to reduce the demand. Buildings can dissipate the earthquake energy by adding damping system.

there are two measures commonly in enhancing damping capacity. Firstly, we can try to enhance damping capacity by equipping the building with additional mechanical device, such as setting the damping cable in moment frames. the other one is by putting the base isolator under the buildings to Isolate the upper structure from ground. The buildings can move without experiencing too much deformation and extending natural period of building.



Fixed base Isolated base

Isolated base

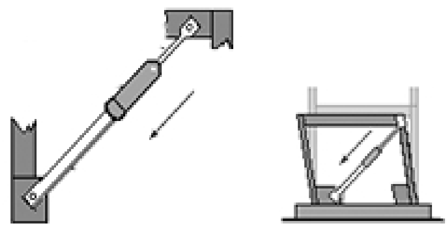


Figure 30. damping system

-7. Non-structural elements

By increasing the stiffness, strength of connection, members and joints, the deformation capacity of non-structure elements will increase and falling hazard will be prevented. For example, diagonal cross timber window frame, intersecting door frame etc... non-structural elements could also absorb the seismic energy in limit extent .

Figure 31.crossing frame non-structure element

4. BIOMIMETICS TRANSFORMATION

4. BIOMIMETICS TRANSFORMATION

4.0 Biomimetics and Nature

-1. Nature & Technology

what is biomimetics? Biomimetics is not only about nature imitation, but by studying their mechanics and principles in order to transform and develop these principles into complicate technological and architectural solutions.

"Being an integral part of nature ourselves, we shall never be able to talk about it from the outside but only from the inside, uncertain whether to consider something created and produced by man as being 'outside' nature."

Paolo Portoghesi's statement touches the general dilemma in the relation of nature and technology. Considering the separation between nature and technology in common understanding, technology is understood as "everything made by man", we can understand the appearance of architectonic phenomena in nature or the application of natural phenomena in architecture, and integrate both views in the investigation. In westen culture, nature and technology are considered to be in opposition. Nature and techonology should not be considered as antagonistic.

technology innovation is one of the driving force for architecture development. In biomimetics research study, the pioneering insight has been focused to the convergence of biology and technology. The term " biomimetics" is not the mere imitation of nature in material and funcitonality in creative regard. It contains all applications of present time like machine or computer technology, all the applications of optimized technolgy solving questions in the comprehension of analogous and natural principles.

In conclusion, how to apply the biomimetics into problem solving, optimization strategy also exists. Normaly the biomimetics is always three-step process: Research- Abstraction- Implementation.

Figure 32. Outside skin

Figure 33. Interior structure

Transferring Method:
The transfer of information from one discipline to the other disciplines is the most interesting part of the biomimetic process. The transfer of form, the application of morphological characteristics , information flow, construction process and material. The Analogies between the different fields are supposed to bring innovation.

Frei Otto said about analogy:*" **Objects can be similar are equal in form, gestalt, construction, structure and material. They may have acquired this analogy through identical, similar or completely different development processes. The development processes play a key role in research of analogies. Typical technical and artificial products differ from creations in animated nature by a basically process of selection ".***

Different concepts exist for bionic transfer.
1.Biology push approach (Bottom up approach):
Biomimetric technology is stimulated from insights of biological research

2.Technology pull approach (Top down approach):
driven by a technical scope, extracting the biological approach to improve an already mostly existing technological product.

3.Pre-researched "Pool Research" approach
"Pool Research" ---- filling with the biological data reservior, which are oriented to a quick generaton of knowleadge quickly. Because in architectural fields, one can not afford research before the construction of each individual building. Pool research is a quick process of developing new prototypes, with using a consistantly changing combination of thousands of different solutions. Pool research means the approach follows an in-depth study of biological precedents from the 'pool' in relations to biological and comparable technical function details, a so-called morphological box.

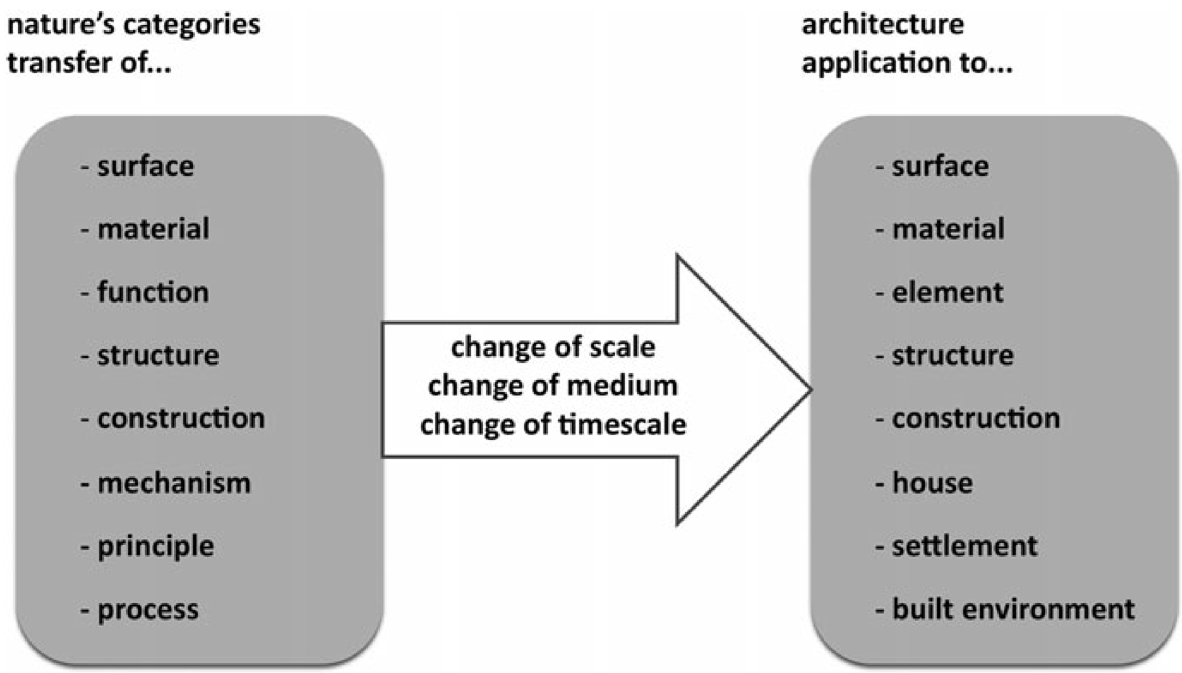


Figure 34. Nature categories transfer & architecture application

4. BIOMIMETICS TRANSFORMATION

4.1 Bioinspired Principles:

4.1.0 Biomorphic structure

Interpretation of the expression "natural construction" according to Frei Otto:

"Talking about 'natural constructions', we do not mean just any object out of the infinite diversity, but the typical. We mean those constructions that show with particular clarity the physical, biological and technical processes, generating the objects... Even if technology is a tool of the natural object man... we interpret it as a product of man and therefore nevertheless as a part of nature."

Natural construction is applied in all respects including architecture and techonology innovation. I divided the biomimetic constructions into three main types: biomorphic structure, process and living mechanism analogy, and interative information analogy.

As for biomorphic structure, Constructions and structures made by animals morphology is the most common representation in biomimetic applications. The appearance of the building is similar to the natural shape as sculptures. (see figure 35. 36) Santiago Calatrava designed many buildings as sculptures similar in appearance to nature. For instance, the shed is like wings of the birds, and the roof Metropol Parasol is like the spider net.

TGV station at lyon-satolas Santiago

Calatrava- Metropol Parasol

Figure 35. biomorphic structure

4. BIOMIMETICS TRANSFORMATION

4.1 Bioinspired Principles:

4.1.1 Process and mechanism analogy

Second type of biomimetic natural construction is Building methods analogous to nature. Frei Otto, architect, in the 60 centuries of last century discussed about the similarities between living and built structure are coincidental. One of the research were alongside behavior mechanism of animals and humans in relation to house and building constructions. Many architects and engineers investigate natural structure and gain insights for their creative processes. In the collaborative research, self-forming, self-organization process inorganic and organic nature technology concerning construction methods are considered and studied. The approach like self-optimization, form-finding from nature, origination of form in technology are widely adopted by architects like Frei Otto.

Figure 36 . Stadium in Munich

For example , minimal structures and lightweight architecturem. (See figure 36) Olympia Stadium in Munich. Architects mimic the structure of spider net and use the minimal material, follow organic construction methods creating the lightweight roof. Other natural form finding like shell structure, diatom, and foldable structure are all also originated from the living creature structure.(more applications will be discussed in chapter 5.)

4.1.2 Interactive information

The life cycle plays a commanding role in nature. the mature living shapes are occupied by new life forms and decomposed into basic elements. The research on the building elements in the scientific areas of biomimetics and use of life cycle observed in nature is the third way of biomimetics architecture.

Specifically, because in nature the structure system never assumes only one function but fulfills a multitude of various demands simultaneously. Exterior skin performs the tasks of load distribution, substance exchange, information communication as well.... The building components in architecture with the considerations of structure support, moisture constrol, acoustics and sound insulation, heat insulation and air flow also perform various tasks.

Thereby,the interactive information is also included in the biomimetic components of architecture. For example.(see figure 37), the building facade is combined with the translucent panels. the material and construction detail is glass fiber weave for light diffusion system. (more applications will be discussed in chapter 6.)

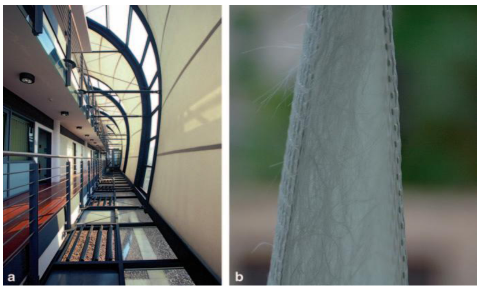


Figure 37 . translucent facade. (left) translucent skin, (right) fiber weave in the micro plant structure for light diffusion system.

4. BIOMIMETICS TRANSFORMATION

4.2 Evolution of Biomimetic structure engineering

4.1.0 Evolutionary Light Structure Engineering

Evolutionary light structure engineering is a method for the development of optimized lightweight structrure. The approaches is based on a systematic and effective development of form-optimized geometries. with five steps of Biomimetic Analogy design.

-Phrase 1: Screening
Through the laser confocal microscopy and REM image, a series of structure is analysed in computer in consideration of structural similarity with technical object.

-Phrase 2: Investigation of structure
The screened geometries of structure are modelled with the tool of cad. Faithfullness to details is important in order to be able to derive an understanding of structure by finite element analysis.

-Phrase 3: Abstraction
structure principle is simplified and abstracted. Stress regions are identified in order to replicate the simplified structure.

-Phrase 4: Optimization
the abstract models are parametric and tested by physical stress simulated by genetic algorithms, evolutionary strategies.

-Phrase 5: Fabrication
The final models of structure and conponent is subjected to economical and fabricated-related restrictions.

Phrase 1 **Phrase 2** **Phrase 3** **Phrase 4** **Phrase 5**

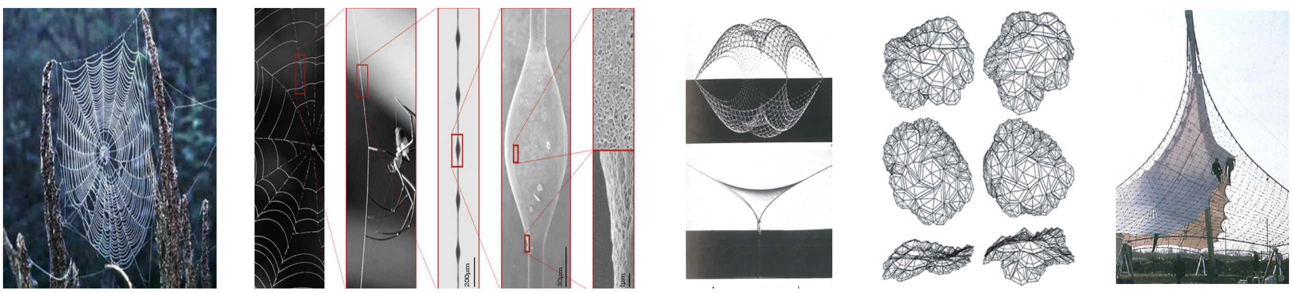


Figure 38. Evolutionary Light Structure Engineering

4. BIOMIMETICS TRANSFORMATION

4.2 Evolution of Biomimetic structure engineering

4.1.0 Abstraction of geometry

In phrase 3How to abstract the geometry and categorize the structure into different classifications? As is essential to avoid the geometric complexity in technology of architecture, which is advantageous for structure, connection, production and assembly chains for the supply of building parts. classifications of types help to have particular application for the construction industry.

For example, diatom according to morphological and typological characteristics, could be classified into central, planar, pennales, radial planar, sequential. Some of these classifications not only fullfill the high demand of static stability, but also have its unique metabolistic and functional capacity. (see figure 39) different diatoms have different organization methods and internal structure. Figures below illustrate some forms and details captured by a classical transmission electron microscope(TEM). On the other hand, the same free form can generate various abstraction outcomes based on different centric pattern, although some of which are unrealistc "fusion" of members at the intersecting point, could only be achieved in digital environment due to the limit of prefabricated and assembling technique or at the expense of complicated joints requiring high-level of manufacture. Anyway, the variants below comes directly from the diatom-inspired surface abstraction.

1.Rhombus-shaped latice
2.Arch construction with diagonal bracing
3.regular rhombus with lattic in plan view
4.addition arch on the 3 way
5.Regular orthogonal lattic
6.Hexagonal pattern along UV-coordinate
7.concentric pattern in plan view
8.Orientation of a concentric pattern along UV-coordinate.

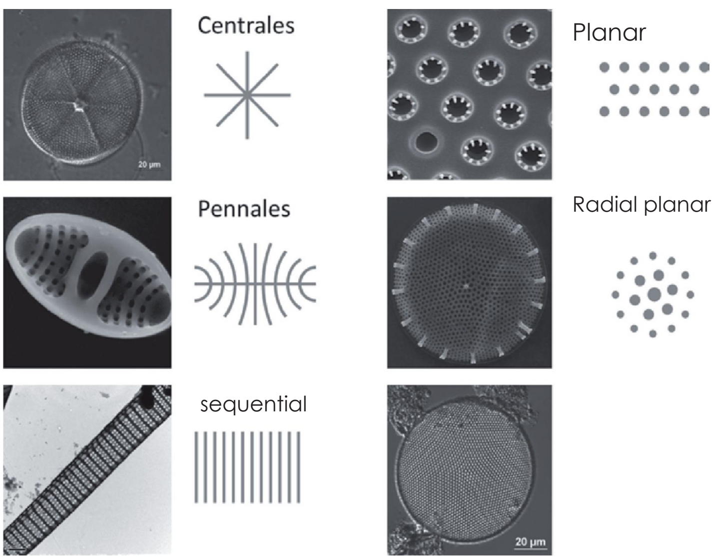
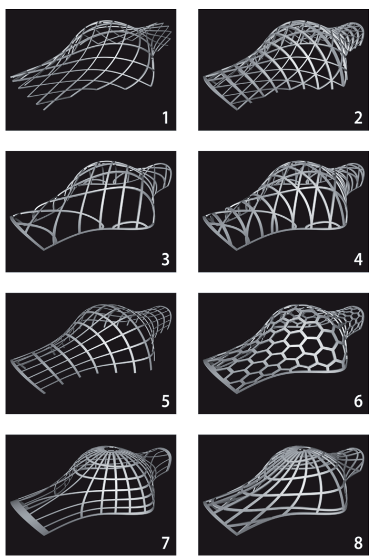


Figure 39. Evolutionary Light Structure Engineering



Modle for free form abstraction

4. BIOMIMETICS TRANSFORMATION

4.2 Evolution of Biomimetic structure engineering

4.1.2 Physical experiment & Computer Model

Generative design:
In the phrase 4, optimization of computer model and structure morphology. Architectes use parameters to describe functional or geometric contexts or requirements and connect the specifications together.

Parametric design tools are used to find optimal solutions or to weigh different design variations. As a tool parametic desgin tools are not only implemented in conceptional phrase, but also in providing limitless possibilities in given conditions. For example, path routes can be simulated, spatial confinements, necessary use space (passage) as well as zoning requirements integrated with each other. Further capabilities could be considering various load-bearing systems for a structure, observing different effects of daylight and building facade transparency.

The application of generative design has been very popular nowadays. One of the case is the roof support system for the exhibition hall of the convention center in luxembourg. The parametric 3D design support the construction principle, integrating fold roof and geometric form together. Consequently, the roof surfaces with embedded solar panels are placed at the optimal angle and postion so as to allow the most glare-free, indirect light into the interior.The multifunctional sky opposite surface requires complicate deformation and various dimension. The parametric optimization define the final dimensions and slopes of the folds and their basic configuration. Such process could also be favour to the manufacture production chain. (see figure 40)

Figure 40. Modle for free form abstraction

4. BIOMIMETICS TRANSFORMATION

4.2 Evolution of Biomimetic structure engineering

4.1.2 Physical experiment & Computer Model

Physical model:
Contrary to computer models, whose graphic visualization only simulates structure, physical models give immediate feedback to this property. The material-immanent characteristics, behavioral tendencies, durability, etc, material accessibility, production and assembly can be well be stimulated for the approximation of the realistic material. Therefore, mainly two aspects of advantages for physical model are illustrated. One lies on promotion of the creative inspiration from abstraction of biological form, the other one is that the physical models are used for testing structure stability and optimization.

Model of paper strips for a free-form structure, paper strips of irregular woven and dome shaped skin is a discovery of natural solutions without background knowledge in technology.

Physical model were translated into CAD models, the computer modeling simplified the process of complex 3D physical models. The advantage of this process lies on being able to indentify realistic and feasible proportion on the computer for the comparing with the realistic construction dimention. Experimental structure models made by Frei Otto research into the tensile and fabric structure, the modeled form was phogrammetrically displayed and replicated on the furthur modeling, finally testing in the 1:1 construction.

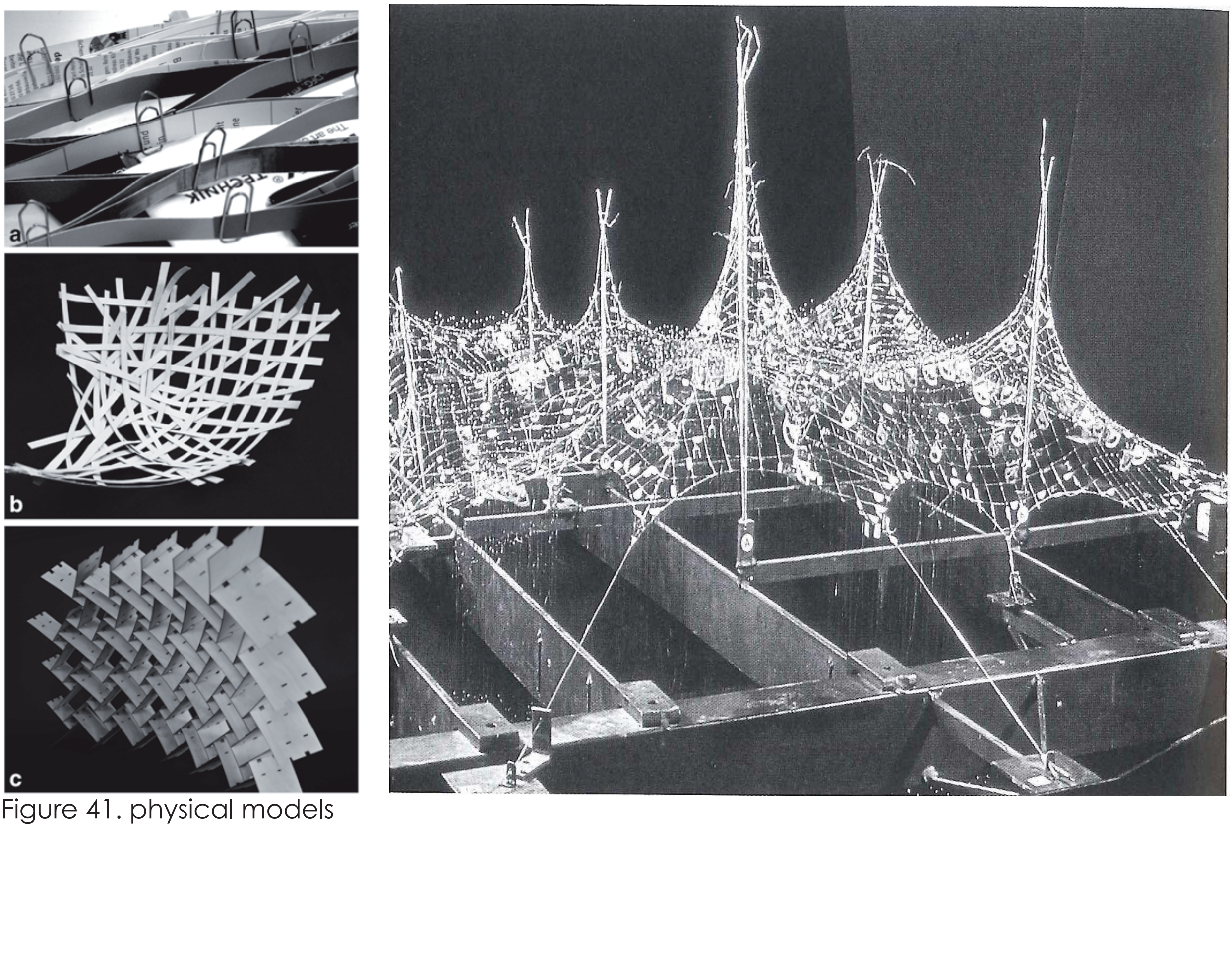


Figure 41. physical models

5. BIOMIMETIC STURCTURES

5. BIOMIMETIC STRUCTURE

5.0 Principles of Self-organization

5.0.1 Self-organization in nature

Self-organization is a complex, active control and regulation: instead of inserting modules of membrane or cellular subsystems “in th exact, right place”. it formulates conditions to which each building elements organizes itselft by actively applying metabolic energy, nature use, passive energy available in the environment. Principles of self-organization is very important in the living world in the construction of membrane structure or path network. Living beings growth is not arbitrary, but responding to mathematical and physical principles.

For example, tortoise shell. The essential characteristic of tortoise shell is multi-dimentional, hexagonal patterns, which are used to obtain highest structural stability and lightweight property. Tortoise shell is shared in technological structural vault formations, with the occurrence of only flexion and pressure membrance forces on the shell based on the energy minimization and stiffening fold structure. The necessary pressure for self-organizing vaults in a shell is generated by a harder exterior tissue. In technology vaults need a prestressing smooth material on the outside. In the result material is highly strengthened in case of damage and being weaken in the manipulation process. The surface-refined sheet metal with stabilization and tension is emerging in application of vault structure.(see figure 43)

Besides the tortoise shell, the spatical configuration in bee honeycomb also follow the principle of self-organization. One can consider honeycombs from the perspective of fold structures. The hexagonal honeycombs is inherently instable while it maintain an mechanism keeping in the balanced position between static-structural stability and its heavy live load. Such hexagonal structure reached a perfect equilibrium by means of Y-shaped(stable panel structue) structure constructed on both sides of the lamella. In technology area, many facade and skin design also follow such structural configuration methods although its instability property. (see figure 42)

Therefore, biological structure can not be directly described as "pure" technical-structural types. Even so, self-organization principles is still the first step for understanding biomimetrical transformation,

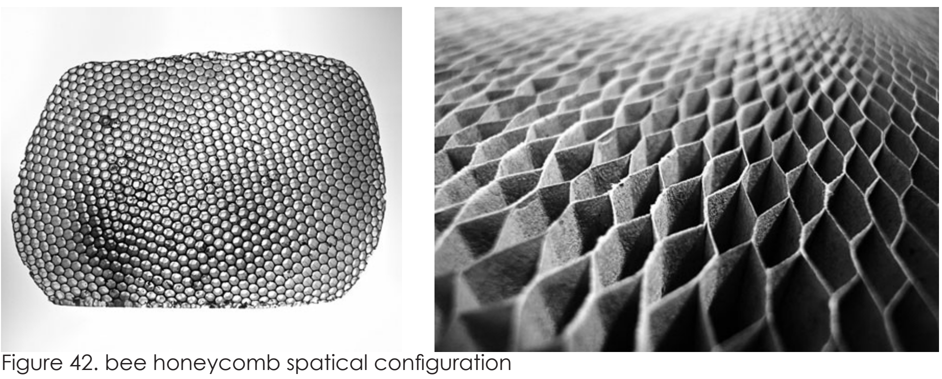


Figure 42. bee honeycomb spatical configuration

Figure 43. Tortoise shell

5. BIOMIMETIC STRUCTURE

5.0 Principles of Self-organization

5.0.2 Self-organization in city

Aerial images of "naturally grown " cities in developing countries often give impression of chaos and randomness. While the in-between structure of narrow alleys and the accommodative street network is the framework which individual buildings develope, expand and adapt to. (see figure 44)

This type of city does not develop with the guidance of urban planning and architects' design, thereby the city exhibite itselft in the most economical and functional way. In retrospect, the dimentions, angles, the arrangement of small and large open spaces, the position of each courtyards are with respcet to the street, etc.... Such self-organization mode is a bottom-up approach, each individual building is more or less standardized, which is customized but similar mass, developable and accessible.

The street network and the random building arrangement in settlement structure require self-formation process. S,Becker give thought to these structure in the viewpoint of fractal geometry. He pointed out that hierarchical construction is the characteristic for these fractal principles, which results from a strict internal order. Spatial hierarchy comform to consistent rule of generation, such like

1. relationship with the edge
2. creation of identity
3. necessity of forming connectons

However, "unplanning" architects put forwards the oppinion that self-organized city is irrelevant with the regulation structure, which is objected by S.Becker. In retrospect ot the technology, hirarchical spatial structure following certain regulation can be used for referrence in architecture structure.(see chapter 5.1.4)

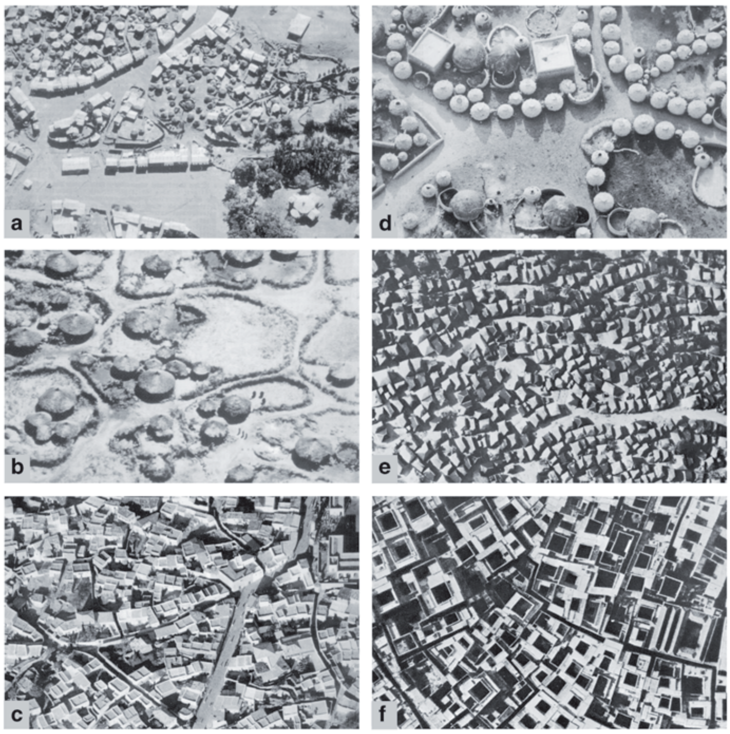
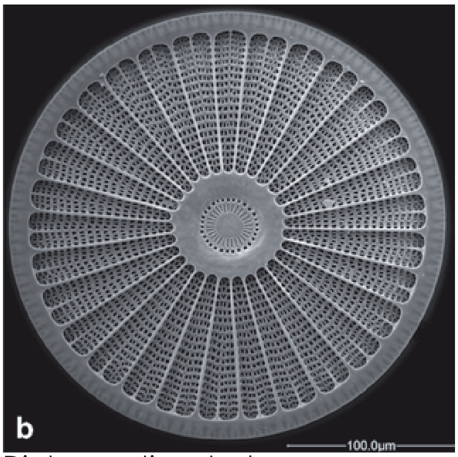
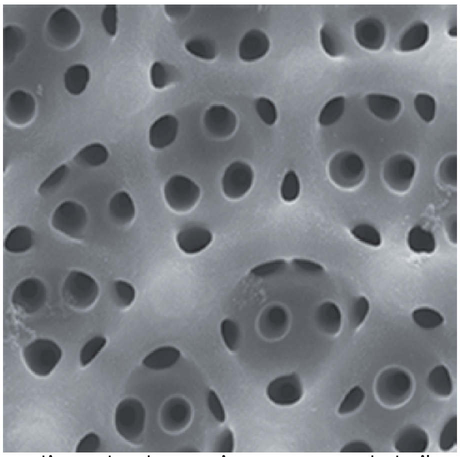
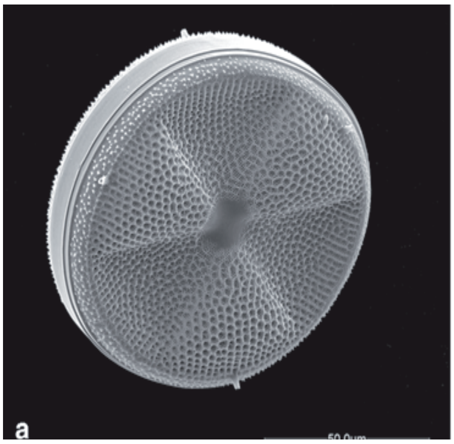


Figure 44. organic urban configurations

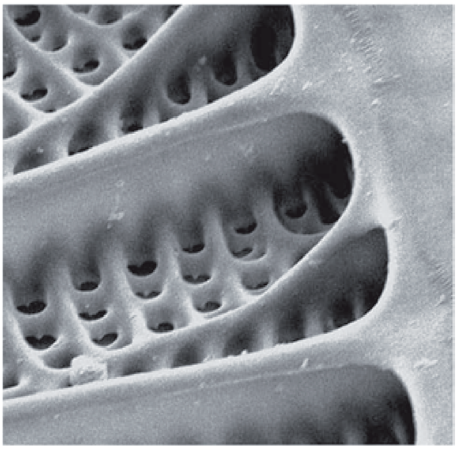


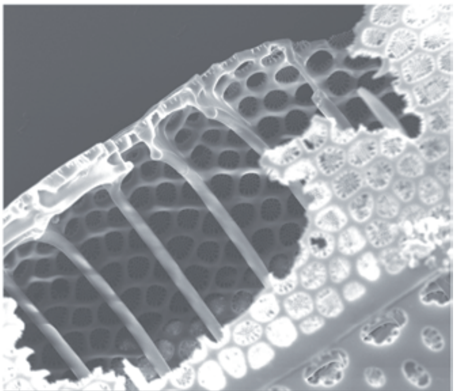
Diatom actinoptychus

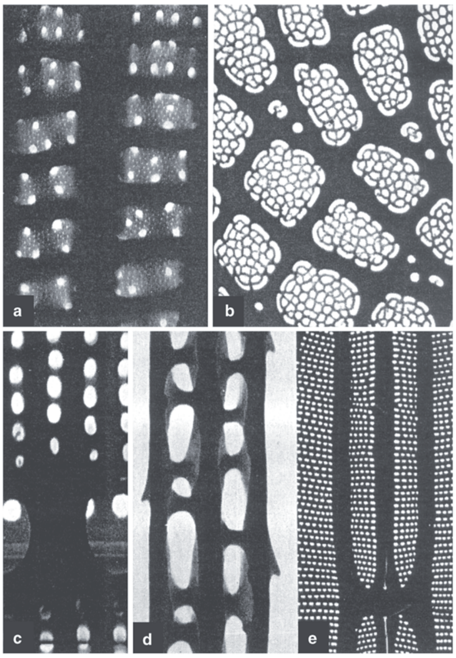

actinoptychus microscope detail



Diatom arachnoidiscus


arachnoidiscus microscope detail


circular diatom



Micro-structure in TEM image

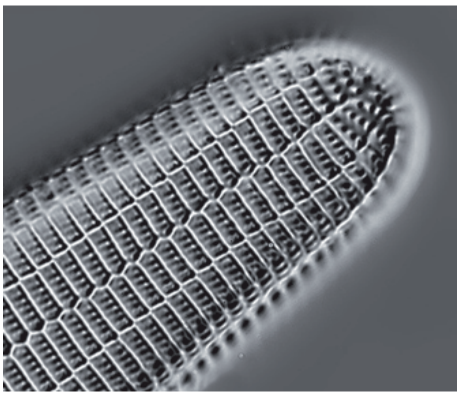

sequential diatom

Figure 45. diatom structures

5. BIOMIMETIC STRUCTURE

5.1 Categories: morphology analogy

5.1.1 diatoms and radiolaria inspired structures

The actinoptychus is an aquatic plankton of ocean floating and anchoring itselft into the ocean floor. the structure under the microscope reveals itself as a lacy, mesh-like skeleton. open pores are filled with several mesh layers, which nested inside the one another.

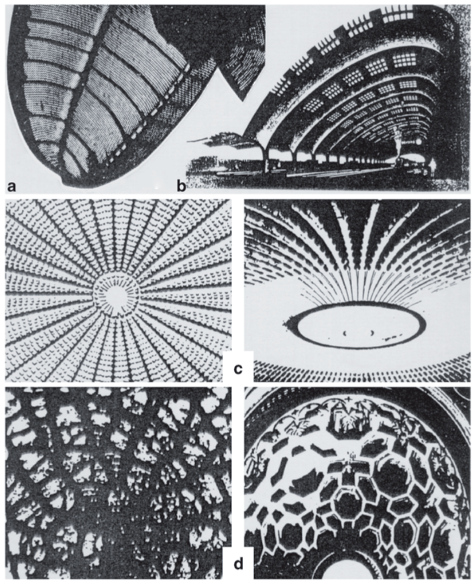
The following content will be about different bioinspired structure forms in the area of architecture. In contrast to previous mentioned diatoms classifications, the architecture structure also follow the diatom structure characteristics.

1.Stadium: the diatom arachnoidiscus exhibits an elongated oval shape, which is circular in plan view; According to the classification of diatom, it belongs to the subgroup of "Centrales". Its structure is correspondingly radially symmetric; The radial ribs run from center outwards supporting the fine mesh layer in between; the strengthening rib is meridial ribs and sub layered concentric ribs, consisting of a parallel or radial system similar to cement-ribbed vault. In architecture, the vault in Palazzetto dello sport, Rome(P.C.Nervi) is studying this type of diatom structure.(see figure 46)

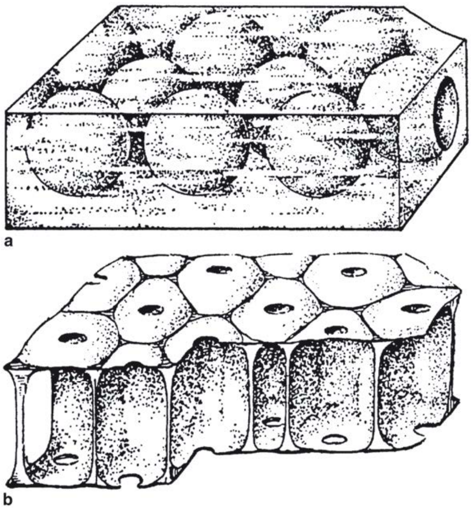
2.Renaissance church-shell of the diatom: The ceiling of the church is constructed in the similar way with the shell of the diatom.(see figure 37)

3.Cast concrete shells
The principle for diatoms to construct their shells is through the fat droplet hyphthesis, which inspired unconventional building design. Architects experiment with pre-pressed soccer ball between pressure plates, then cast the form with plaster or polyester, which results into the hollowed hexagonal frame form. (see figure 47).

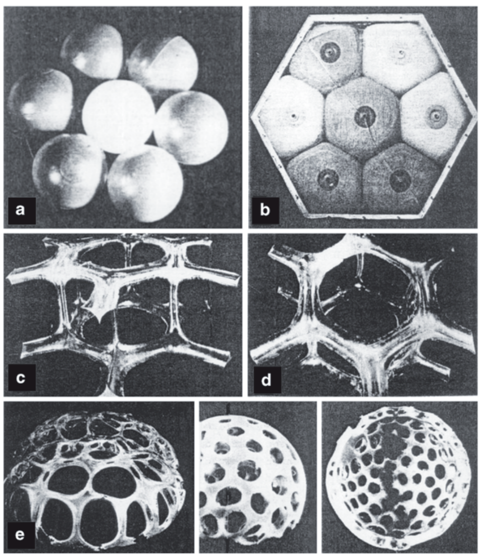
As for architecture usage, the hexagonal concret shell can be assembled into the lightweight shell roof sustaining windload and snow load. (see figure 48)



46.Diatom inspired architecture



47. Diatom concrete cast forms

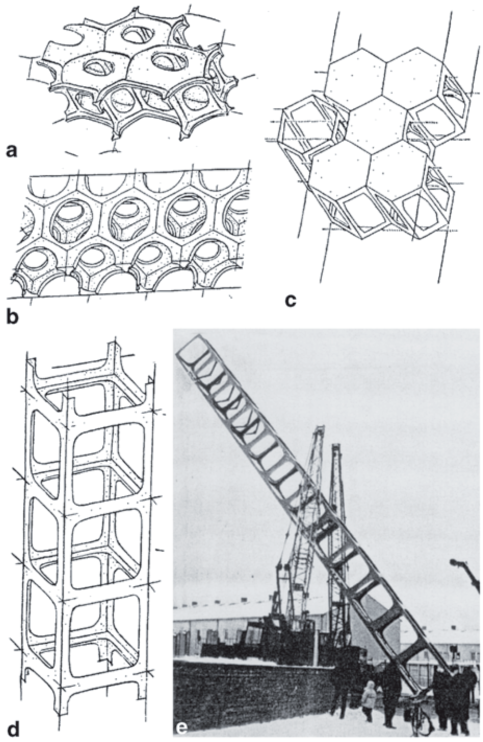


48. Formation of hemisphere forms

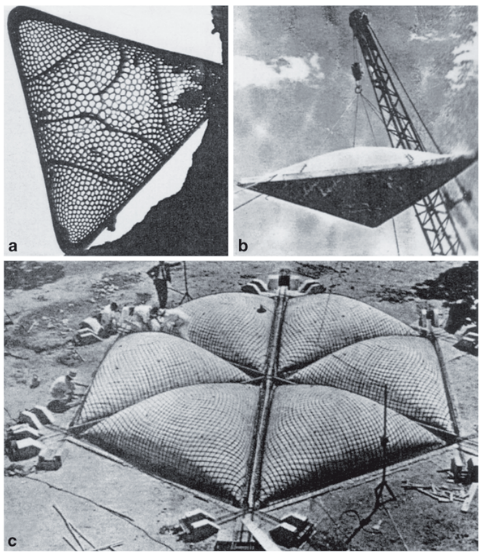
The hexagonal panels roof and the hexagonal concret building blocks are connected covering the hollow hexagonal frame.The formal characteristic for a stabel panel structure is that the arrangement of no more than three panels around one vertex. The panels edges is linear connections with the other panels.

Besides of mentioned above, Frei Otto also design new lightweight structure column, easy to be erected and strong enough to resist torsion and wind load. the simple hexogonal units can also be disassembled and melt easily. (see figure 49) on the other hand, six pieces of diatom-shaped steel reinforced concrete shells for water reservoir is arranged together. (see figure 50)

When the structures of diatoms are limited to round, cylindrical or hexagonal shape within these basic frameworks, radiolaria-inpired structures vary in forms more drastically. A good example of radiolaria structure is geodesic dome.



49. diatom-inspired structure blocks

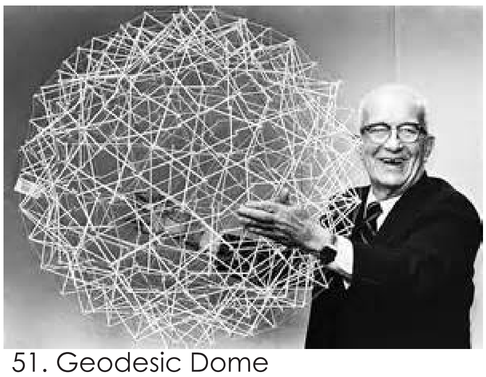


50. diatom-inspired structure blocks

4.Geodesic dome

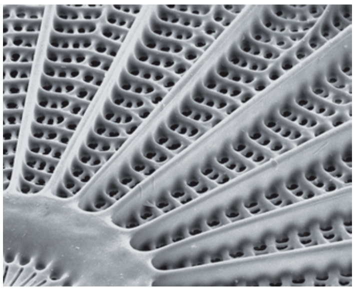
Geodesic dome consists of compression-resistant members and tensile connections that sustained deformations during pressure tests.(see figure 51) Such structure achieved a very large span with the minimal thinkness of structure.

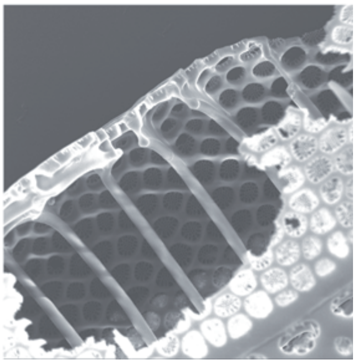
In comparision to the stalks of grasses, the length-width proportion of geodesic dome also illustrate the similarity. In another perspective, such structures must have a broad base to absorb the torsional forces at the foundation for dissolving and reducing the overall mass. which is similar to the spines of radiolaria and diatoms structure.

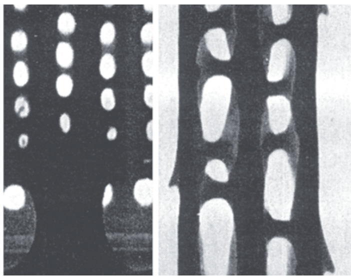


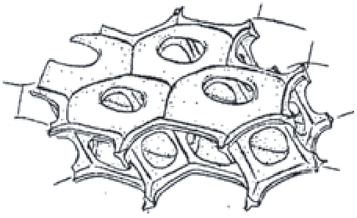
51. Geodesic Dome

Diatom and Radiolaria structure



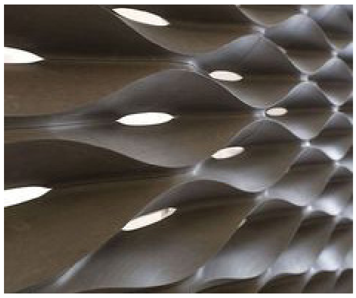


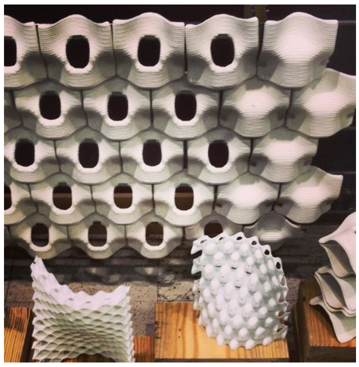


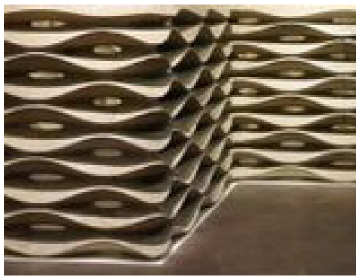


Diatom structures & details

Architecture application







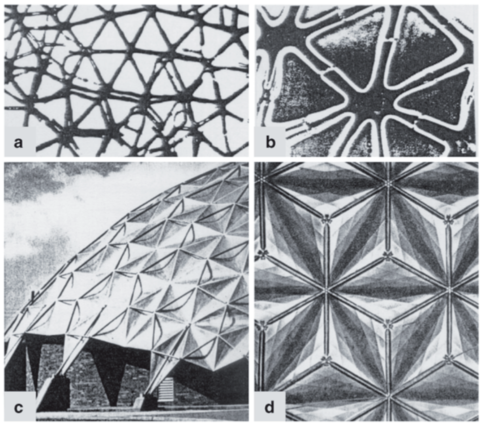
Facade design & Artistic decoration

5. BIOMIMETIC STRUCTURE

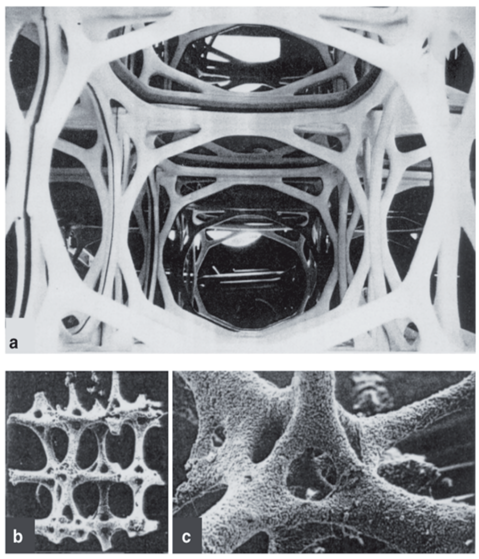
5.1 Categories: morphology analogy

5.1.2 nods and rods framework

From nodes with the lowest material expenditure to analogous nodal structures in technology. Such structure can be related with the structure of siliceous sponges, of which the nodal points are more dissolved and forming a network of branching struts. The entire structure is oriented on the tragectories of forces. They can grow with the accumulation of corresponding strandardized elements. At the same time, such nods and rods structure system acts as a basis for large, long-spanning, lightweight structure.



From the biological-physical insight, the skeleton part of fossilized sea sponge inspires spatial nod-and-rod framework, which has high torsion-resistant capacity. Fret Otto related such structure in bend-resistant support system with the minimal material costs from 1960s, contributing to the development of lightweight large span structure. The skeleton of nods follows the trajactory of load-bearing in order for the optimization of the structure stability and strength. (see figure 52)



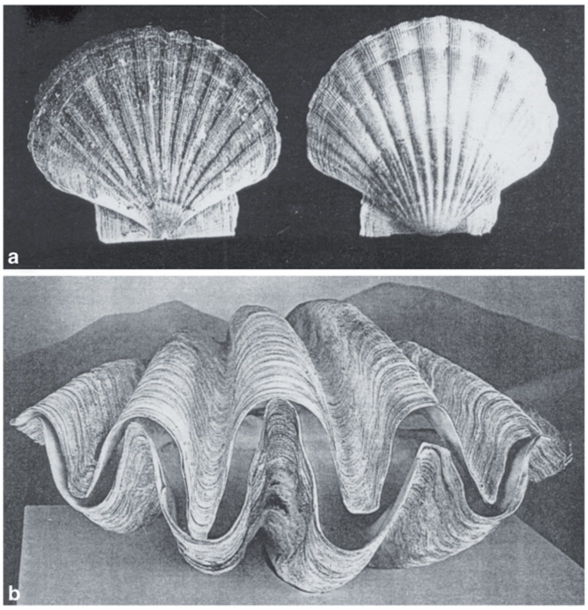
52. Nods and rods structure

5. BIOMIMETIC STRUCTURE

5.1 Categories: morphology analogy

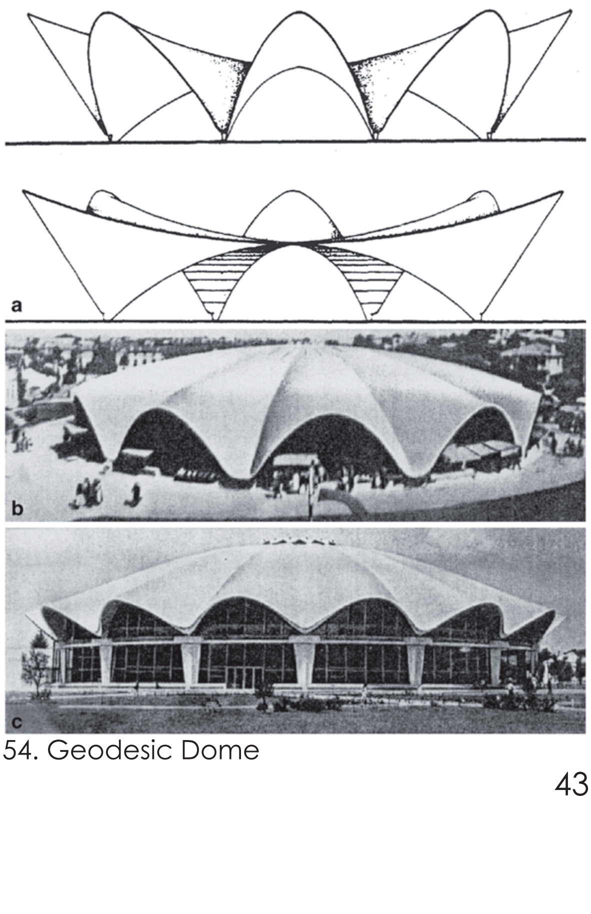
5.1.3 shell structure

Shell structure is charateristic for its wide-stretched, thined-walled form. It analogous forms were enabled in the building material like pre-stressed concrete. archietct Le Ricolais attempted to abstract such shells as building structure entity, he conceptionalize such structure systems, consisting of perpendicularly crossing corrugated panelsl, which he described as isoflex. (see figure 53)



53. Mussel shells

The example (see figure 54) shows how architect analyse the form of shell and transform it into the hyperbolic parabaloid structure with 15 mm thick and a span distance of 52.4m. The roof with its radical wave-forms is not the final purpose of the architects although the form itself truely draws from the elegant shell forms. the shell is made of prestressed concret which must be the self-supporting network found by hanging chains, the coordinate of the perpendicular cutting catenary curves were marked, the experiment for form finding is performed by welding the hanging chains together at one meeting point and flip it over to help it self supporting. The ratio between the diameters of shell structure and shell thicknesses correspondes to 1/1000 in Market hall in Algeria, even 1/2400. the technology has made an impressive achievement compared with the Pantheon vault only 1/44 in second century.



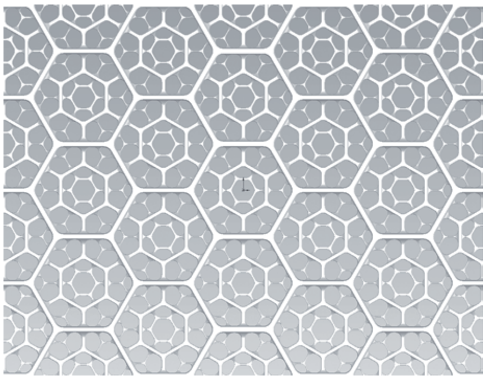
54. Geodesic Dome

5. BIOMIMETIC STRUCTURE

5.1 Categories: morphology analogy

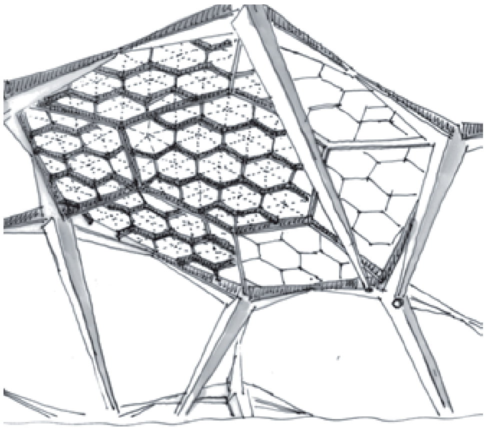
5.1.4 hierarchical structure

The diamtoms build up their stable shells for protecting themself from the outside enermy. therefore the shells exhibits rigid ribs and secondary branching structures. The large ribs are supported by smaller substructures, forming stable so called "hirarchical structure". the investigation of this type of functional construction discover a new way to integrate the substructure tightly with the result of decreasing the numbers and thickness of main ribs.



55. bee honeycomb and hexagonal spatial arrangement

The abstracted translation of this techical building part is exemplified in the envolop structure and large span canopy design. The hierarchical structure developed by Pohl architects and Steinmetzdemeyer is a roof system, modularly constructed with the same size structure unit. The span and dimension of the beams are negotiated according to efficient principle, heavy building parts are avoided. the hexagonal module enables the flexible geometric accumulation of standard modulars. The secondary structure not only support and stablize the main structure, but also shape spatialy into a pressure-resistent shell structure, dome form. According to the comparative analysis of integrated structure and envelope system, the particular combination and configuration of major and minor ribs is proven to be the most efficient for structure.



56. bee honeycomb and hexagonal spatial arrangement

57. bee honeycomb and hexagonal spatial arrangement

5. BIOMIMETIC STRUCTURE

5.1 Categories: morphology analogy

5.1.5 Bone braces

Architect S.Calatrava is famous for his biomorphic appearing structure. The structure form do not imitate any particular biological principle, resembling to rib arrangements. Unavoidably such design expressing the beauty of bone-inspired structure, which bring dramastic influence on people's mood change. There is no wonder that this design would be criticized by certain architects or architectural historians depending on the canon they prescribe.

58. Train station Lucerne, Model, S.Calatrava

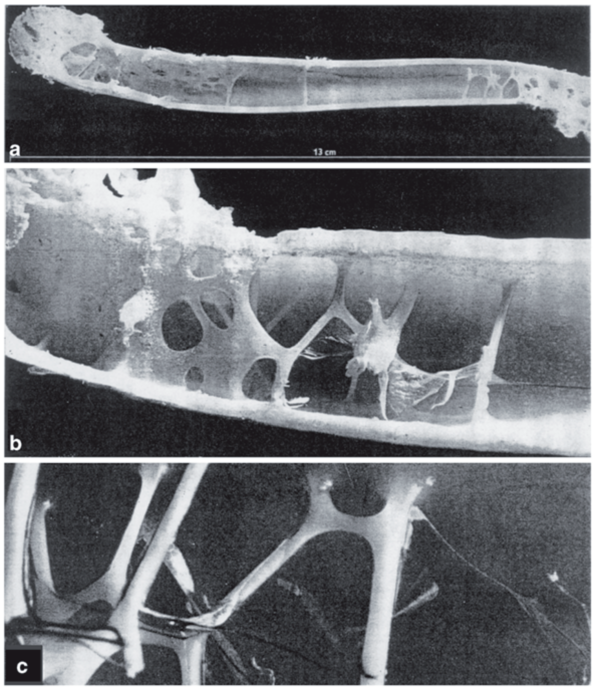
The structure of the " bone struts" was developing by the direct parallel stucies on bone and tree growth systems. Such technological finding and innovation is on the basis of the existing available prefabricated products (T profiles) to produce an affordable and stablizing structure. The lightweight steel profile also optimized the wiith the minimum amount of material cost. The "bone struts " adapted to the load-carrying requirments and optimized as "natural precedent".

Compared with the sea urchin shell sturcture with the shell-like arched frame structures of the speed skating hall. The similarity in both construction method lies on the rib structures. The bone brace and arched frame arise both with sparial emerging of the rib structure. The example of bone brace illustrates the optimization process of bone structure by analysing of natual effiency and technical constraints.

59. Sea Urchine dome

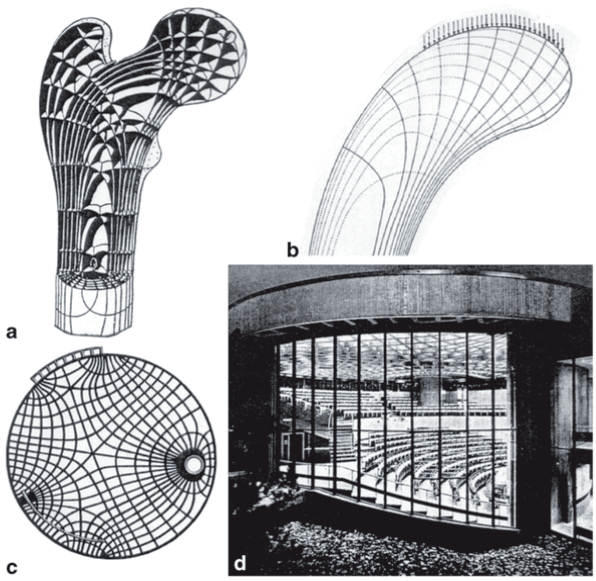
The spongy bone is generally structured so that its spans align with the major stress acting on the bone. The interior structure of the bone probably consists of larger mesh network.

Interior bone correspondingly correspond to the stress trajectories of compression and others which correspond to tension trajectiries. The trajactories always meet at a right angle, and that not only functions in one dimension. The dimension of slender ossified bone varies according to the specific force situation based on this principle.



60. bee honeycomb and hexagonal spatial arrangement

The structure member can be very light when one aligns them with stress trajectories. P.C. Nervi, a famous architect hinting that the bone-inspired structure for stress trajectory contributes to the occurence of prefabricated concrete elements. The example (see figure) is classical representation of the crane cantilever principle based on a.c scheme for teh joist and support system of the ceiling of the hall. The force trajactory aligned beams make it very light. The tension and compression are also expressed inthe form of "biological structure".



61. bee honeycomb and hexagonal spatial arrangement

5. BIOMIMETIC STRUCTURE

5.1 Categories: morphology analogy

5.1.6 Folding system

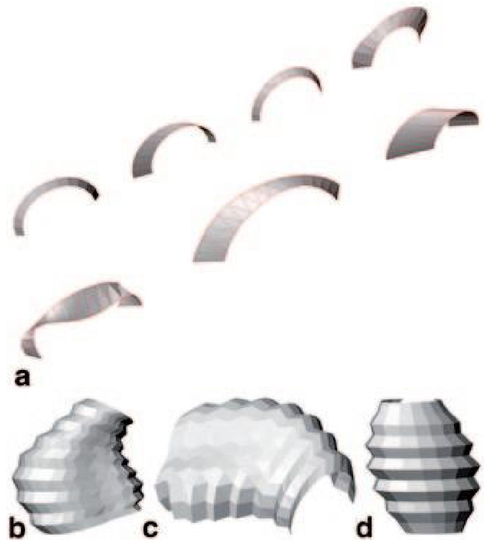
Folding is a common principle found in nature for increasing the rigidity of surfaces and surface area. we can find folding in insects' wings with open and close, leaves surface and sea shells.

The direct transformation of the biolocial folding form is very difficult for both computer model and physical model because the irregular surface must be fragmented into planar shape and the edges would also exhibite irregular angles to one other. (see figure) Because they should be light and rigid to be folded, the panels are produced as thin as possible, although sometimes extra thickness for the insulation construction is needed in folding element. Therefore, wood folding structure is researched on for its lightweight and well-insulated construction property. The conventional construction of wood shells can be optimized and dismantled into single timber panels which can be easily made with CNC milling technology. irregular folding elements are tested and customized. Architect G.P. attempt to make the curve volumn of folding structure only using woodshop and capenery machinery.

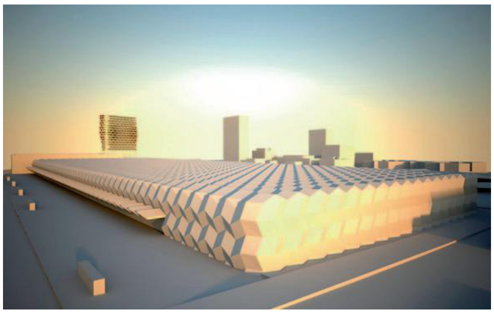
In the architecture applications, owing to its complex geometries, folding structure is very hard to produce. The folding panels are configurated in "X-shape", meaning the arrangement of linear joints can be produced around the x-shape vertex. for instance, the roof design with modular panels for convention center construction in Luxembourg follow the x-shape principle, simutaneously place the solar panels above supplying solar energy and partly transparent to allow light in.

In terms of the property of fold structure. One panel can be best coodinated with the neighboring panel automatically resisting the deformation and movement, and lastly forming a very rigid frame. with such arrangement a large spanning roof of a folding structure can be realized.

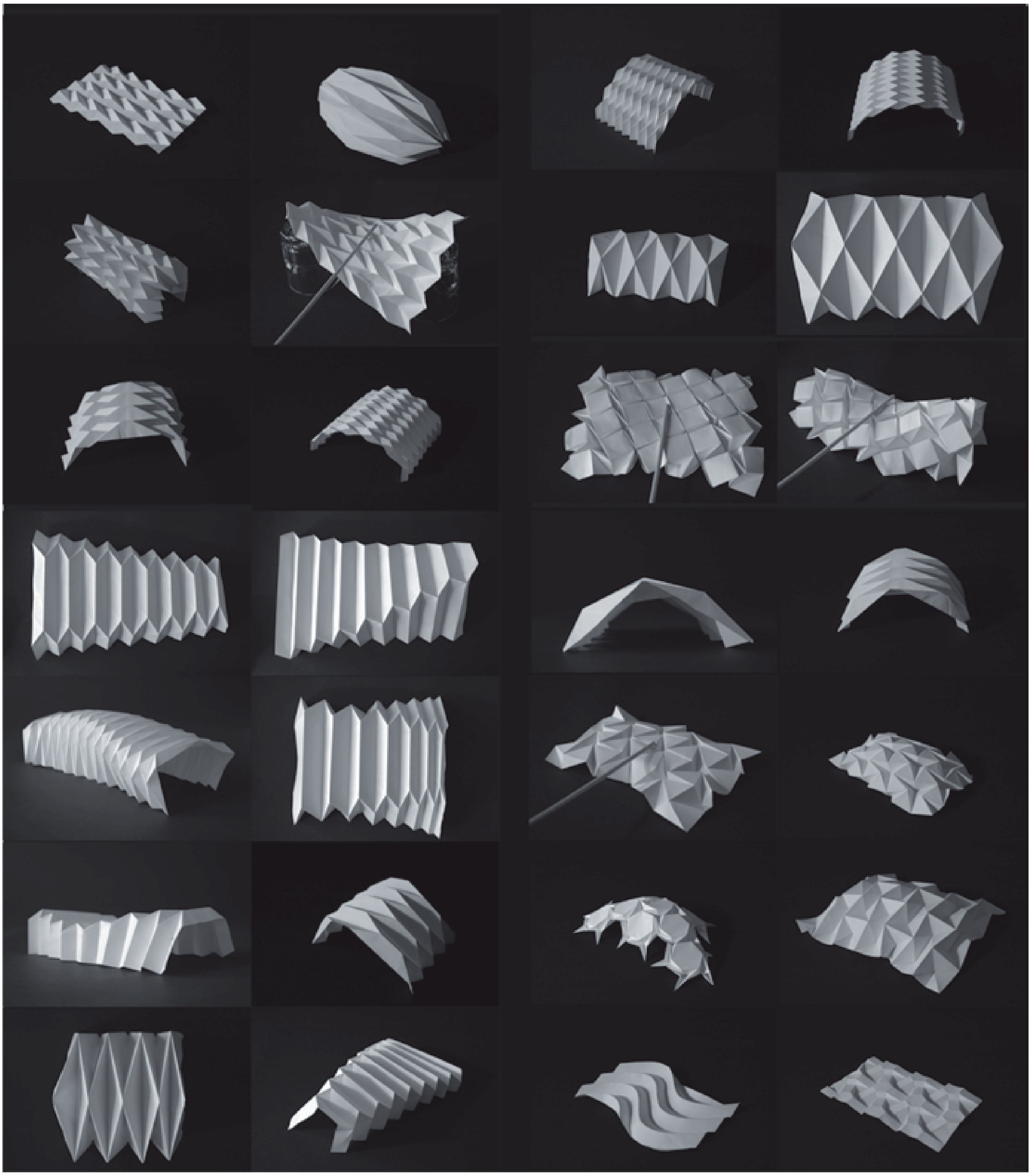
62. bee honeycomb and hexagonal spatial arrangement



63. bee honeycomb and hexagonal spatial arrangement



64.convention center in Luxembourg



65. folding paper structure

5. BIOMIMETIC STRUCTURE

5.1 Categories: morphology analogy

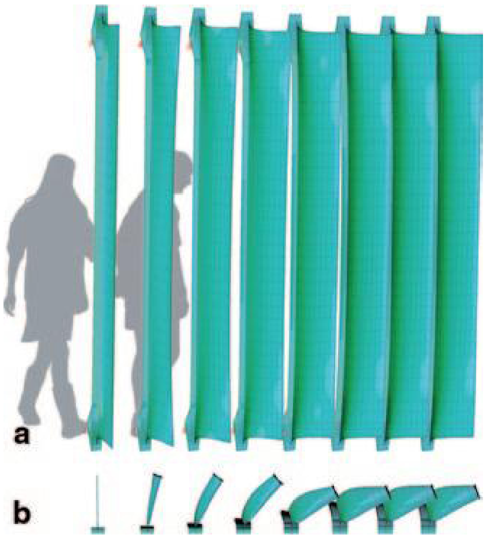
5.1.7 Autonomous Movements

Non-autonomous organ movements of plants is very common in nature, with a large breadth of movable forms of leaves. These non-automouse movements are usually a series of responsive reaction to the exterior environment, categorized by their triggers, chemonastic, seismonastic, thermonastic, photonastic, etc.... For instance, the folding pollination mechanism of the bird of paradise flower is a reversible mechanism only evoked through being bent downward by birds. In terms of human's physical mechanism, How to achieve responsive movements for human beings? Normally such movements are driven by muscles, sinews, ligaments.

Active and passive movements are of particular interest for scientists and architects. Subject area design and construction is developing applications in architecture, for example responsive fastening systems for lightweight roof, thermoregulating envoploe structures and ventilation systems for breathing building skins by Lydia Badanah.

Natural apparatuses that open and close themselves without mechanical elements prossess a high potential as precedent for application in the building industry, SOMA architects achieve the theme pavilion of Expo 2012 in Yeosou, Korea with a automoveable facade, which is based on the elastic deformation property in material. The only 8 mm thick glass fiber reinforced plastic is spreading to up to 15 meterss tall strengthening ribs on both sides. They are deformed elastically by the torsion force from both up-and-down joints. (see figure) It illustrates the experiment and analysis of facade shading, in which the lateral displaced spine lead to lateral torsional bulking of each shading plates.

66. Non-autonomous facade system of "One Ocean" Expo pavilion



67. Finite element analysis of facade shading

68. Geodesic Dome

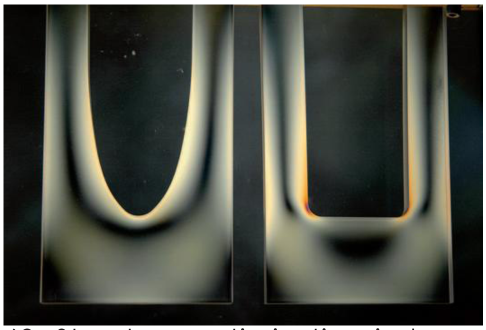
5. BIOMIMETIC STRUCTURE
5.2 Structure optimization

There are some basic principles for structural optimization.

Optimize form
one simple and diversly applicable method is "Method of Tension Triangles" , which is a graphic tool for exhibiting the contours along the direction of force. (see figure 69) left picture describe the tension-optimized construction visualizing the behavior of force from a thin to a thick crossing section of steel conponents, while the right one shows the traditional abstracted form of straight edges and round corners. With the help of simple branches in the structure that are superior to the perpendicular geometries in conventional construction. The optimized form with the tension triangles is similar with the bone forms, which shape themselves through adaptive mineralization.

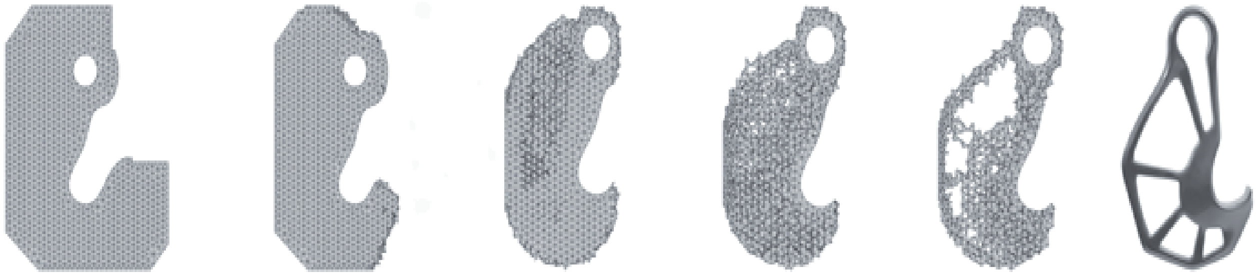
Reduce mass
in particular regions to favorably (reduce the weight of the overall bone without compromising the structure.

SKO methods
“Soft kill option” from KIT, Germany, and simulates this principle of adaptive bone mineralization, which is that heavily burdened region have increased rigidity while less burden regions are reduced in mass. Such principle is demonstrated in which the unequal tensions bring about the irregular growth and high tensions produce thicker root in section. (see figure 70). SKO strategy lead to the efficient use of the material and logical load distribution so that areas under more stress are supplied with more strengthen material and non-structure areas receive less pressure.



69. Structure optimization in bone growth

70. SKO optimized principle in tree section



71. Process of optimizatin on heavy-duty hook design by students in University of Magdeburg-Stendal, Germany

5. BIOMIMETIC STRUCTURE

5.3 Cases studies: Form finding from nature

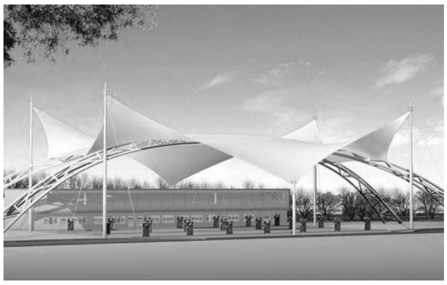
5.3.1 Tensile structure - cable net system

Frei Otto is famous for his form-finding from nature, bubble experiment, umbrella structure and tensile tent structure etc. His concept of minimal material - the idea of achieving maximum structural and aesthetic effectiveness with the least possible investment of material- has been a model for principle of effcient and biomimetic approach in later discovery.

One of his famouse coposition is cable net structure. How to create more with less material and effort, Frei Otto elevated the traditional tent to a modern building type, envisioning the structure of extreme lightness as well as extreme strength. By making use of thin cables of high strength steel or thin membrane. Web structure has the similar form with the spider net, which is also applied into the tensile structure construction or evolution process. During the development of optimization, there are mainly 4 types of cable net systems .

- Simple saddle membrane
- Arch-type membrane
- Ridge-type membrane
- High-point-type membrane
(Mast and cable supported membrane)

Simple saddle membrane



Arch-type membrane

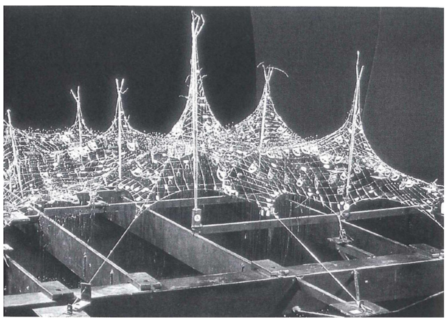
ridge-type membrane

High-point-type membrane

There are evident silimarities between spider web and Frei Otto's tent structure, not only in form and ethetics but also in constructions. Architects in collaboration with biologists closely observed spiders net and other web constructios. The interconnection relationship between both area is undeniable. The similarities lies in manay aspects. for example:

- **pre-stressed** cable(tensile structure): band curved structure.
- **The loops** "eye" is introduced in the web structure to ease the exessive point load also found in spider web
- **Extra mass** in the severely stressed nodal structure. spiders strengthen these regions by adding more silk threads or thickening the individual threads.
- **Large span** can be bridged by tensile structure.

Tensile fabric roofs incorporate double curvature and high tension to provide membrane stiffness. The curvature and tension helps and prevent the membrane from fluttering under wind loads.



Physical Model
figure 72

5. BIOMIMETIC STRUCTURE

5.3 Cases studies: Form finding from nature

5.3.2 Moveable structure - Retractable roof, Umbrella structure

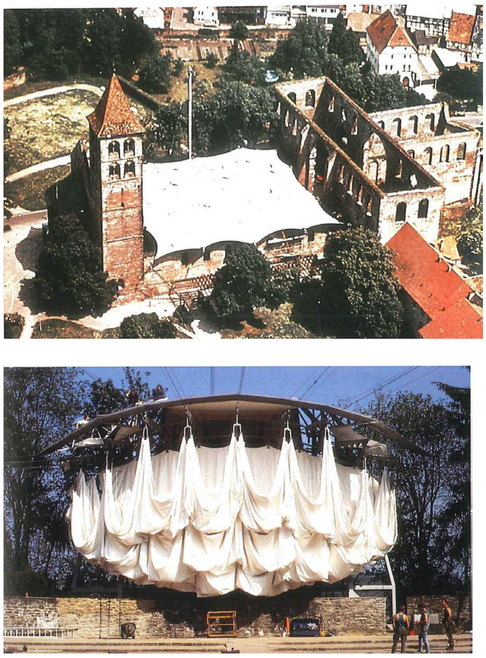
- **Retractable roof**

These deployable structures are substantial in size and involve very complex engineering. One advantage of deployable structures is construction and disassembly each takes quite less time.

The material of preferred fabric for these deployable structures is coated polyester. (see figure) On a much larger scale, this German soccer stadium has been enhanced with a retractable fabric roof where pulleys are synchronized to allow fabric deployment. When the roof is open, the fabric is retained in the 'garage' behind the suspended TV screens.

73. tensergrity structure

How to adopt the minimal intervention into the histroical building without damaging the existing construction? Cable, pulley, cloth roof constitute the whole tensile structure. The cable is spreaded from the central mast. When the cloth roof is unfold on the ruin inside of the damaged middle-aged buildings, the exterior courtyard immediately becomes the interior pavilion with the white shed above people's head.



74. tensile structure

5. BIOMIMETIC STRUCTURE

5.3 Cases studies: Form finding from nature

5.3.2 Moveable structure - Retractable roof, Umbrella structure

- Temporary Architecture

Otto's approach on moveable structure grew out of his early interest in temporary structure. The approach is a response to the extreme conditions in post-war Germany, when architects felt strongly responsible to react to the social issue by using the most efficient and minimal material to creat utopia world due to the limited availability of resource at that time. In another view, the temporary architecture could be relative with his early experience of being prisoner in the war camp. Thereby, Otto believed that all the architecture is not permanent. The imprint of temporary architecuture had been in his architecture notion.

- Umbrella structure

Just as its name implied, Umbrella structure is utilizing the mechanical principle of umbrella. The tensional cable and central slender column constitute the such moveable structure. The membrane of the rood is foldable and lightweight. With the elongation of the major cable hooked above the skeleton, the roof surface goes down and contract itself.

The specific construction detail and the changing process of umbrella structure are shown in the figure. The major load-bearing is concentrated into the central column, the bottom of column is a little bit bigger in the diameter for the stablization consideration.

75. Umbrella structure

76. Umbrella structure process & Construction details

5. BIOMIMETIC STRUCTURE

5.3 Cases studies: Form finding from nature

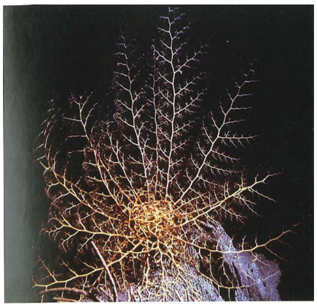
5.3.3 Tree column support

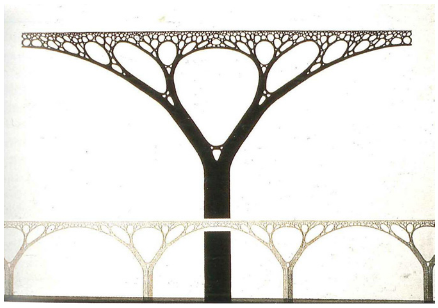
Tree Columns

" *The idea of the tree structure is that trees branch themselves more and more intensely towards their canopy as bodies of constant tension.*"

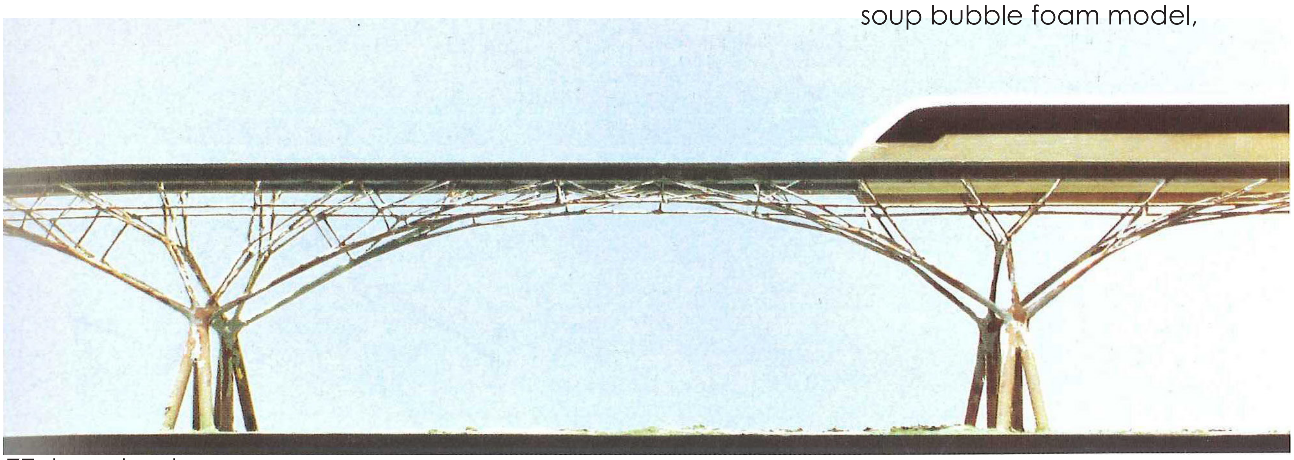
In the traditional column structure system. the flat roof is supported by the a few point column, while in the tree column structure, the load is distributed into many point tree-branched column. Consequently, in latter structure each column bears less force than the former one, evitably with less material. Essentially, the branches of the columns in with narrow diameters weight less than the traditional columns, representing the idea with minimal mass given constraints of a load-bearing structure.

The tree column system is a process of structural optimization, In comparison with tree growth, the tree branch is a process of self-formation alongside with calculation and evolutionary strategy of optimization. Frei Otto use the soap bubble experiments to demonstrate a support structure optimized for mass. (see figure) The figure describes the process of transition from the conventional Y-shaped bridge bases to the tree-branch supports.

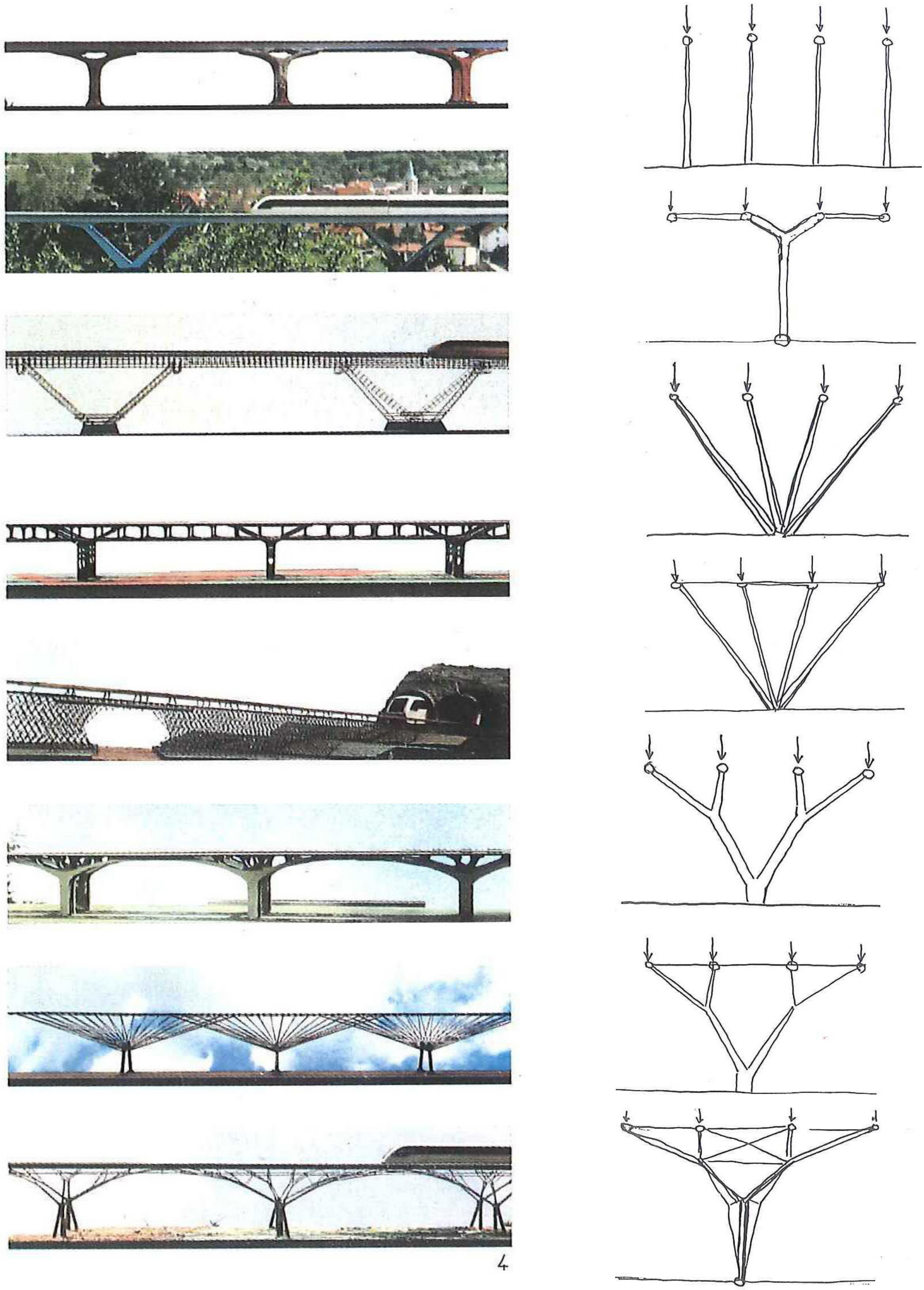




soup bubble foam model,



77. tree structure



78. bridge with tree supports

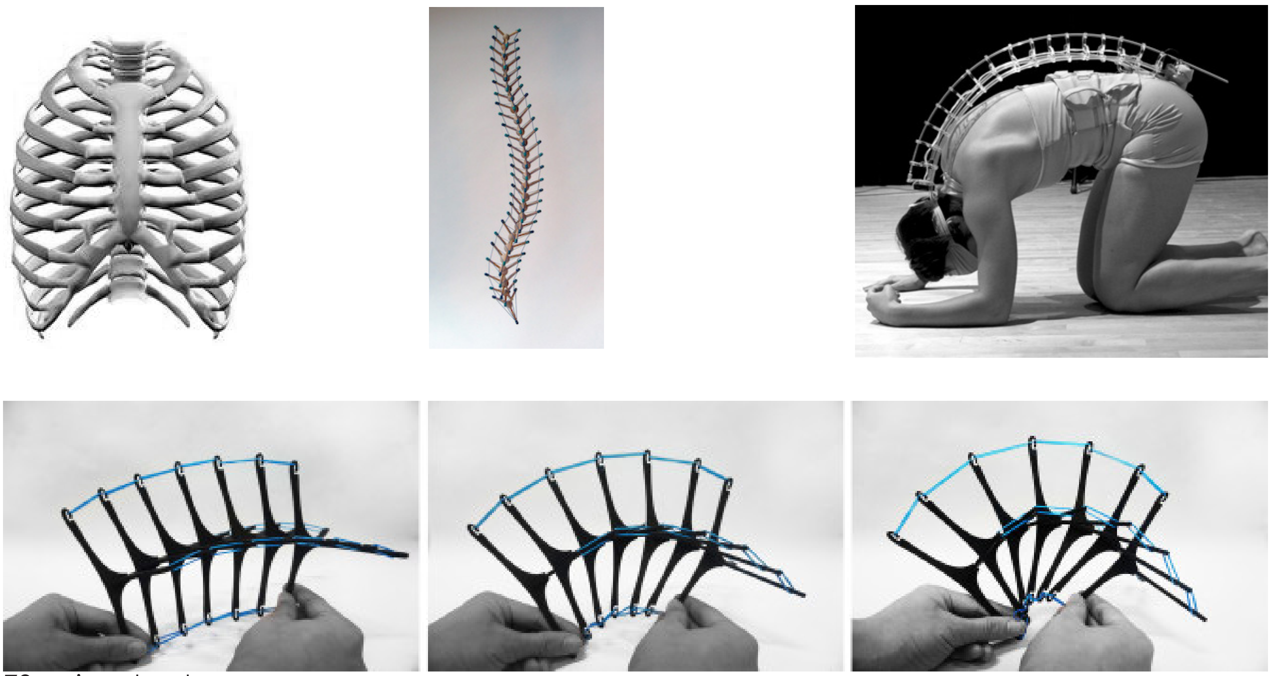
5. BIOMIMETIC STRUCTURE

5.3 Cases studies: Form finding from nature

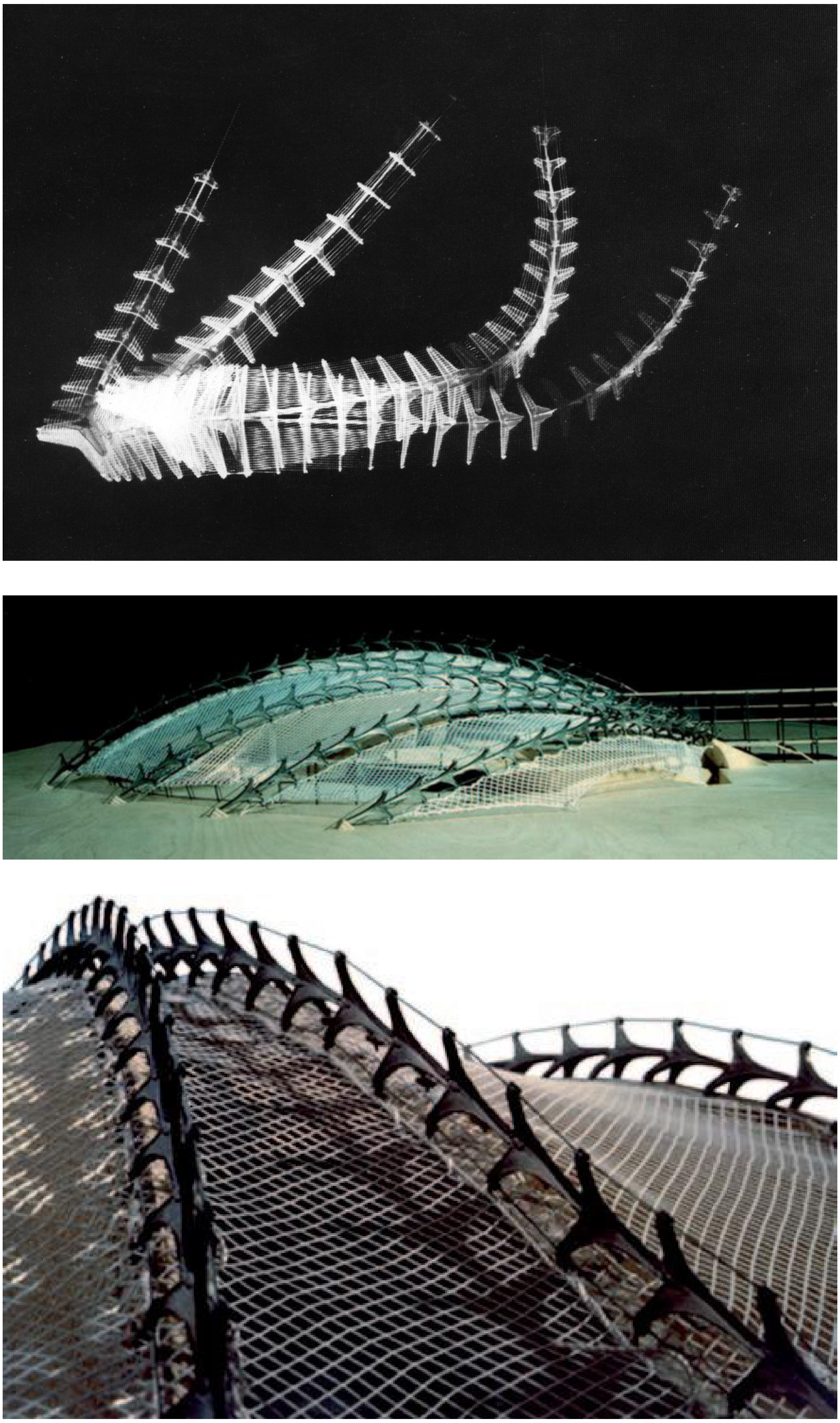
5.3.4 Spine structure

The human spine is a system of ligaments, tendons, muscles and bones, which is very flexiblestructure that can efficiently bear loads and distribute them evenly into structural limbs and members. In a sense, human as well as animal spines represents a framework construction. the difference is the former spine correspondingly supports perpedicular cross-beams in upright position while latter one. the spine of the quadruped is a truss system. Both spine structures connect the extremityies in body to the other, support the whole framework of the body.

Freit Otto concerned himeself with the structural system of the spine, he did some experiments related spine with frame structure and tensioned, free standing mast. The core analogy between vertebrate and his man-made spine is that he use pre-tensioned steel cable to imitate the ligment and muscle. The spine system could be tensioned in longitudinal as well as in the radial directions of the arch.



79. spine structure



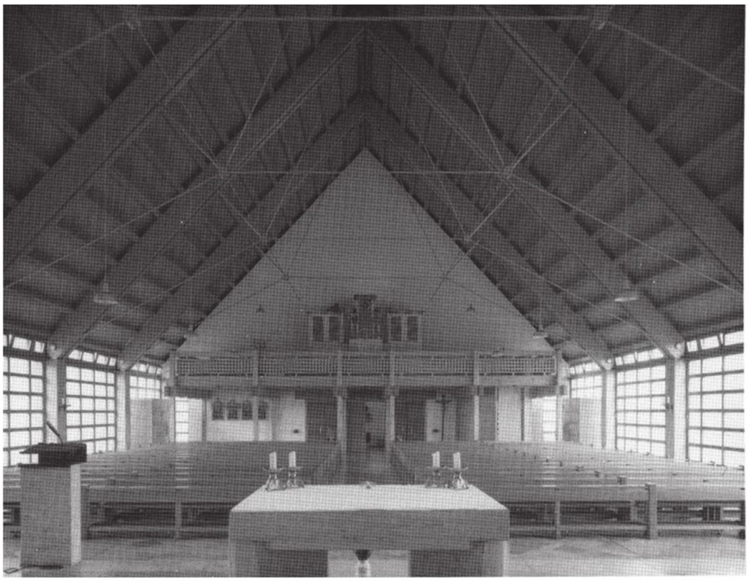
80. experiment with spine structure

5. BIOMIMETIC STRUCTURE

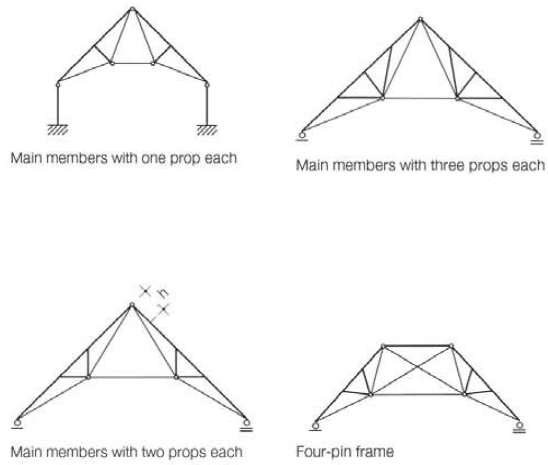
5.4 Organic architecture in timber construction

5.4.0 Timber structure with cable nodes

-Transform tensile stress to compressive stress

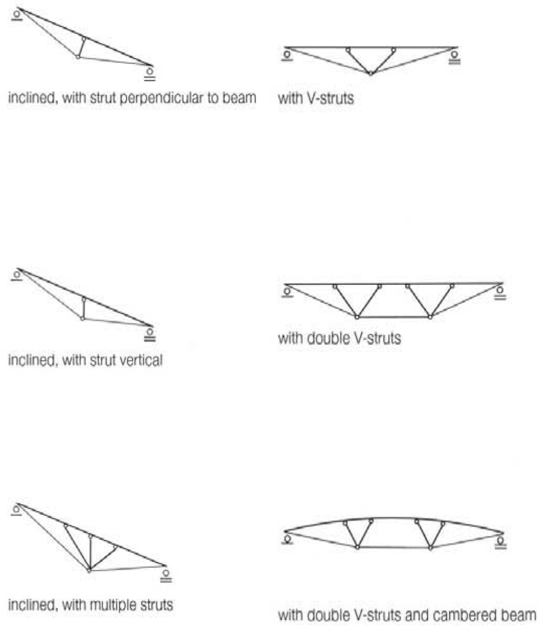


81. St Martin's Church



Three-pin frame with raised tie

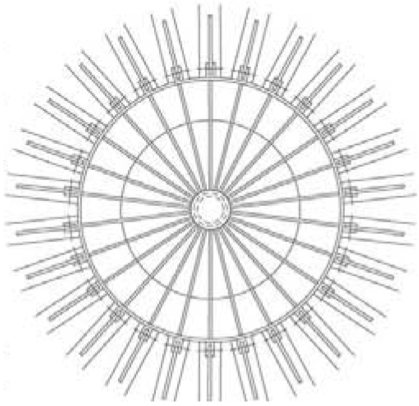
82. Multiple-purpose hall in primary school



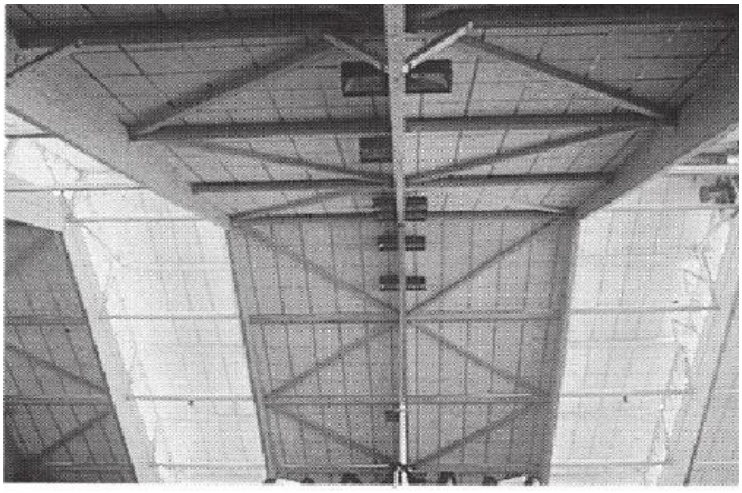
Trussed beam with tie in middle or steel

-Symetrical layout of structure

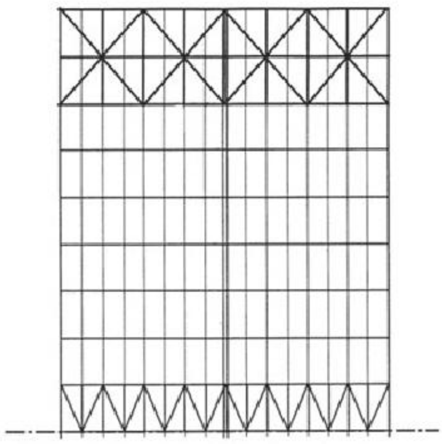
83. circular dome



Cable and Simple

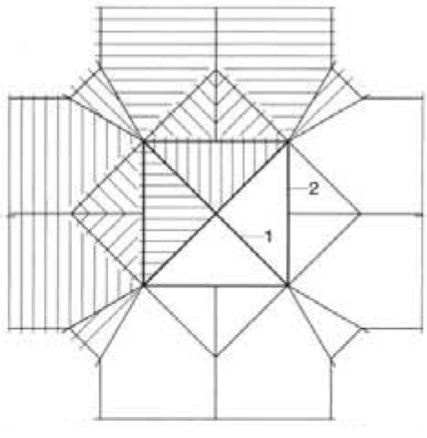


84. Girder with X



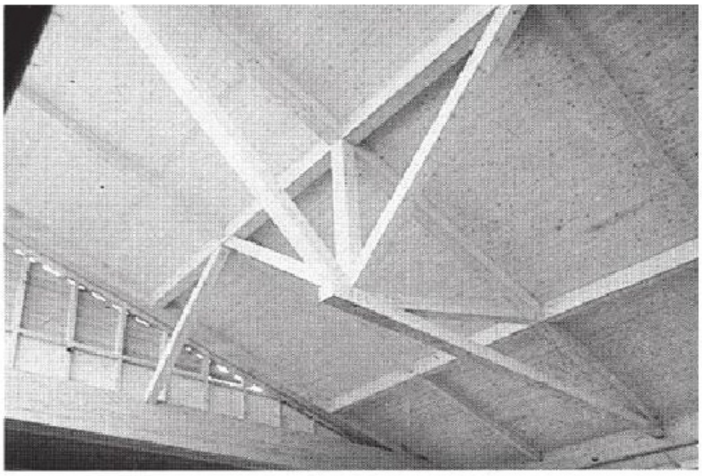
Diagonal tranverse brace

85. hip roof with tensility

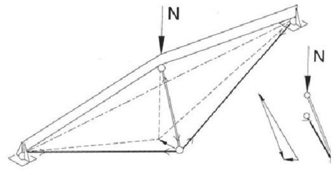


Cable and Simple

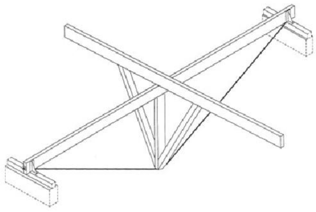
-Stability element



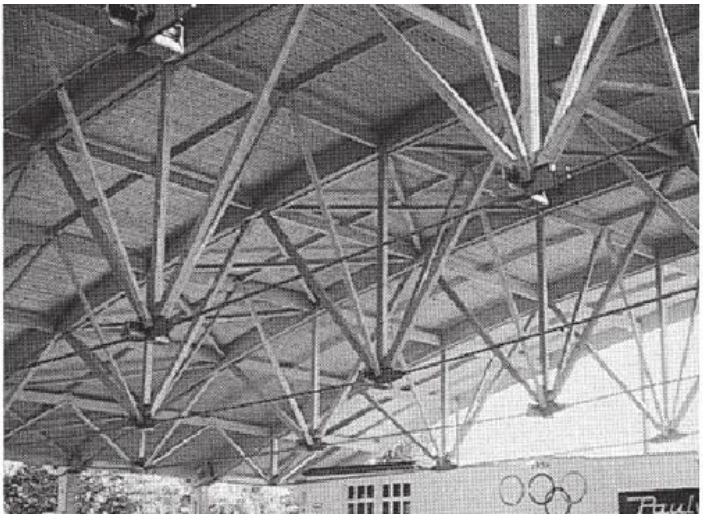
86. Trussed arrangement with K-braced purlin



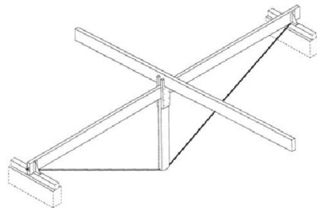
Restraint by inherent resilience



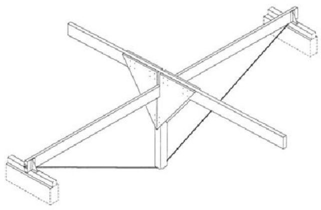
by kneebraces



87. Fish belly truss with steel tie

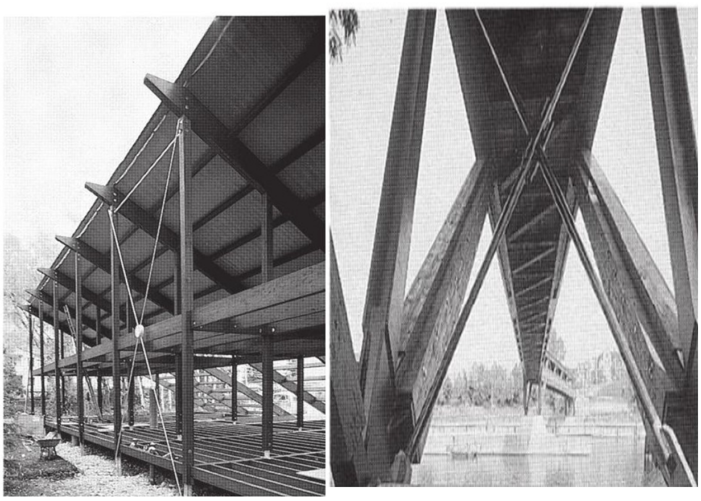


by fixity at supports

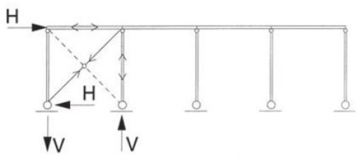


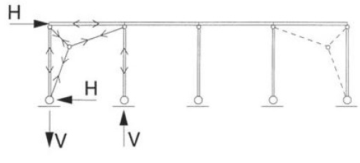
by purlin frame

buckling of tension chord in trussed beams



88. X-bracing System





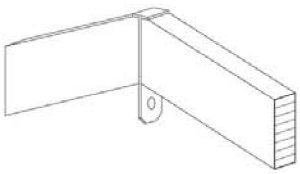
Guyed beam-and-post system

5. BIOMIMETIC STRUCTURE

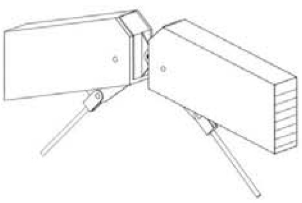
5.4 Organic architecture in timber construction

5.4.1 construction joints

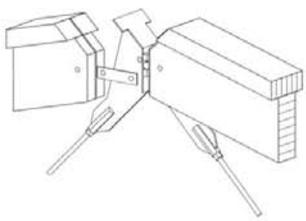
Tie-Ridge Connection at junction of two beams



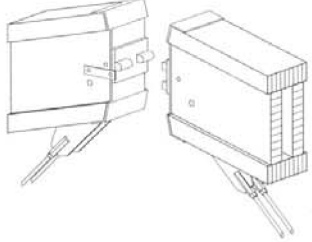
as simple suspension with welded T-section



with bearing plate and welded web, ties connected with fish-plates

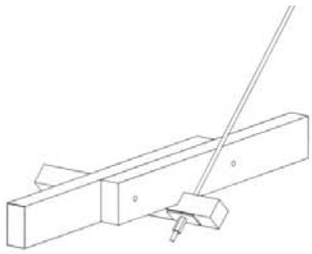


with bearing plate and connecting web, ties fabricated from threaded steel bars

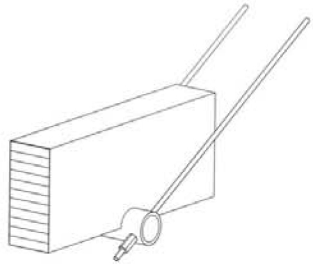


comprising steel bracket with connecting web and rocker nibs, ties in pairs

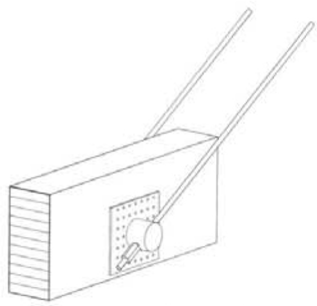
Cable Connection Joint



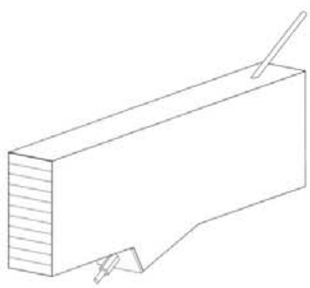
to transverse deck beam



to steel circular hollow section transverse deck beam

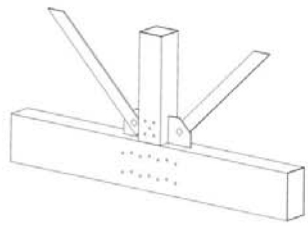


to longitudinal beam via hinge pin

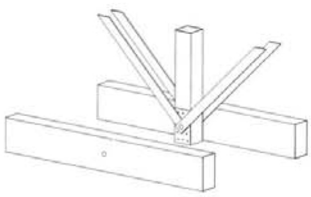


to longitudinal beam via block

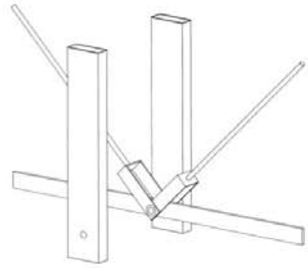
Truss joint at mid-span with post and two diagonals



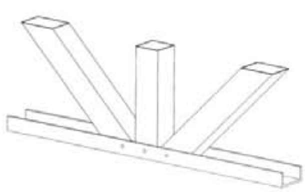
Gusset plate let into slits with steel flat diagonals



Two-part bottom chord with nailed gusset plates



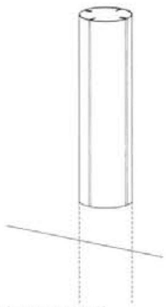
Steel flat tie and steel diagonals with steel lugs



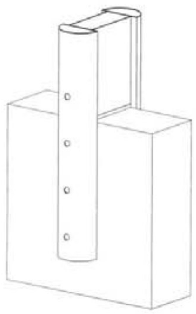
Channel tie with hinge pins

89. Figures from < Timber_Construction_Manul >

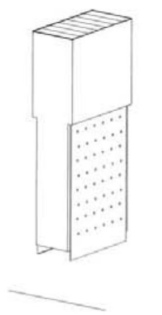
Column fixed detail at concrete base



cast into concrete



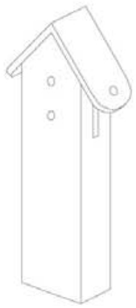
with timber side plates



with nailed metal plates

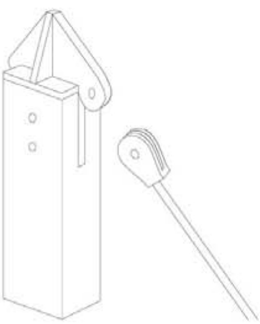
with dowelled timber plates

Cable Support Joint junction



with saddle

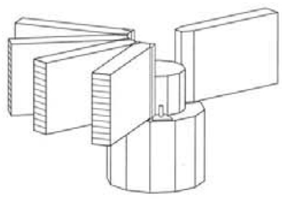
with saddle



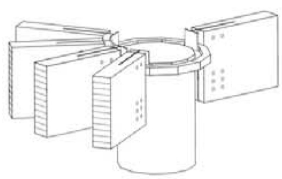
with web plate

with web plate

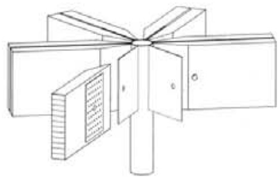
Central support detail



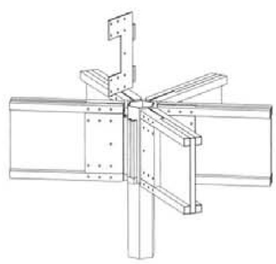
on concrete column, held in position by steel shear connectors



steel ring with peripheral bracket, beams hung on bracket via end plate on dowelled web plate let into slit



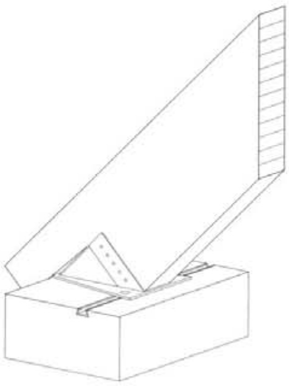
steel circular hollow section with web plates welded on, hinge pin connection



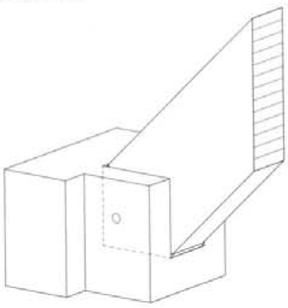
steel tube with rails welded on and beams hung on rails

89. Figures from < Timber_Construction_Manul >

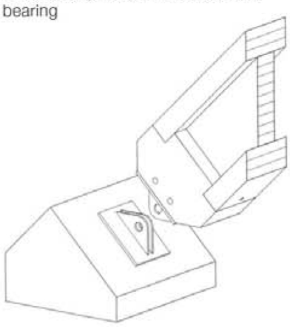
Support for pinned members



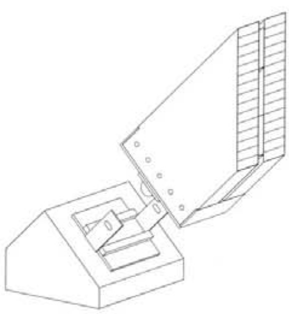
with steel bracket and rail for adjustment



in concrete pocket with elastomeric bearing

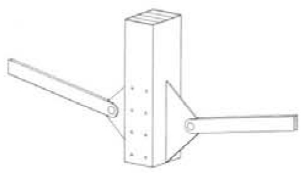


with end plate and hinge pin

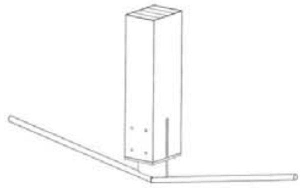


with rocker bearing and steel lugs both sides

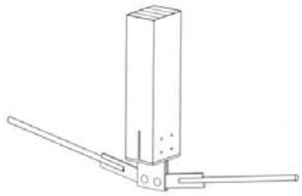
Post-trussing junction



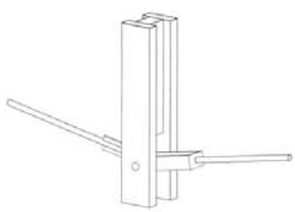
dowelled plate and ties connected via pins



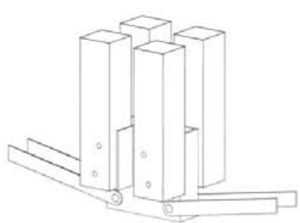
dowelled web plate welded to ties



dowelled web plate and ties connected via pins

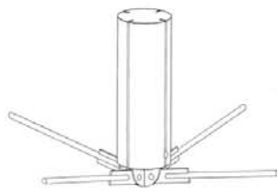


three-part strut with hinge pin or dowel

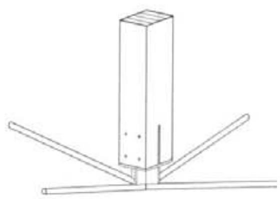


four-part strut with steel connector

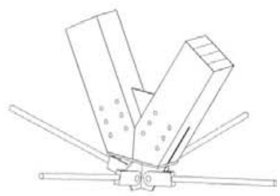
Post-trussing connetion in three dimension



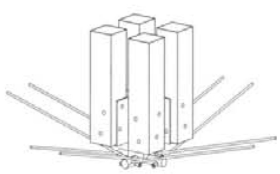
Metal plate let into slits, with web plate and screwed connections



Dowelled metal plate, with web plate a welded ties



V-posts, metal plate let into slits, with w plate



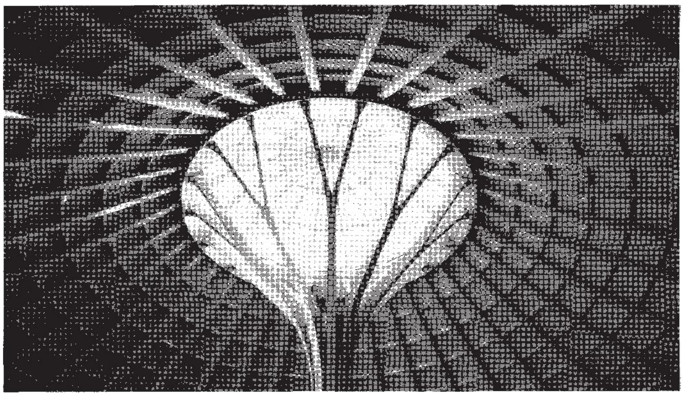
Four separate posts, ties made from threaded reinforcing bars

89. Figures from < Timber_Construction_Manul

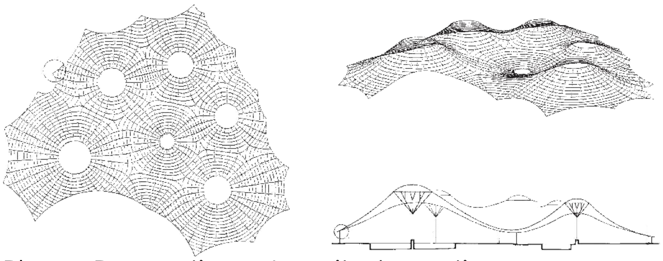
5. BIOMIMETIC STRUCTURE

5.4 Organic architecture in timber construction

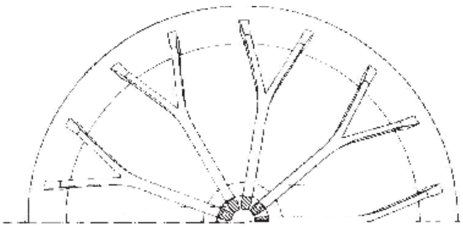
5.4.2 CASE STUDY: Sphere, curve morphology of structure

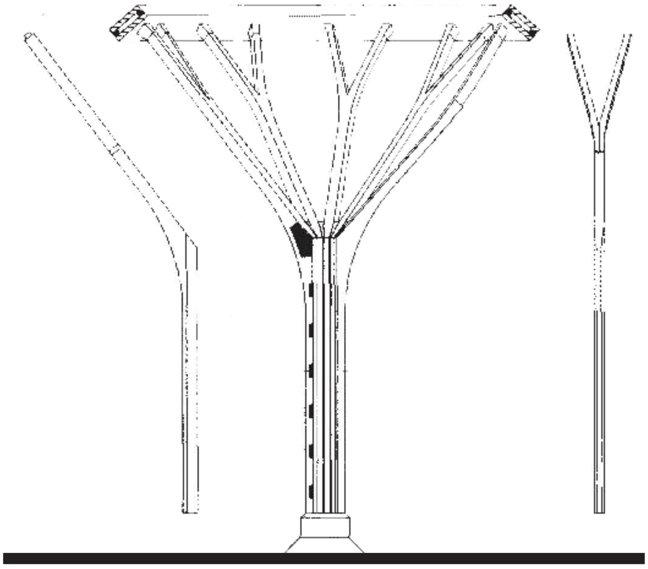


Central eyes



Plan & Pespective & Longitude section





Section of Timber tree-structure column

90. Figures from < Timber_Construction_Manul

Project: Brine Baths, Bad Durrhein,D 1987
Architect: Geier & Geier, Stuttgart
Structural Engineer:
Wenzel, Frese, Portner, Haller, Barthel, Karlsuhe, Linkwiz, Presusss

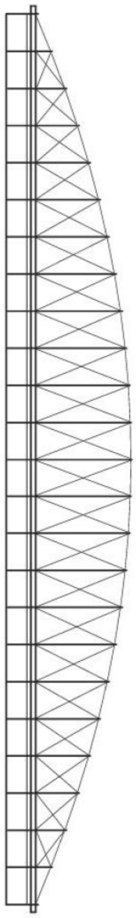
Five "tree columns" suspended shell of timber ribs spinning for over 1500 m2 leisure complex. The shell shape is defined following the principal stress trajectories. The timber rib form are generated by the computer model via simulation test. Therefore, the load could transfers essentially as membrane stress through the meridian glulam ribs, which are twisted in double curvature and interlocked at the nodes.

On the other hand, two layers of diagonal timber boardings are installed on the timber ribs, giving the shell its high shear strength. The exterior roof is made of PVC protecting inner structure. The connection between edge members and facade columns is by means of ball-and-socket joints.

The tree columns are set around the circle ring with many branches struts supporting the roof.

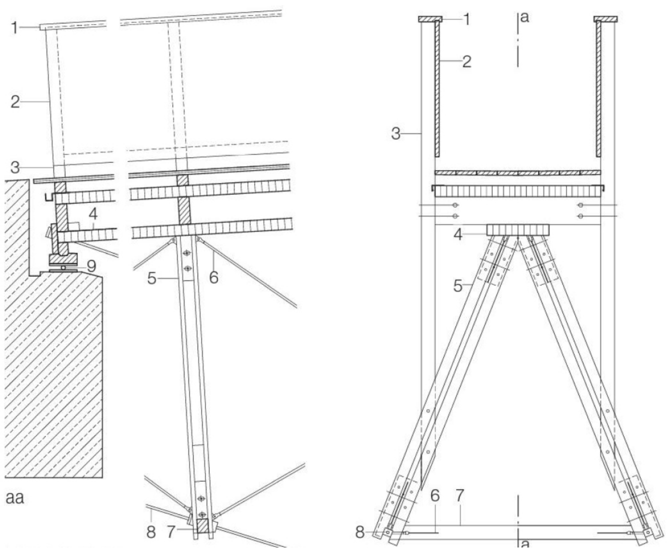
Central eyes

Central eyes



Project: Traversina Steg bridge
Architect: Viamala,CH; 1996
Structural Engineer:
Branger, Conzett & Partner, Chur, CH

The case is a lightweight bridge between the hard cliff. It is one of the exemplification using pre-tensioned trussed beam to support the whole construction, The bridge is without no doubt the successful example in timber structure engineering in the perspective of aesthetic and structural economy.



Section of fish belly beam
91. Figures from < Timber_Construction_Manul >

The bridge consists of two major structure elements. One is the parabolic three-chord timber truss. The truss is the support member fixed with x-shaped cable brace between each adjacent two members, beneath of which two major longitude cables or steel rods in tension sustain the loadbearing truss. The other element is the Spandrel beams which prevent torsional movement of the bridge. These beam connected with the bridge deck and vertical post. The horizontal deck is attached on the compression H-shaped chord.

6. BIOCLIMATE: RESPONSIVE SKIN

6. BIOCLIMATE: RESPONSIVE SKIN

6.0 Active light control and collection

Aside from geothermal energy and moon-induced tidal force, solar energy is the only source of energy that is directly availbale and the most for living organism on Earth.

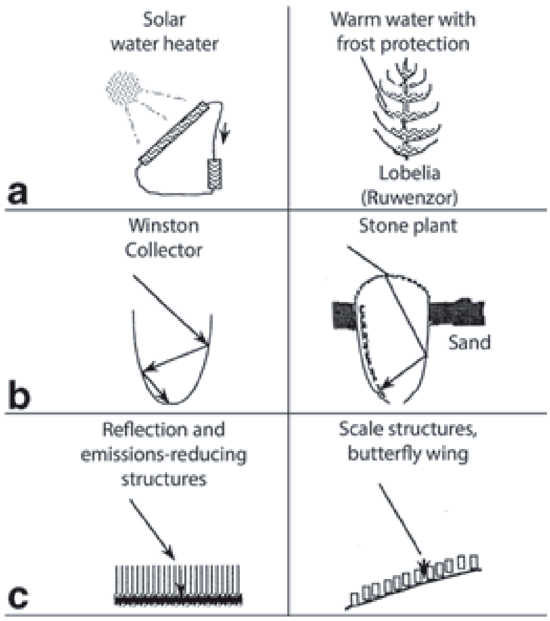
Thereby, How to learn form nature to maximumly utilize the solar energy in the building area is a long-lasting question for architects. Modern archtects are considering various building technologies to develop themselves parallel to the traditional building experience. The low-tech and primitive experience like construction configuration, orientation is the result of passive analogy to nature and is also a trial-and-error process without the influence of specialists. Nowadays, the solar-driven energy system makes a major portion of the total energy required for functionality in biology as well as technology.

Solar-driven energy system includs both direct and indirect ways siezing energy. Photosynthesis in green plants is doubtless the most fascinating solar energy system with also the most technology potential for energy economy of future as well, plants achieve the energy production and material exchange in the process of photosynthesis. Besides of it, there are some other possibilities for solar usage like light collection interaction between light and exterior surface, solar-contingent electricity generation, and so on. The right figures describes 6 examples for solar-driven system in nature and technolgy.

-a. Solar-heated water system
devices for solar heat gain warm water in radiation-absorbing collectors. The warm water circulates at night to warm the cold indoor

-b. Light collection
light is transferred by means of the optical lenses, due to the limit size of apetures and reflection ratios of the material. The reflected light is scattered and collected for photo-synthesizing in stone plants and for illumination in architecture.

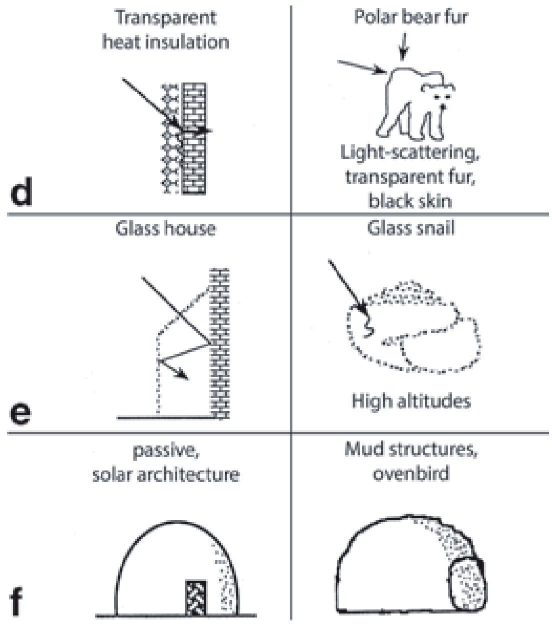
-c. Optimization of light reflection and scattering
different species are differently outfitted with various reflections and absorption of heat. for example, the butterfly can absorb the warmth or limit the radiation effect by spreading the wings to a slanted angle and reflecting the sunlight. Similar technology is applied into the building skin in architecture area on the basis of butterfly principle for self-cooling or self-heating purpose. For example, the surface structure with the gridded scale of this butterfly imprinted on the metal electronic chips could be easily overheated during the use.



-d. Transparent heat insulation
in arctic area the polar bear use the thick white fur in the exterior surface to absord the heat and warm the body in beneath brown hair as insulation layer for storing the energy.

-e. Greenhouse effect
use the green house to allow the light go throught the transparent window to warm up the building.

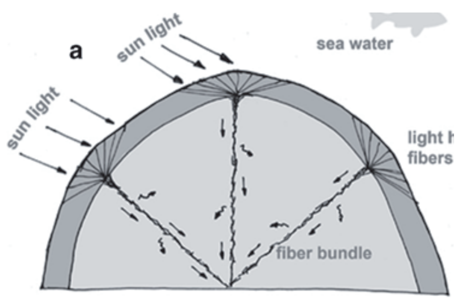
-f. Temperature regulation with thick mud walls
Oven birds build their nests with mud and clay to lay their eggs. similarily human constructed the dome shaped mud house as solar house which is the exemplification of passive using solar energy in architecture.



92. various use of light

The orange puffball sponge (Tethya aurantia) lives in deeper waters. The speciality of this living thing lies in its ability to transfer, distribute light through the bio-fiber bundles. (See figure 93) the light havesting fibers is showing a form of bundles. The ending part of the silicate shreads absorb sun light from the environment and emit it into the interior of the body.

The sponge is identified as the precedent for day light usage on building facade. The application like light collection is the condensing lenses arranged in the building surface tightly. The other innovation is the 3D knitted fabric of fiber-based material with light directing capibilities to provide extensive distribution of natural light.



93. Section of orange puffball sponge

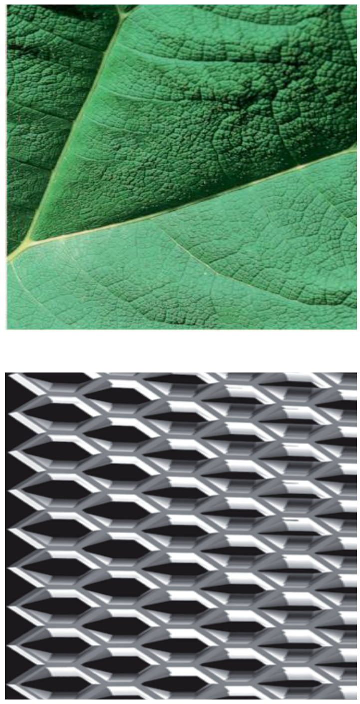
6. BIOCLIMATE: RESPONSIVE SKIN

6.1 Shading system and light utilization

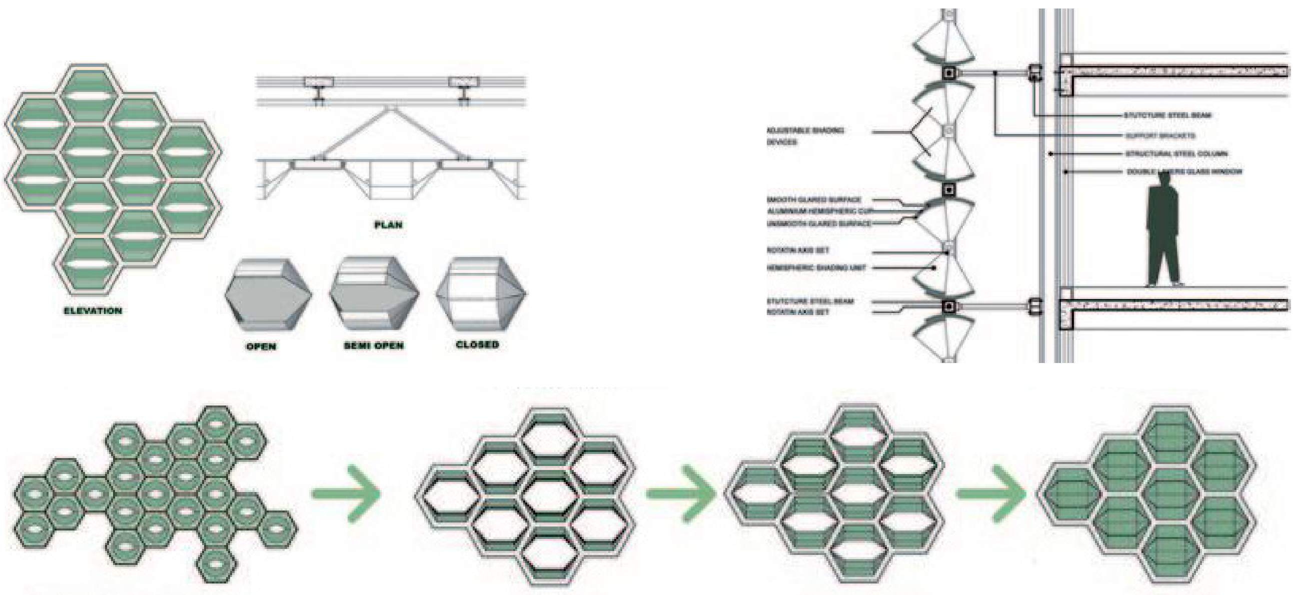
The leaf element is the producer with the process of photosynthesis. The pores in between the outer protection layers called stomata controlls the tranpiration of water and CO_2, thereby controlling the process of photosynthesis.

Bio-inspired facade system is constructed corresponding to the transformation and abstraction of the leave surface microscope structure and mechanism of photosynthesis. A double-layer skin is made with the outer layer as "guard cells" controlling light and heat transmission, the inner layer consisting of louvers to redirect or prevent the light into the interior space. The inner layer of louvers can respond to the various light condition, such as low and high angle light, diffusion light, direct light. As for heat entry and dissipation, the double facade also can do something.

(See figure 95), international student workshop in Melbourne University, Australia developed an adaptive facade. A cluster of modular composed of the facade envelope, which can react to environment conditions technically. In the view of



94. Facade system



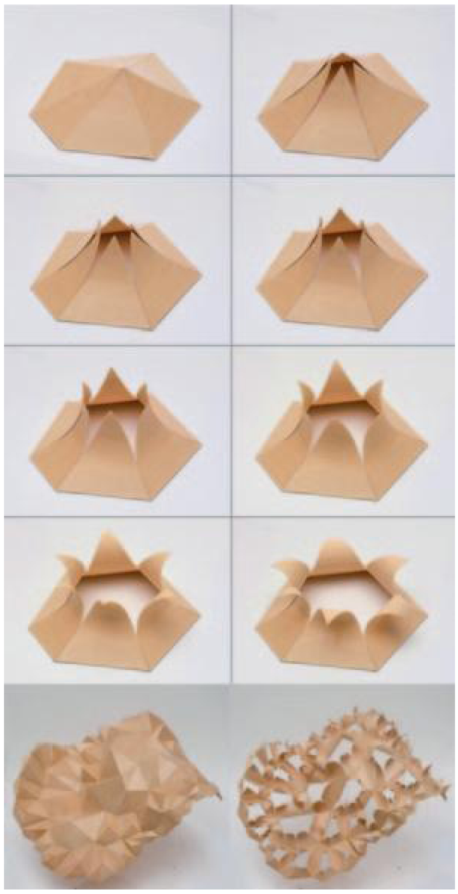
95. The transformation process of pores in leave surface

6. BIOCLIMATE: RESPONSIVE SKIN

6.2 Interactive breathing envelopes

Cones of conifers is sensitive to the environment of "humidity" and "airdity". The exterior skin process hygroscopic changing abilities, which are evoked by anistropic behavior of the wood fibers. The wood changes with absorption or desorption of water, the cones open in dry conditions and close in moist conditions.

Technical Application
Reactive envelope design following this precedent of conifer cones has been explored and developed in University of Stuttgart. The reactive envelope can respond to the weather condition without motors. The veneer has dramastic change in the shape when exposed in the the relative humidity between 40% to 70%. The veneer compsite element enlongates and shrinks based on its characteriistic. Therefore, the veneer elements is applied in the building facade as an integrated sensor, energy-less actuator. each element reacts to its specific locaton, functions independently, forming into a highly robust, decentrally, adaptive system.



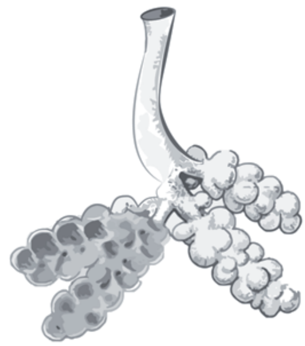
(see figure 96) the opening mechnism of a roof structure exhibites itself in dry and humid condition, The conception of reactive skin would be supposed in the builidng facade application.

96. cones of conifer

6. BIOCLIMATE: RESPONSIVE SKIN

6.2 Interactive breathing envelopes

Lung organism have particular geometric arrangements and reactive sensation to the world change. The respiration system finish the exchange of substances in this organ. ***Lidia Badarnah*** at the Tu-delft translates the active principles and methods of natural respiratory and circulation system into the building envelope.



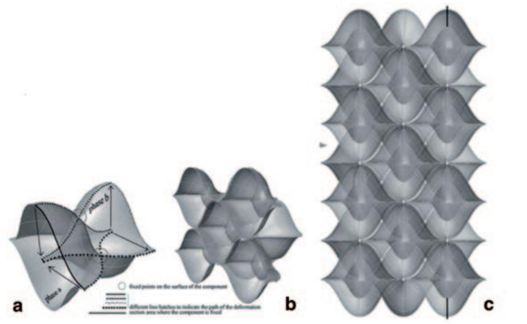
Lung: respiration system

The designed breathing skin is a system which results in regulating the interior microclimates based on the following principles.

-Generation of pressure gradients with the movement of the building parts.
the respiratory organ and the ventilation system as a whole, is an active system. The breathing envelope is consisted by singular active components that are arranged in specific regularity. The pressure gradients is with the change of each component, the movement of the skin.

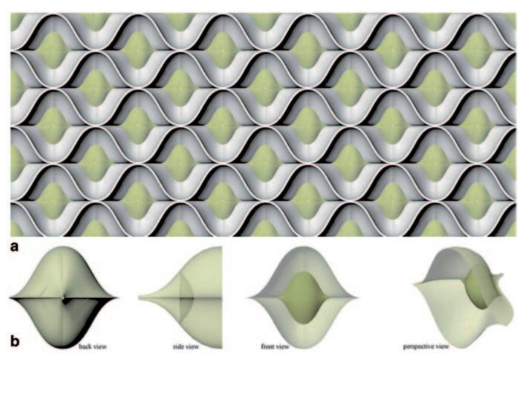
-Inhailing and exhailing system
skin that reacts to changing conditions influences the air pressure on the surface to perform a process of inhaling and exhaling. The reaction of skin is archieved by means of entension and contraction of components.

-The air exchange system is hierarchically membered
The component cross section consists of three hierarchical parts: opened, semi permeable chamber, and a closed part. This hierarchy creates three chambers with different air pressure, allowing the air to flow in and out. Sensors are attached to the inner side of the skin, which give signals (through a control system) to the component to increase or decrease the deformation velocity.



97. component deformation by Lidia Badarnah

-The arrangements of chambers
The chambers are fixed in the middle of the basic component cross-section. They are arranged in a diagonal crisscross pattern to optimize the stability of the system. This net is the basic support of the dynamic system, where the basic component is attached to this net too. The air flow through the system and it doesn't flow in reverse direction through the same lung-like-chamber.



98. Lung-like-chamber arrangement in system

7.Conclusion:
Proposal For New Constructions

7.Conclusion: Proposal For New Constructions

7.0 Assessment & Analysis

The research in Groningen shows that the seismic hazard is estimated to be of a mignitude of 4.1 M with a GPA of 0.12g. Chances on an earthquake with higher manitude are expected on 10% (Namplatform, 2014). Therefore, the limits of earthquake on design in Groningen is not so strict that there are more possibilities for architects to explore space. The compromise between seismic principle and architect's conception would be made.

In the matching process of seismic resistant principles with biomimetic structure, cable-integrated structure has high ductile capacity, which plays essential role in dissipating seismic energy. An assessment of seismic resistance and optimization of the sstructure can be done by the physical models and non-linear dynamic time domain calculation. On the other hand, necessary structure strengthening methods need to be adopted with the application of the organic arrangement of individual structure member. For example, the panel structure can be utilized as roof glazing structure. X-brace and bone-bracing strut can strengthen the stiffness of beams.

In conclusion, based on the existing biomimetic application, I will supply three potential structure types for my latter design. The simple force analysis would be given to illustrate the anti-seismic principle and its advantages for both architecture concept and structure stablization.

Seismic design Principles & Toolbox:

DESIGN PRINCIPLES

. lightweight mass

. Strength and Stiffness of structure, ductile material

. Preventation of torsion

. Building configuration: Regularity in plan and elevation

. Reasonable loadpath transfer

. Provide the building with second load paths and redundancy in structure

. Provide Adequate connection between the members

. Reduce the demand by dissipating energy, or increasing the building period

. Non-structure elements like windows and doors stablize the structure.

TOOLBOX FOR SEISMIC RESISTANCE

. Strengthen the connection between horizontal diaphragm and vertical shear wall

. X-brace to stablize the loadbearing members

. Add damping isolate member under the base to dissipate the earthquake energy.

. Add the building components with high ductile capacity like cable and strut.

. Add triangular or hegxagonal non-structure members like window or doors.

Biomimetric structure application	advantages	Potentials usage
STRUCTURE SYSTEM . Diatoms and radiolaria-inspired structures	hexagonal units and cast frame structure	roof structure, column
. Nods and rods framework	light, large span, stablility	roof, frame structure
. Shell structures	light, large span	roof
. Hierarchical structure	good loadpath,rib repeat	column, arch and vault
. Bone braces	good loadpath	arch frame
. Folding system	light, stable	roof and facade
. Tensile structure -- cable net system	light, tensile	tensile cable member
. Tensegrity system -- retractable roof	light, moveable	roof
. Umbrella structure	light, moveable	column and roof
. Tree column system	reasonable loadbearing	column
. Spine structure	tensile, dutile, stable	arch and vault
. Parabolic arch system	stable, good loadpath	arch
CONSTRUCTION STABLIZATION ELEMENTS . umbrella brace support	add more supportig points	truss & beam
. Fish belly Truss	Transform tension into support	cable truss & beam
. K-brace Truss	add more supportig points	truss & beam
. Post-trussing connection	Transform tension into support	cable truss & beam
TECHNOLOGY OF SKIN . Active light control system	energy saving, space	roof glazing, facade
. Addaptive sunshading facade	energy saving, space	facade
. Humid-sensitive skin	space	roof glazing, facade
. breathing Envolope	Energy saving, space, ventilation system	roof glazing, facade

MATCHING AND RECOMBINING PROCESS OF STRUCTURE DESIGN

Seismic design Principles & Toolbox:

DESIGN PRINCIPLES

. lightweight mass

. Strength and Stiffness of structure, ductile material

. Preventation of torsion

. Building configuration: Regularity in plan and elevation

. Reasonable loadpath transfer

. Provide the building with second load paths and redundancy in structure

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Biomimetric structure application

STRUCTURE SYSTEM

. Diatoms and radiolaria-inspired structures

. Nods and rods framework

. Shell structures

. Hierarchical structure

. Bone braces

. Folding system

. Tensile structure -- cable net system

. Tensegrity system -- retractable roof

. Umbrella structure

. Tree column system

. Spine structure

. Parabolic arch system

CONSTRUCTION STABLIZATION ELEMENTS

. umbrella brace support

. Fish belly Truss

. K-brace Truss

. Post-trussing connection

TECHNOLOGY OF SKIN

. Active light control system

. Addaptive sunshading facade

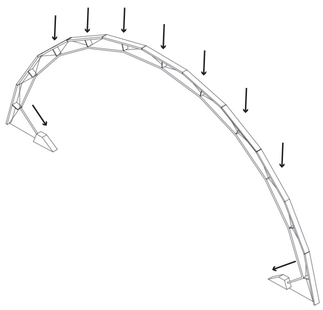
. Humid-sensitive skin

. breathing Envolope

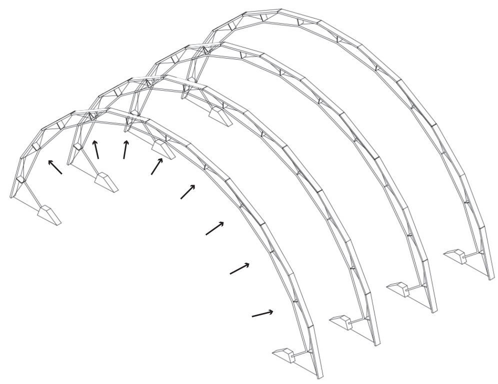
7.Conclusion: Proposal For New Constructions

7.1 Structural Proposals

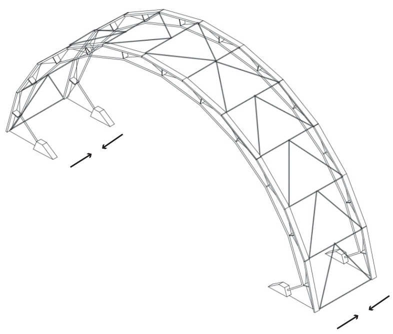
1. Fish-belly beam composed arch structure:



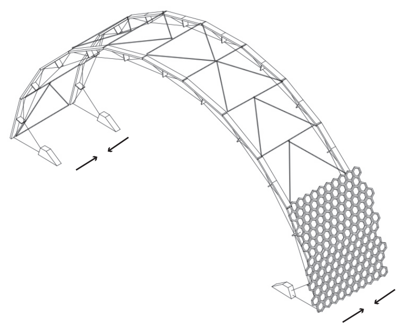
Windload and gravity on the arch



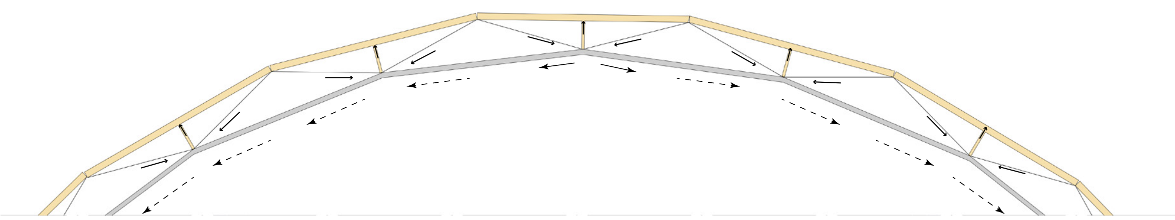
supporing struts of the beam



Lateral triangle brace between arches



Hexagonal panel skin as secondary structure

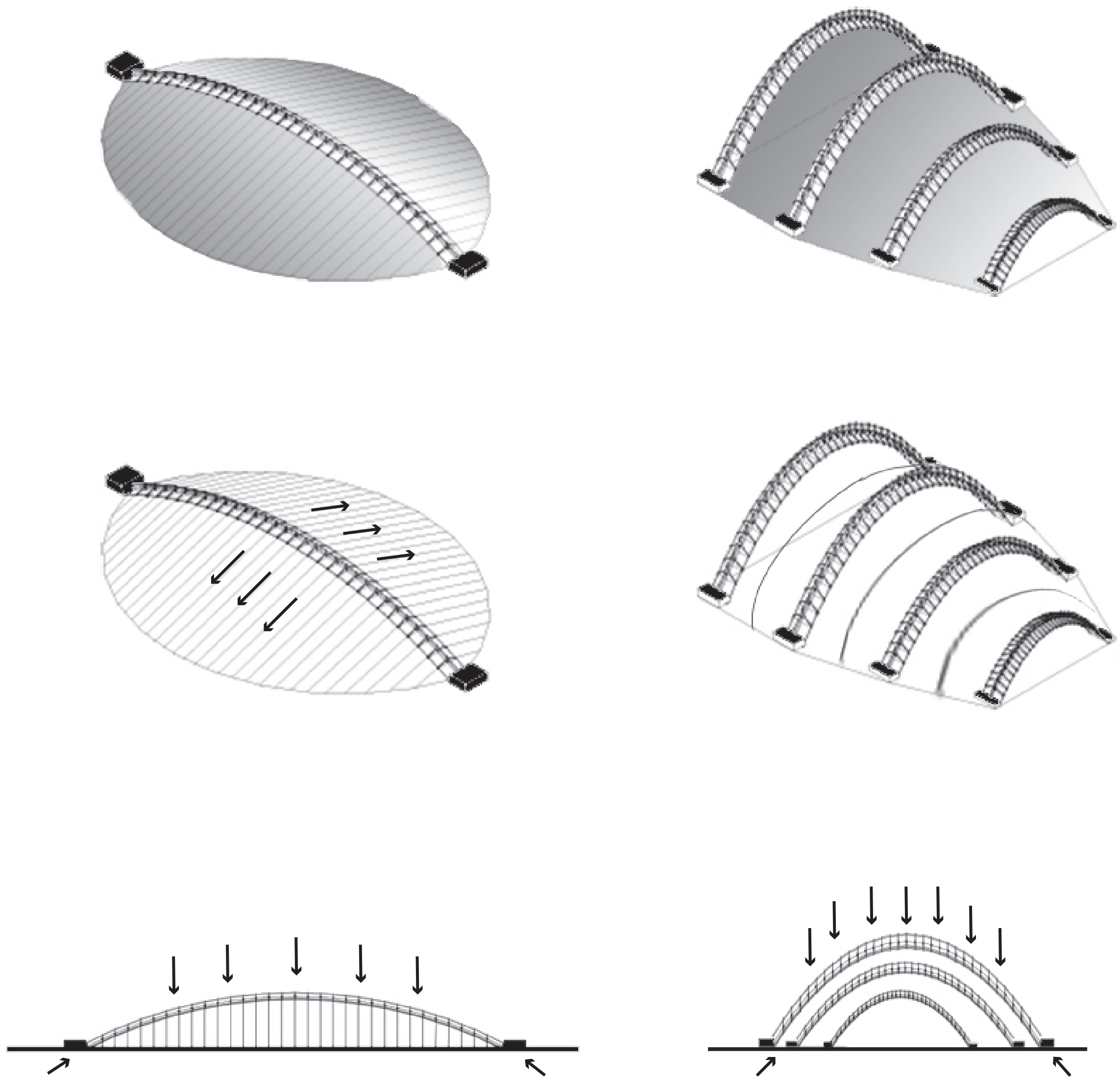


The force analysis of structure

figure 99. fish belly beam supported arch

Fish belly beam replicates itself one by one, tranforming the tension of cable into the supporting force. The triangle braces between each archs provides the lateral force. Simutaneously the hexagonal skin is the secondary structure also offer additional stablization.

2. Spine structure with guyed support



One arch in middle

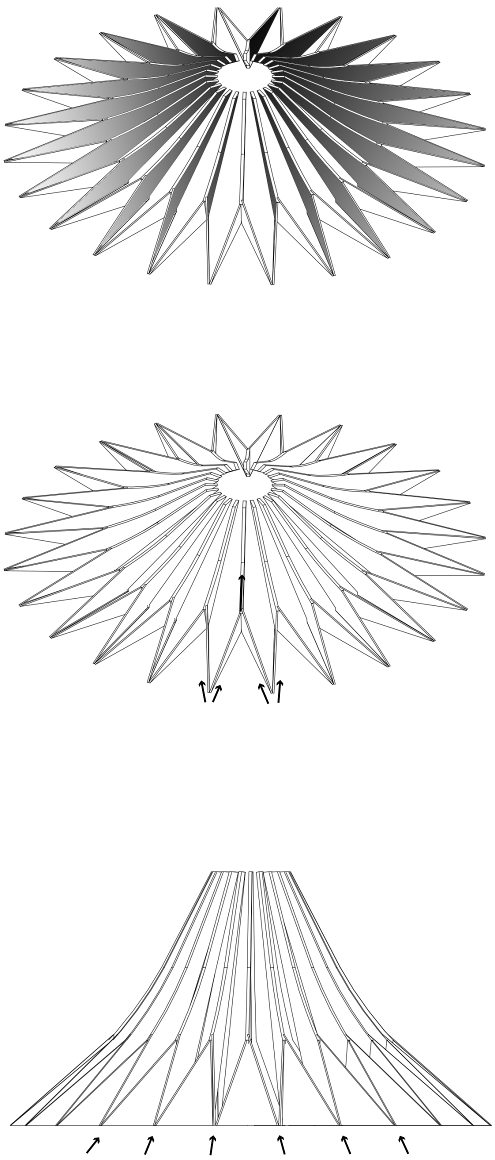
Parallel arches of various heights

figure 100. spine arch

The spine-arch is an integrial structure system consisting of both tension and compression of members. The central struts provide the supporting force between each units and surrounding cables offer tension to stretch the whole arch.

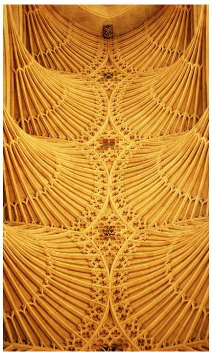
3. Hierarchical tree structure

arches arranged in two dimensions



Hierarchical tree structure

figure 101. tree structure

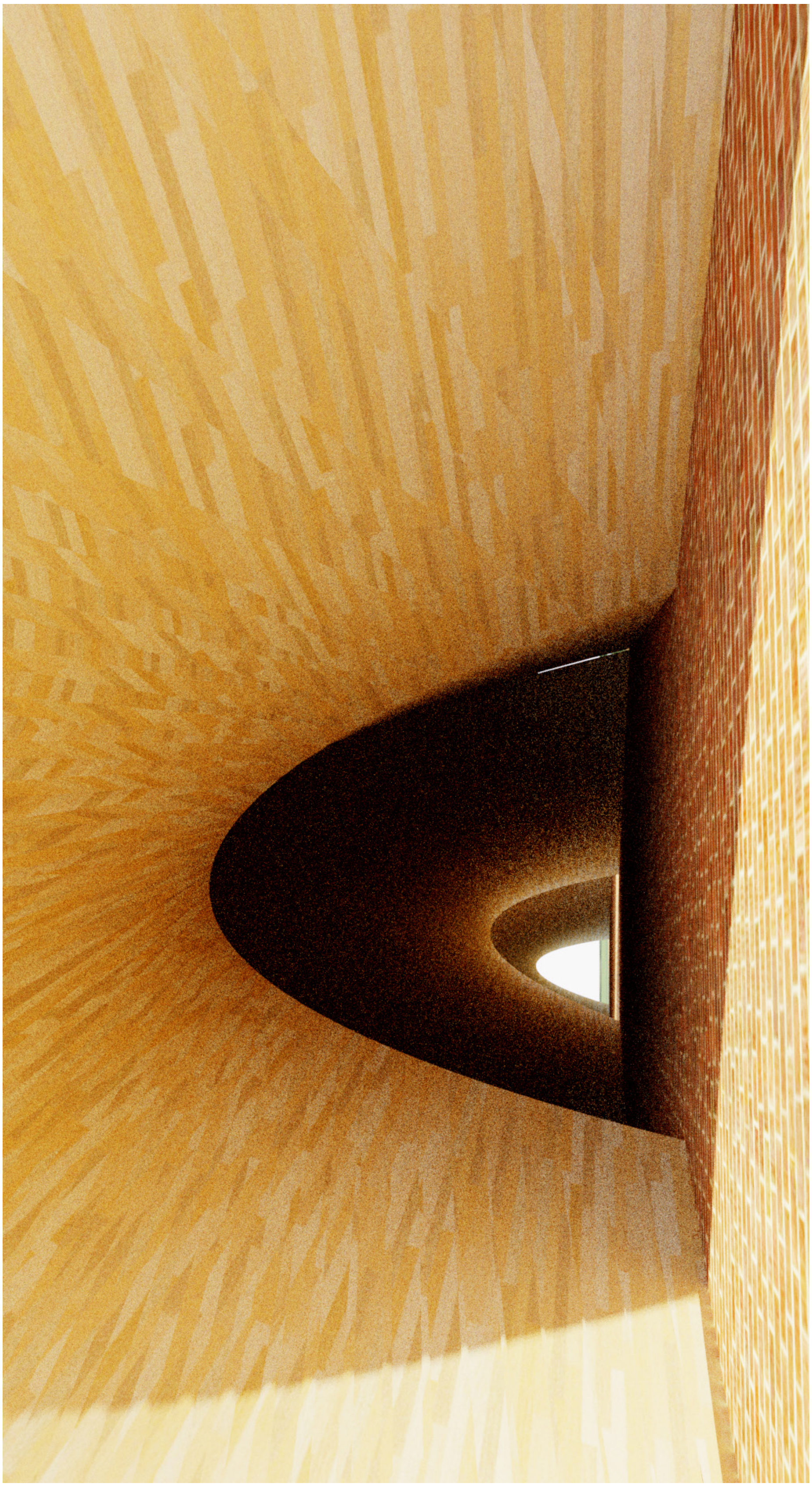


The hierarchical tree columns form into a bunch structure to support the roof. The branches of support stand in a circle.

4. preliminary design

Living pavilion with parallel arches

Interior Perspective



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