PARAMETRIC MODELING AND STRUCTURAL ANALYSIS FOR WOODEN BOARD STRUCTURE USING NEW COMPUTATIONAL METHODS

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Abstract- In architectural engineering, Board structures have economical and constructional benefits. They are used for heavy loads and large spans structures as they exhibit higher stiffness and smaller deflection.But the traditional architectural modeling and structural analysis processes cannot be automated. This paper will present an approach to optimization of efficiency in Board structures. The work presented in this paper is explanation of the key link of process of parametric architectural design. This is a result of generating parametric structure system and structure logic of the final design form by researching the stress analysis and structural analysis of wooden Board structures. The paper first introduces the concept of parametric design and a kind of modeling platform, Grasshopper plug-in of Rhinoceros. By referring to the project of the Ongreening Pavilion that keeps concept of green technology as a study case to research architectural form, energy conservation, structure bearing and construction, a kind of parametric form with board structure pavilion is inspired to generate for explaining the rationality of practical application. Then, the main process of the parametric board structure design will be described, which includes the rationality of the different architecture forms, selection of key input and output parameter, script programming, structure system analysis(Karamba), optimization of the model by genetic algorithm and generation of construction plan and so on... On the other hand, the selection of materials is also a focus in this paper, the board structure is generated to achieve a new web-based platform for green building. For the initial design concept, the wood used is Japanese cedar that has a specific size.

Keywords- Parametric modeling, Board structure, Structural analysis, Japanese cedar

I. INTRODUCTION

The rapid development of modern computer technology has brought revolution in the architecture industry(He and Wang, 2012). The key idea of parametric design is changing all elements of architecture design into variable of function. People can get different architecture design schemes by changing functions or algorithms. In the parametric system, the structural model is built just like building blocks. Even if the architecture parameters change, the structural model can change in a timely manner through inherent logic. At the same time, the change of floor information, material consumption, single area, etc. can be apprehended at a glance. For the fixed construction scheme, the parameterization can be based on the existing building skins, establish models of different structural systems fleetly, optimize the corresponding structural system gradually, and refine to the structural components, materials, loads and other information.

II. RHINO AND GRASSHOPPERPLUG-IN

Grasshopper plug-in provides a parametric technology integration platform for architectural designers in Rhino. It has many tool modules, and also provides rich plug-ins interface, increase the designer ' s creative freedom through enhanced interactivity. Grasshopper is a kind of visual node programming platform, the advantage of visualization node programming is designers can build program by using various controls that are provided by software, which greatly improve the structure design of non computer professional background of the software development work efficiency(Zeng et al., 2011). “Node” is the encapsulation of various program that commands into nodes with certain functions, forming a certain logic script process through the association operation between the nodes, the modular programming method emphasizes the data association between each part of the program, the structure design of the relationships between the various parts of the complex structure model can grasp clearly(Fu et al., 2012).

III. KARAMBA PLUG-IN

The Karamba plug-in provides fast finite element analysis, apply to the small-scale architectures with complex structure perfectly for Grasshopper, which embed in 3D modeling software Rhino. In comparison to traditional structural analysis methods, traditional way on geometric objects like points, lines and surfaces which needs to be placed manually by designers that makes time-consuming and error-prone to incorporate changes. On the other hand, most of parametric structural analysis software lake bidirectional information transfer between geometric model and finite model. It causes they can not interactive calculate and when designers try to change the features of models and display of static response in many aspects, it will be a waste of time. In Karamba, the above describe problems are avoided, the advantage of this new computational method is the calculation core as a dynamic link library which

makes it easy and fast to access and control all aspects of the FE-model via scripting languages like C# which is the language of choice within Grasshopper(Alegria et al., 2012).

IV. MATERIAL

4.1. Wood

Choosing wood as the materials, because as an architecture material, wood has many advantages compared with concrete and steel, it is widely used in residence, commerce and public buildings in developed countries because of its material features, structural characteristics and aesthetic value. It is a living material which has specific geometry with high levels of manufacturing(Tamke and Thomsen, 2011). In addition,

The use of wood contributes to the prevention of global warming through the storage and emission control of carbon dioxide. For example, if we use lots of wood in houses and furniture and keep using them carefully, it will keep a lot of carbon fixed in the wood for a long time. It helps reduce the concentration of carbon dioxide in the atmosphere. Also, compared to iron and aluminum, wood requires very little energy for manufacturing and processing. If using wood instead of these materials, it leads to energy savings. Ultimately, if it is used as energy instead of fossil fuel such as petroleum, the emission of carbon dioxide can be suppressed further.

4.2. Japanese cedar

Japanese cedar is a shade tolerant species that can withstand frost. It occurs in mountains and hills in areas of higher rainfall in south and central Japan but is rarely spontaneous. In the past, Japanese cedar is cultivated as an ornamental in Japanese gardens for centuries, and by the time people realize the advantage of using Japanese cedar as a building material. The advantage in using Japanese cedar is they are very fast growing so that the price is affordable. It is easy to get because its habitat, the timber factory, workshop and retail seller is available prevalent in the whole area of Japan. This thesis is intended to be adopted Japanese cedar 35mm thickness.

V. STUDY CASE

5.1. Introduction

Ramboll Computational Design were approached by Ongreening Ltd to assist with the design of a temporary pavilion to mark the launch of their new web-based platform for green buildingin Fig.1. The pavilion structure was made from timber at Eco-build 2014 in London, a public exhibition on sustainable building (John and Will, 2014).



Fig.1. Ongreening pavilion

5.2. Parametric form-finding

The model is based on a plan drawing with a central circular focus point and an elliptical, these primary laths were initially assumed to be planar, vertically oriented and set out radially on plan. Put a point in an elliptical, create radial lines, then use dynamic relaxation of Kangaroo plug-in to get the resultin Fig.2.

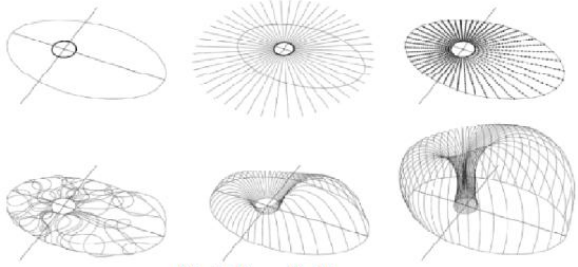


Fig.2. Form-finding process

5.3. Structural analysis

The loads of structural analysis of the model was included self-weight and several impose loads as prescribed by Eco-build. Euro-code 5 was used to calculate the sum of bending stresses of lath that is required. The result shows 6.5mm thickness Finnish Birch plywood is the best choice of high bending capability and high strength.

VI. BOARD STRUCTURE MODELING

6.1. Concept

Board structure are defined as a combinations of a flat flange plate, or deck, and a system of equally spaced parallel ribs, or grid, that may be arranged in either orthogonal or skew assembly with monolithic inter-sections. They are also known as two way ribbed flat slab and it includes recesses between the ribs. Board structure also has economical and constructional benefits. They are used for heavy loads and large spans structures as they exhibit higher stiffness and smaller deflection(Naziya and Chitra, 2014). As a result, Board structure has been widely used for office buildings ,hotels, auditoriums, vestibules, theatre halls, show rooms of shops where column free space is often the main requirement.

6.2. Parametric form-finding

The first step in creating a Board structure is to create a base surface. Ideally it is better to have a surface

that does not have exaggerated peaks and valleys as this will result pieces that are too thin. The surface itself can be any size, but eventually it will need to moved into a laser cutter. The laser cutters in Architectural Technology Department are limited, so it is best to accommodate the model. Then at this point the initial contours in both the X and Y axes can be created. To begin, create a layer for the X-contours, and Y-Contours. Use the Surface Offset command to give the surfaces thickness, this thickness is determined by the thickness of the material being used. The further operation is using the Boolean Split command on both the X and Y axes extruded contours. This will result in a slots that allow to join the parts. Create labels with the text command that will be etched on. X-Axis contours can be labeled A0, A1, A2in Fig.3...Fig.4 shows the all Batteries of parametric generation process of model.

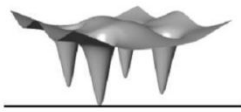
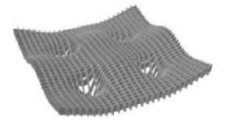
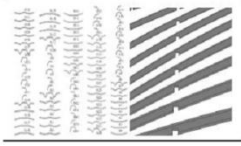
Geometry	Batteries(main)
	SqGrid: 2D square with square cells Slider: Numeric slider for single value Pt : Construct a point from coordinate Srf: Contains a collection of surface
	Project: Project a point onto shapes CP: Find closest point in a collection Replace: Replace certain items in a list SrfGrid: Create a surface from points Preview: Customized geometry preview
	BBox: Solve geometry bounding boxes BBX: Solve intersection events for brep SrfSplit: Split surface with bunch curve Volume: Solve volume properties
	Z: Unit vector parallel to the world axis Factor: 0.8 Extr: Extrude surfaces along a vector BRep: Poly surfaces
	Box Corner: Extract the corner of box PFrame: Generate a number of spaced Shift: Offset all items in a list Sec: Solve intersection events Clean: remove all null and invalid items SDiff: Perform a solid difference
	Planar: Create planar surface from curve Area: Solve area properties for breps Rotate: Rotate an object in a plane Series: Create a series of number Tag: Represent a list of text tags Text Tag 3D: Represent 3D text tags

Fig.3. Parametric generation process



Fig.4. Batteries of parametric generation process of model

VII. BOARD STRUCTURAL ANALYSIS

7.1. The strain energy

The calculation process is as follow for large span structure: divide the mesh manually and disperse the surface into lines according to fixed architecture skin, import the grid to calculate software to give the section, the loads, the specified bearing and so on for bars, then, the structural model is calculated to adjust the cross section of the components. If the architecture surface changes, we need to repeat the above process.

In the field of statics, structure is to transfer the force to the destination, which means that the structural engineers guild the flow of the materials through assembling. And which route is the best solution is one of the focuses of this research.

Externally, the work will be done by the external force is stored in the structure as the form of strain energy, the strain energy(C) of the structure is equal to the product of the external force(P) and deformation(U):

$$C = \frac{1}{2} PU \Rightarrow \frac{1}{U} = \frac{P}{2C}$$

1/U is the structural stiffness, assuming that the load is a constant, the C is more smaller, the structural stiffness is more greater. Therefore, under the same load, the minimum strain energy indicates the maximum stiffness.

From the inside of structure, the strain energy(C) is the integral of the strain energy density(c) to the volume(V):

$$C = \int c dV \Rightarrow c = \frac{1}{2}\sigma\varepsilon = \frac{\sigma^2}{2E} = \frac{f_y^{\,2}}{2E}\lambda^2$$

$$\therefore C = \frac{f_y^{\,2}}{2E}\int \lambda^2 dV$$

In formula, σ is stress, ε is strain, λ is stress ratio. The stress radio represent the stress level of the structure, and the volume of material used is the amount of material used in structure. The strain energy reflects a relationship of material used. When the amount of material is certain, the smaller the strain energy is, the lower the stress ratio is. When the stress ratio radio is certain, the smaller the strain energy is, the less material used.

In summary, if we take the amount of material to evaluate the efficiency of structure power transmission, the strain energy can be used as indicators of force transferring efficiency.

7.2. Method of analysis

It is important to note that Karamba only works on the lines that connected each other. Set of lines are projected onto a surface, the cross section optimizer determines the appropriate cross section for each element. Various concepts for the analysis of Board structure from which few are as listed below: element, support, loads, material, cross section, assemble, analyze and visualize.

7.3. Element

The lines that were made in the main geometry, there are many different lines show the direction of skin based on its position. Line to beam: create beams with default properties from given lines, lines that meet at a common point are thus connection with each other, and Karamba assumes input to be in metersin Fig.5.

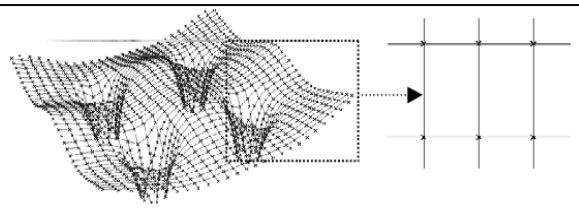


Fig.5. Center points in geometry model

7.4. Support

The next step is the determination of the points of support structure. Support will be defined on one or a set of points. Support positions can be determined in accordance with the previously planned loading scenarios. In this design proposal, the support is designed at the base of the building. Selection of the location of the point is done by creating a null of several members of the list. The rest of the members will be point of the location of the support. The number of support points is equal to the number of members or the division of the main geometry. In line with this system made parameter, then the amount of the support structure will change as parameters movingin Fig.6.

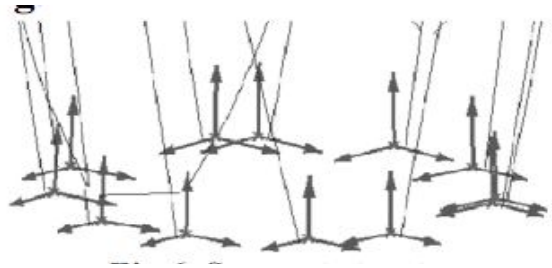


Fig.6. Support structure

7.5. Loads

Determining the point load and define the load. In the vertical loading, loading point is divided into two parts. The first is the starting point on the member which defines a heavy load of wood(gravitation). And the second is at the intersection of the members. For the amount of load, Karamba expects all force definition to be in kilo Newton (KN). On earth the mass of 100 kg corresponds to a weight force of roughly 1 kN. The exact number would be 0.981 kN but normally 1 kN would be accurate enough. Consideration is taken because the pavilion is not included into the live load in dwellings where specified criteria is 3 kN/m².

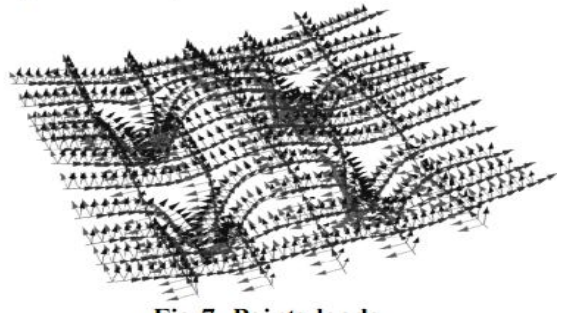


Fig.7. Points loads

7.6. Material

There are two kinds of input component to define material properties in Karamba. The first kind of component is the material properties used are common materials and embedded in the system. The second kind of component requests information of material properties in specific numbers, we need to set mechanical material properties manually. In this research, the material properties is to be defined manually, the component used is MatProps in Fig.8 as a part of representation of Japanese cedar material properties that can be seen in Table 1.

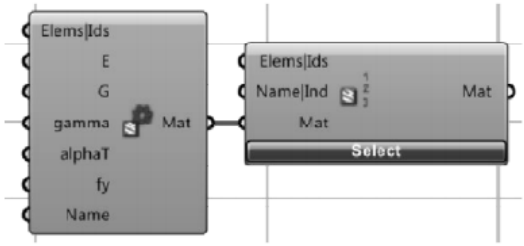


Fig.8. The component of definition of material properties

Elem Ids: identifiers of beams with identifiers to attach a material to.
E: Young's Model, kN/cm^2.
G: Shear module, kN/cm^2.
Gamma: Specific weight, kN/m^3.
Alpha T: Coefficient of thermal expansion, 1/℃.
Fy : Yield stress, kN/cm^2.
Name: The name of material.

Table 1: Material properties

Elem Ids:	Element
Young's Modulus:	960
Shear modules:	450
Specific weight:	39.5
Coefficient of thermal expansion:	0.000003
Yield stress:	1.3
Name:	Japanese cedar

7.7. Cross section

The next step is to define the cross section. In geometry and science, a cross section is the intersection of a body in three-dimensional space with a plane, or the analog in higher-dimensional space. Cutting an object into slices, creates many parallel cross sections. A cross section of three-dimensional space that is parallel to two of the axes is a contour line; for example, if a plane cuts through mountains of a raised-relief map parallel to the ground, the result is a contour line in two-dimensional space showing points of equal altitude.

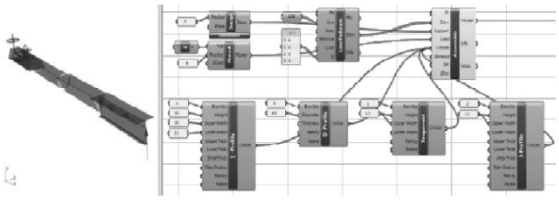


Fig.9. Cantilever with four different kinds of cross section

Karamba provides five basic types of cross section, such as circular tube, hollow box section, filled trapezoid section and shell section in Fig.9...

7.8. Assemble

When all information of structural properties is defined and completed, assemble them is next step. By watching Fig.10, point, element, support, load, cross section, material will be required to input. And use the Optimize Cross Section command for the automatic selection of the most appropriate cross section of beams. It takes into account the cross section load bearing capacity and optionally limits the maximum detection of the structure.

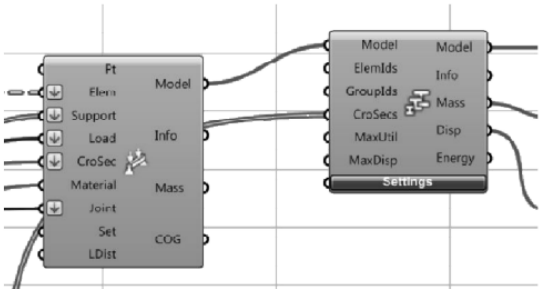


Fig.10. The algorithm component of section

7.9. Analysis and visualize

All structural information has been assembled, the next step is to calculate. Fig.11 shows a simple sample about Analysis command and overall information can only be analyzed when the command receives correct input data. Fig.12 shows the components analysis and results of Board structure. And the visualization of the model that has been analyzed to generate view. The final model of Karamba can be seen in Fig.13.

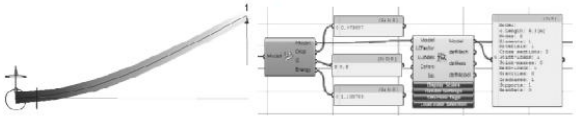


Fig.11. Simple sample

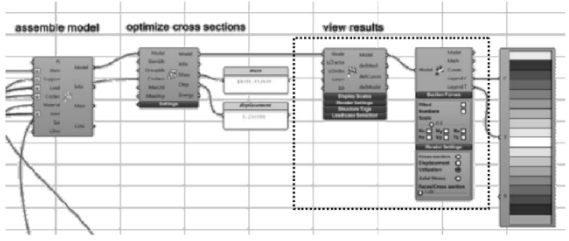


Fig.12. analysis and results of Board structure

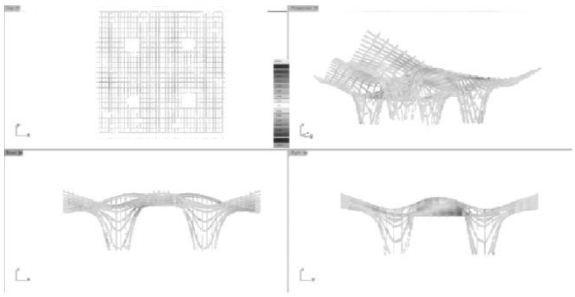


Fig.13. visualization

VIII. GENETIC ALGORITHMS

8.1. Introduction

The number of generations and design possibilities gained from the structural analysis process is the same with the main geometry generations. That is why the introduction of the basic and basic theories of structural optimization will be explained. Suppose that we construct a surface through various conditions and optimize the surface with the minimum of the structural strain energy. If there are ten parameters to control the surface, each parameter has 10 optional values. Then, there are 1010 possible solutions to the surface. For example, the enumeration method is used to find the optimal solution. It is feasible to consider the computational cost and the computation time.

Therefore, it is necessary to introduce the optimization algorithm to find the optimal solution or the approximate optimal solution in the shortest time. The genetic algorithm does not only belong to big data analysts and software engineers, but it's also needed by structural engineers. The generation of parametrically structural analysis is listed below:

$$10 \times 20 \times 2 \times 3 \times 3 \times 30 \times 20 \times 10 = 21.600.000 \ generation \ s$$

Genetic Algorithms (GA), first proposed by Professor J.Holland (USA) in 1975, is a heuristic search algorithm inspired by Darwin's natural evolution theory. The algorithm reflects the process of natural selection, that is, the fittest are selected to breed and produce the next generation. The operation process is initialized to individual evaluation, selection operation, crossover operation and mutation operation to determine the termination conditions in Fig.14, the operation process as the survival of the fittest in natural selection and survival of the fittest, only the selected individuals will pass on genes.

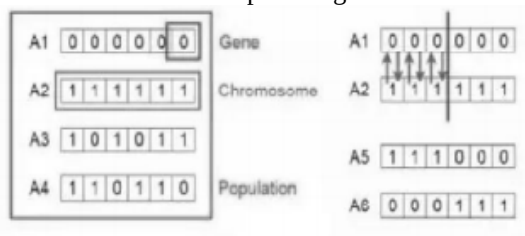


Fig.14. Genetic Algorithms

8.2. Case study

Fig.15 show a simple example of two-dimensional operations, introduced the principle of Grasshopper optimization module. The following figure shows a mountain model that contains two variables (approximately X and Y coordinates) that can change simultaneously. Find the coordinate values corresponding to the highest mountain peaks. At the start, the computer then spilled a whole lot of random points, and we assumed it was 100. Then select 50 points of higher position, and then arrange 100 points around them, you can know that the 100 points are closer to the peak than their previous generation. Repeat step by step until find the highest point. As an

example of the two-dimensional mountain peak optimization, the computer can not only compute two-dimensional variables, but also get the optimal solution when the initial variables are increasing and it takes longer time.

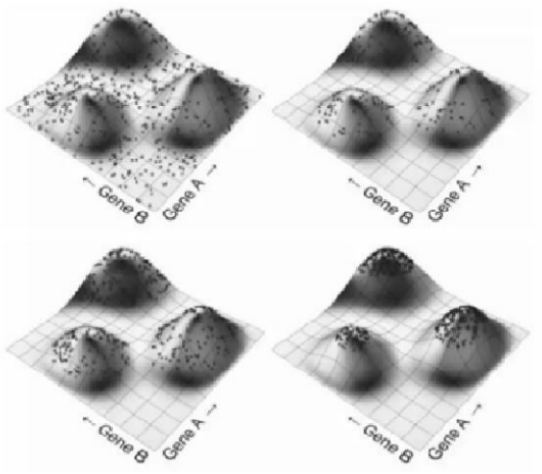


Fig.15. Simple example of two-dimensional operations

CONCLUSIONS

The paper has introduced, given examples and discussed the importance of early exploration of architectural geometry based on performance evaluations. A design method and a tool have been presented to support this process(Michela et al., 2010).

1. Conforming to the trend of rapid development of BIM and parametric design in architectural design, it is imperative for structural specialty to urgently require parametric modeling tools.
2. Generate Board structure simulation systems, analyze and compare deformation under different conditions.
3. The Board structure architecture form rapid modeling tool is programmed by using Grasshopper plug-in. The program structure is simple, the operation speed is fast, the effect of parameter adjustment can be previewed in real time, and the work efficiency of the structure engineer is improved effectively. For similar functions, engineers may refer to this procedure for development.

EXPECTATION

This paper has almost finished the parametric architecture form-finding and structural analysis of board structure by using a surface that is generated by Sinusoidal function curves. After the algorithm of the Board structural analysis is completed, the further plan is the genetic algorithms optimization, this process aims to get the maximum performance of stabilization.

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