Guideline to Include Structural Factors in Developing Morphogenesis Operations of Architecture

Development of the 2D projection on 3D complicated geometry

Light and soft structures in which people do not die even if they collapse

Little by little, learning Great Nature

Morphogenetic operations of structure in architecture have advanced into the phase where structural elements also serve as environmental elements. Some of them will be developed by the following practices:

- **Dynamics Operations**: Single structural design method used for diverse forms based on dynamics
- **Geometry Operations**: Choreography of complicated geometry
- **Experimentation**: Physically sensing the operation processes that appear in workshop scale structures

Structure in Architecture is appearing diverse forms composed of diverse materials, constructed by diverse methods, and exposed to diverse impacts.

If we can compose a single structural design method for those complicated targets, we would be able to design more material oriented forms based on dynamics, geometry, craftsmanship.

It will also be valuable for the situation that we are now in – attempting to design and construct forms so complicated they are too difficult to even draw.

We are learning little by little about natural phenomena such as the vibration of the ground, water and wind flow, optical permeability of vegetation, porosity of insect bodies, buckling phenomena and the plastic state of material.

- **Dynamics Operations**: Approach from Transparent Glass, Resin Structure

*Stained Glass Structure*, Design & Research: Jun Sato Laboratory, the University of Tokyo

The *stained glass* panels are made by fixing glass in a slight metal frame, which represents the diverse forms in the manner mentioned below.

As the cushioning materials inserted between the glass and metal frame are required to be resistant to UV damage, we are using *tin* plates which we found to be effective.

![Stained Glass Structure test specimen](image1)

![Pop-up Stained Glass using brass frames](image2)

Left: *Stained Glass Structure* test specimen
Right: *Pop-up Stained Glass* using brass frames, Workshop 2012, Jun Sato Lab

This structure is representing a design that can take on diverse forms and are subject to the diverse phenomena:

- Composed of multiple materials.
- Composed of bar and plate elements.
- The optimized framework pattern existent to make it stronger using curved line elements.
- Elastic behaviour of the tin plate while in a plastic state.
- Algorithm to describe plastic hinges, which also describes buckling behavior.
Mutual buckling resistance between the glass plates and the steel frames.

The development of the algorithm mentioned above is now under investigation using the condensation of the eigenvalue equation of buckling. As we can see it is sufficiently complex composite to develop a structural design method, when completed, it can be adopted for many of other structures.

**EXTREME NATURE, Venezia Biennale 2008**
Architect : Junya Ishigami
Structure : Jun Sato
Slight, rigid frame structure using ultra high strength steel with glass walls acting as tension bracing.

Heat cambering of the steel is an important process in the fabrication of the structure as it reduces deflections as well as bending stresses.
Development of “Manual Form Optimization Software” is contributing for optimised location of columns.

Screenshot of form optimization software

*Iz House*
Architect: Sou Fujimoto
Structure: Jun Sato
Stacked structure of glass and acrylic resin walls.
A structural analysis model was also developed for seismic response analysis.

*Approach from Manually Operated Form Finding Software*

*Community Centre, Kawatana Onsen*
Architect: Kengo Kuma
Structure: Jun Sato
Polyhedral form generated by adjusted position of nodes.
Development of software for form finding under several load combinations such as gravity, seismic load, snow and wind. The parameter to be focused will be safety ratio, energy absorption.
This form finding software is applicable to various shapes as Free Curves, Stacked Clusters, Branched Tree, Randomly Located Columns, etc.

The next issue, some examples of the craftsmanship is necessary to generate these structural – environmental elements. Some of them shown in the following examples of mesh tectonics.

- Approach from Steel Forms based on Welding Technique and Operation of Buckling Phenomenon

  * Research Building, Hakodate Future University
  * Architect: Riken Yamamoto
  * Structure: Jun Sato
  * Steel mesh structure composed of vertical and diagonal elements.
  * Welding technique and reforming technique is necessary to fabricate these mesh.
Tsuda Veterinary Clinic
Architect : Kazuhiro Kojima / CAt
Structure : Jun Sato
The shelf shaped structure with 6mm plates, without backboard by controlling 3 dimensional buckling.

- Approach from Wooden Structure Developing Traditional Connection System Kigumi

Communication Center of Local-Resource-Utilization, 2010
Architect : Akiko Takahashi, Hiroshi Takahashi / Workstation
Structure : Jun Sato
Thin laminated timber structure inspired by bamboo baskets.
The timber bands can be woven in various directions and the members follow a geodesic line of surface.

Prostho Museum Research Center
Architect : Kengo Kuma
Structure : Jun Sato
1st Experimentation of “Kigumi” with Kengo Kuma
Timber 3D grid structure without metal fixings at joint.
Starbucks Coffee in Dazaifu
2nd Examination “Kigumi” with Kengo Kuma
3D diagonal grid acting as a hunched portal frame.

Sunny Hills in Aoyama Tokyo, 2013
3rd Examination of kigumi – timber joints without metal fixings with Kengo Kuma
Compared to Prostho, it has evolved into a very complicated geometry. It is difficult to tell how the elements are overlapping and how they should be carved just by looking at 3D images on a display.
Thinking about these operations of complicated geometry, we should develop a suitable way of projecting onto a 2D display.

Considering the geometry operation, this system can be composed as follows:

Local State (shape of components and connection type):
Component with complicated but singular shape, with no parameters.
The connection type is singular with no parameters.

Growth Process
The growth process will be easy, and any global shape can be generated.
As one of the developable operations, a random operation can be composed as follows:
Growth process can generate many random global shapes, and each shape is evaluated individually. Finally a
single shape is then decided upon. This method is applicable to many systems but it has limited convergence.

When the global shape has been composed, we can estimate certain values:
- Structural dynamics values such as safety ratio, strain energy
- Environmental factors
- Space volume

In this system, when the units were connected constant porosity is guaranteed, which is useful when thinking about light, wind, insulation, etc.

In this case it is easy to compose a feedback process:
- Information from the global shape, such as points of weakness, is fed back into the system and units for reinforcement can be added.

It indicates when we have a target global shape, we already have a way to compose the local state. As it is easy to make the feedback process, an iteration process is therefore also an easy operation of geometry.

● Geometry Operations: Choreography of Complicated Geometry

“¿-cube”, Design & Construction: Ken Yokogawa Laboratory, Nihon University, Structural Adviser: Jun Sato

Like particles gathering into a protein molecule, 60 mm cubes made of hemlock spruce are connected by “¿-inverted question” mark shaped eye bolts.

The structure gradually changes from a hard structure at the base to a soft membrane-like structure on the roof.

The distance between nodes should be the dimension of the cube with factors of $x \times 1, x \times \sqrt{2}, x \times \sqrt{3}$.

In this case, the operation can be composed as follows:

- **Local State**: Particle with simple and singular shape with no parameters.
  - The connection type is simple but the angle coordination of the particle may be the parameter.

Almost any global shape can be generated but, the growth process will be complicated.
Adding a single particle: difficult but hard and strong
Adding multiple particles: easy but soft and weak

When the global shape has been composed, we can estimate some values:
- Structural dynamics value like safety ratio, strain energy
- Environmental factors
- Space volume
- Porosity;

In this case it is complicated to make a feedback operation:
When we want to add a cube, the distance between the nodes might become a limiting dimensions.
On the other hand, if the distance to be spanned is found to be outside the cube’s dimensions, we can add multiple cubes to span that distance.

However, if we can understand the relationship between the local state and the target global shape based on reinforcement, stiffness, curvature, porosity, we can develop growth, feedback and iteration processes.

*Different Brick, Exhibition Real Size Competition 2013*
Design & Construction: Yusuke Obuchi Lab, the University of Tokyo
Structural Adviser: Jun Sato Lab

Masonry structure composed of ellipse shaped bricks.
The bricks are cast using cone shaped moulds. The moulds were soft enough to be deformed, so different ellipses could be generated from the same mould.

*Ellipse packing* is a very complicated geometric problem which is solved by finding the solution of simultaneous quartic equations. These are developed using the conditions that the length of circumference must be identical and every adjacent 2 ellipses should have single intersection. Here we proposed an approximate solution.
In this case, the operation can be composed as follows:

**Local State:**

- Particle has a simple shape but it has the parameters of cone type and cone deformation. The connection is simple and singular without any parameters.

Not every global shape (surface) can be composed. This will be limited but the limitation should be considered as a characteristic of this system.

Growth process will be simple and easy.

Another estimation other than those mentioned above will be the compression state, which necessitates that the final shape should be developed with no tension arising.

In this case it is complicated to make the feedback operation, mentioned above.

If we can understand the relationship between the local state and the target curvature of the global shape, we can develop the growth, feedback and iteration processes.

- **Experimentation:** Morphogenesis appearing in workshop scale structures

Through performing design-build processes like workshops and exhibitions, we can learn how to develop morphogenetic design based on geometry, materials, dynamics, craftsmanship, site matters and the spirit of engineering. It is also necessary to develop a way of running a workshop in a matter of a few days.

**Creative Structures:** art4d workshop in Bangkok, 2012

Using local materials, 4 teams constructed pavilions of 4 to 8 m spans, in only 2 days.
Experiments on Geometries and Dynamics: workshop at Stanford University, 2014

Students studied 2 categories and materials of my proposal for 2 days in February and constructed it in 2 days in May.

Category 1, Tensegrity Volume: Tensegrity to have “3 dimensional” volume.

Left: “3D” Tensegrity Volume composed of 18 galvanized bars and lengths of stainless cables (photo by Nick Xu)
Right: Tensegrity model, Pop-up Tectonics model

Dimensionality of Tensegrity

It is hard for a basic tensegrity to find a stable shape as a “3 dimensional” volume as it is not a modular system that can be made up of standard units.

It is hard to find an exactly foldable shape when using thick plates. Extensions of sides should cross at the same focus point. Panels belonging to the same layer should not be overlapped when they are folded down and the total angle of the sets of panels, which coupled, should be same.
Geometrical conditions can be recognized by studying the model. For example: from the top view, a ridge line or thalweg line should be seen to lie on a *straight line*. When the loop is connected, panels have twisted shape like a Mobius loop and it is hard to find the focus point.

- Workshop Scale with Copper, Aluminium, Carbon, Membrane

*Copper Shell for “Earth : Material for Design” by The National Museum of Emerging Science and Innovation*

Design: Jun Sato Laboratory, the University of Tokyo

Considering the total energy consumption for this structure to appear, we discovered the energy consumption in processing the copper shell by hammering was only 7%, of the total energy, while 93% for manufacturing copper plate.

*Balloon*

Architect: Junya Ishigami
Structure: Jun Sato

Aluminium “balloon” of 14m height, weighing roughly 1 tonne.
The balloon with aluminium lattice endoskeleton, filled with helium gas.
“architecture as air” in Venezia Biennale 2010
Architect: Junya Ishigami
Structure: Jun Sato
Rigid frame structure composed of 0.9 mm CFRP columns, 1.2 mm CFRP beams, and invisible braces made of 0.02mm polyalylate fibers.

“MOOM” (Membrane Oom)
Design & Construction: Kazuhiro Kojima Laboratory, Tokyo University of Science
Structure: Jun Sato
Tensegrity structure composed of membrane and aluminium pipes.
Length 26 m, Span 8 m, light enough to be lifted by 40 persons.
It was rebuilt 3 times for some events in Tohoku area, where the huge earthquake happened.
• Light and soft structures in which people do not die even if they collapse

Through workshops like this, I feel we are thinking about structures that are adequately light and soft such that people do not die even if they collapse. I hope this does not end just as a fantasy.

Japanese Umbrella, representing a light and soft structure made of washi paper coated with linseed oil for waterproofing. The frame is slight and woven with colorful string to prevent buckling.

• Little by little, learning Great Nature

Everytime a disaster happens, we engineers feel:

it is impossible to know everything about great nature,

it is impossible to control great nature,

but if we could know a little bit more about the vibration of earthquake, a little bit more about the flow of water,

we could save a little bit more people.

This will be our mission and dream.