20.2020
Building Structures Design
Spring 2020

Studio Instructor
Sam Conrad Joyce

Teaching Assistant
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Visting Instructor
Iori Kano
(Kyoto Institute of Technology)

Description

The Architectural Structure & Enclosure Design course introduces the interplay between design and physics. Looking at how buildings can be designed to be imbued with a sense for the forces and mechanics which dominate their forms in the real world.

The course seeks to fuse intuition and computation into a continuum of physical calculation which informs safe and environmentally efficient designs whilst supporting creativity. It does this by exploring the iterative process of model making, speculative testing and experimentation both physical and digital.

This is realized though the repeated action-based learning by doing with students working to build performance orientated structural models, firstly this is done live in workshops with a proposed 'toy' physical scenarios and linking to real work at various scales to explain the context and architectural relevance, then asking students to undertake structural inquires though fast prototyping. Their final designs in these sessions are then collectively tested, enabling students' exposure to a range of solutions to reflect on both the ideal performance requirements of the system and the relative success of each of the design to them.

The second phase then is taken slower more considered group design phase with students asked to create more refined solutions given more complex briefs and work over a longer period of a week using digital tools and more precise physical modelling. These final designs compete against each other in a more highly specified friendly competition. With aesthetics, construction elegance and performance traded off.

Ultimately a final project is undertaken combing the structures courses learning. Students are required to design, protype, simulate, and test a 1:1 full-scale structure that has to literally and figuratively stand up to the real world. One that is tested as a real structure would be to bring the students full circle that structures are real and tangible and ultimately impact the built environment.

Learning Objectives

The learning objectives constitute of the essential elements of a holistic understanding of the various ways in which contemporary building structures deliver services to occupants in a reliable, safe and efficient manner. The main learning objective will be the acquisition of an analytic understanding of the inner force flow of structural systems and a qualitative appreciation of the flexibility of these systems within the larger construction and with regard to architectural and performative requirements.

The objectives are for students to be able to: 1. Identify the range of loads and mechanical stresses present on building structures and their physical origin. 2. Measure the magnitude and aspect of these forces and characterize the behaviour of the building system under a variety of conditions. 3. Formulate a variety of viable strategies for a buildings structure. 4.Design and specify the materials, components and assemblies that attend to the set of performance requirements for best performance of a structural building system

Measurable Outcomes

The initial outcome will be for students to be able to articulately describe and understand the performance of a structural system, its function, its intended operational goals and its essential working elements. Leading them to be able to conceptualize an appropriate structural system and modify its form towards a desired performance with respect to a given pre-existing or open context and boundary conditions.

Students will be able to: 1. Explain in detail the correlation between the physical form and inner force flow of a structural system and the performance profile of that system. 2. Describe and quantify the behaviour of the structure at the component and system scales. 3. Derive and apply metrics for efficiency that consider the resource intensity of all aspects of the system. 4. Design a complete and integrated structural system for a

Figure 01: Interim and final models of the studio projects

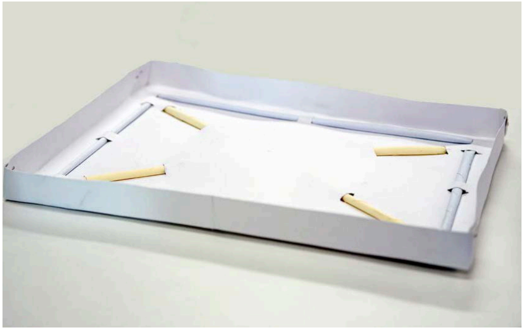
The geometry in a slab

For the first design and modelling activity one of the most elemental developments of architecture is explored. Before architects and formal planning most dwellings were simple single-story affairs with rudimentary walls and roofs. In the main these crude buildings could be constructed with little consideration for the forces in them. However, as civilisation grew, along with its conurbations, the desire to live more densely and thus vertically began, building levels through the use of floors and slabs. This additional complexity sparked the need for dedicated individuals with mastery in this field. Thus, the foundation of masons the precursor to architects. Almost in unison with this begin issues of safety, as we built up, so we increased the danger of collapse and thus consideration of structural safety. This goes back as far as 1750BC with the Code of Hammurabi stating the first formal liability for builders whose buildings collapsed influencing others.

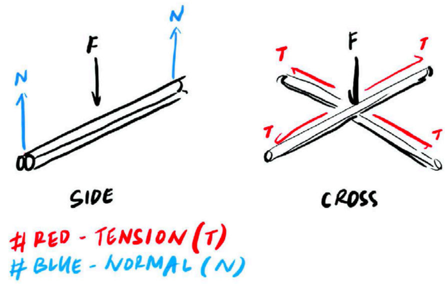
The assignment revisits this early floor slab technology and asks students to make and test floors built from first principle thinking and experimentation. The introductory workshop challenges first with making a basic spanning structure out of a single piece of weak A4 paper to understand the benefits of structural depth and geometry to overcome material weakness and buckling. Then rising the difficulty to look at how the paper can be cut and joined to introduce greater rigidity (stiffness) and fail resistance (strength), being careful to differentiate the two properties. This basic study introduces the idea of a design lead experiment; by giving the test apparatus of a given span and uniform loads. The solutions were then calibrated to realise the observed demands with limited resources.

This challenge then culminated in providing a fixed inventory of card and paper as the basis of a two-way spanning slab similar to modern column supported rooves and floors. This extended challenge requires deeper thought and more precise fabrication. It is then tested together by taking each and loading each one progressively, firstly to a given load to see the deflection then to failure to again reinforce the idea of serviceability (stiffness) dominated design and ultimate limit (strength) dominated design.

During the assignment they are asked to document and reflect on their design and experimentation process. So that they might begin to link their intuitive design thinking to a more intentional mode of consideration where the structural behaviour may be designed to counteract any observed or perceived issues.



Chng Kai Jiunn, Loo Wei Sheng Dixon, Syed Faizaanullahv

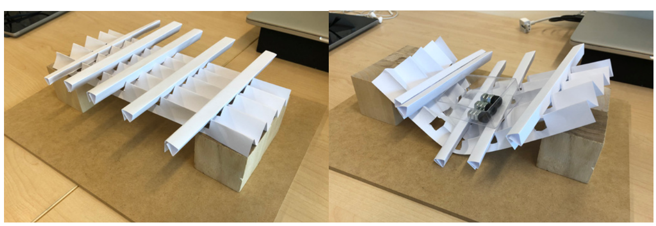


Chong Yuan Wen, Yang Funing, Melvin Wong WeiJie

Group 1 Designs

Group 2 Designs

Load Test

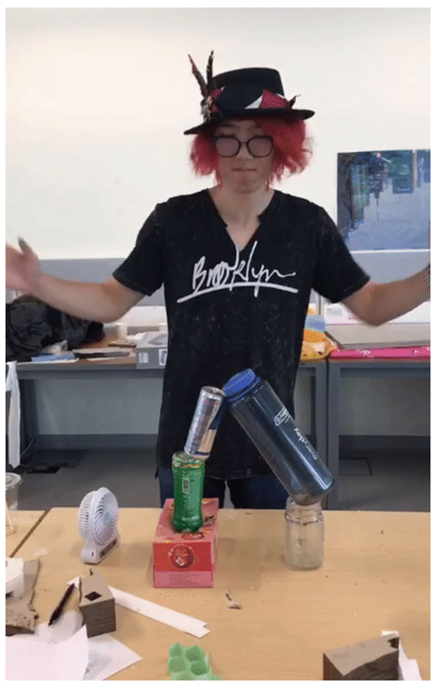


Destruction Test

Balance

Moving beyond pure intuition-based fabrication and experimentation. This next session aims to introduce a more considered categorical approach to loading basic structural forces, taking a simple Meccano like pin jointed system and showing how different forces effect the equilibrium and movement of a basic elemental structure. Developing a numerical approach in calculating these forces to obtain equilibrium. Simultaneously 'playing' with the physical model to understand though tactile feedback and manipulation the forces. Continuing on to appreciate the reciprocal nature of combining these simple assemblies to make a hybrid structural system, highlighting their interlinked behaviour to obtain equilibrium and understanding though this how forces can be broken down into cartesian components, as well as appreciating ideas of moments and torsion though feel.

This workshop is then capped with an equally playful assessment to develop a personal response to Heath Robinson's work 'How to Live in a Flat' in 1936 which used comics depicting precarious structures and systems to challenge the then new modernist ideals of space limited apartment blocks. Perhaps to answer these concerns with fun and develop a sense of structural innovation for its own sake. Also inspired more recently by OMA's Maison A Bordaux an important collaborating with feted structural engineer Cecil Balmond. Where a buildings structure is used to illicit surprise and visual excitement from how it functions. The assignment was for student to develop their own mini stable but seemingly precarious balance structures from assemblages of common objects to challenge the viewer and themselves. Presented as small animated '.gif' to show off the balancing behaviour. There was a contest with a class voting for which ones were the best technically and stylistically.

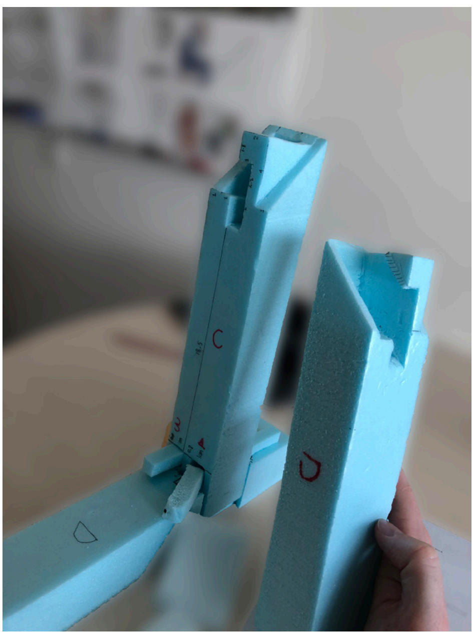

Brooklyn

Foam Node

Jointing is the focus of the fourth assignment and workshop. Developed in collaboration with Professor Iori Kanao from Kyoto Institute of Technology it investigates a number of topics in unison. Fundamentally it concerns the structural design of moment bearing structures commonly used in many framed buildings, how forces are calculated and resisted. However, it also offers an opportunity to look deeper than the general configuration towards detail design. Simultaneously it investigates Japanese timber craft, thinking in a volumetric way and acting though subtractive stereotomy.

The aim is to make stiff well-fitting re-constructible nodes, purely out of one material. During the workshop a simple one axis tension and compression node is requested, challenging students to think about how to resist these opposing forces in the same element. Students are given square section lengths of Styrofoam to experiment with, whilst being introduced to concepts of shear, local crushing and stress over an area. Simultaneously getting a feeling for working with the material using hot wire cutters to understand the tolerances required. Each of the creations is tested until breaking to understand its failing mechanism and to collectively gain insight into how this works, whilst referring to the theoretical background to interpret why some designs are weak or strong. Building both intuitive estimation of structural activity as well as analytical understanding.

For the weeklong assignment the challenge is expanded to build a 'C' shaped hangar which tests some key moment baring connections. The need to be able to put it together and take it apart rapidly deepens the challenge. With designs having to deal with a number of forces as well as element continuity connections at the same time. The solutions ask that students go beyond known solutions to develop their own tectonic language. And in some cases, examining traditional timber fastener-less construction and adapting it to the foam material. Appreciating the difference brought about by the relatively weak and brittle material.



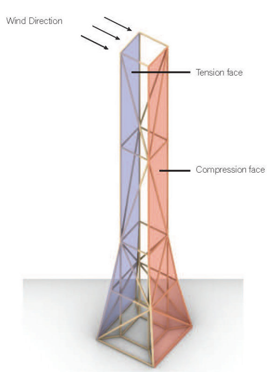

Variation of node support situation

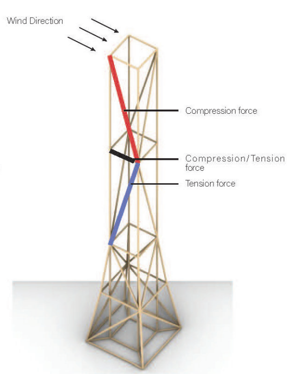
Skewer Tower

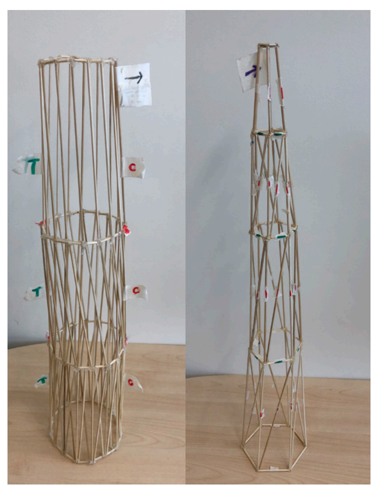
The last one-week workshop and assignment cycle centres around exploring more thoroughly spatially designing with liner elements, whilst still maintaining a fixed set of boundary conditions. Moving to a larger scale and greater complexity the intent is that this is a foray into considering and generating a whole building form. Looking at what works by applying the intuition and constructive logic gained whilst keeping a dialogue about balancing the needs of a functional but also aesthetic structure.

The workshop section looked at how skyscrapers were initially designed in section understanding their need to support additive vertical gravity loads, as well as lateral wind and earthquake loads. Appreciating that there is a stress path reconfiguration under reversals of later load direction. Initially looking at the taxonomy and history of this typology that has adapted to ever greater heights though innovation and optimisation. Investigating though simple model making the benefits and issues of working with moment frames as compared with braced structures. This is done in 2D initially so that issues around repetition, rhythm, and proportion can be tackled in their simple form.

From this start the assignment investigates the development of a full 3D of a ~300m tower. The super frame being explored physically though modelling as well as developing basic calculations to understand Freebody diagrams to calculate key force distribution. The models then being used to try to apply loading to understand the basic forces of tension and compression showing towers act like vertical beams. However also using them to demonstrate ideas of local and global buckling which drive high-rise design with its need for bracing and outriggers. And though the making of the model getting a feeling for the complexity of large building structures.







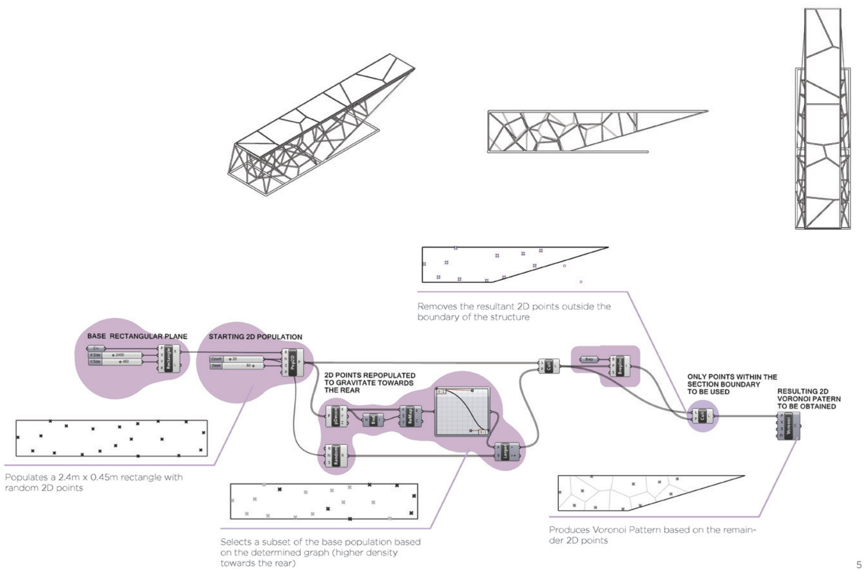
Bench

The Final Project was the biggest project taking half of the term, ramping up the scope by aiming to combine many aspects of what was exploded in prior designs. The project was shared with the Digital Design and Fabrication course. Investigating at 1:1 scale a bench that could be made with steel rebar using practical welding techniques and machinery from the Fab lab. The limited number of rebar available was set as an efficiency constraint whilst simultaneously asking students to consider how they can keep deflection to sensible values and not fail under extreme loads.

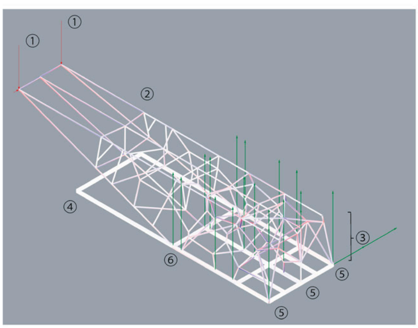
Design review sessions were held to investigate initial configurations and performance needs. Followed by workshops on using Grasshopper plugin 'Karamba' which is able to do fast finite element analysis so that structural design and optimisation can be applied to complex geometric forms. This leveraged the previous model and intuition building assignments but pushed it into a fully digital realm, with Karamba giving real time deflection and stress feedback to ascertain serviceability and ultimate strength of the design. In parallel the fabrication considerations and methodology were developed by the students which both aided and challenged the overall structural arrangement.

The end output resulted in a group design and FEA model able to demonstrate the behaviour of the structure. The bench requested was a modest 2.4m long, 0.4m deep and 0.45m high. The challenge however was that the connection base was only allowed to use 0.9 length at one edge thus requiring a sizable cantilever. This requirement demanded that students push their designs to achieve this, whilst also considering how to make the end result aesthetic. To make it work would require understanding of back span, buckling, sectional bending and torsional strength.

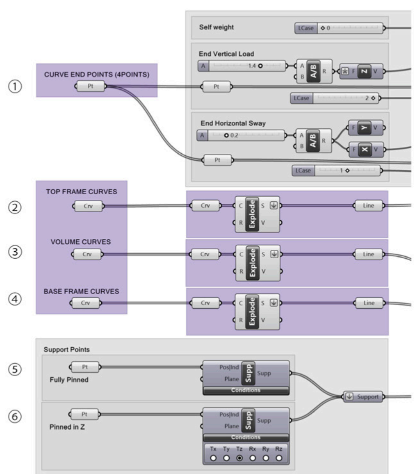
Chong Yuan Wen & Megan Riri Moktar & Natalie Ng & Tseng Yun Ching



Chong Yuan Wen & Megan Riri Moktar & Natalie Ng & Tseng Yun Ching

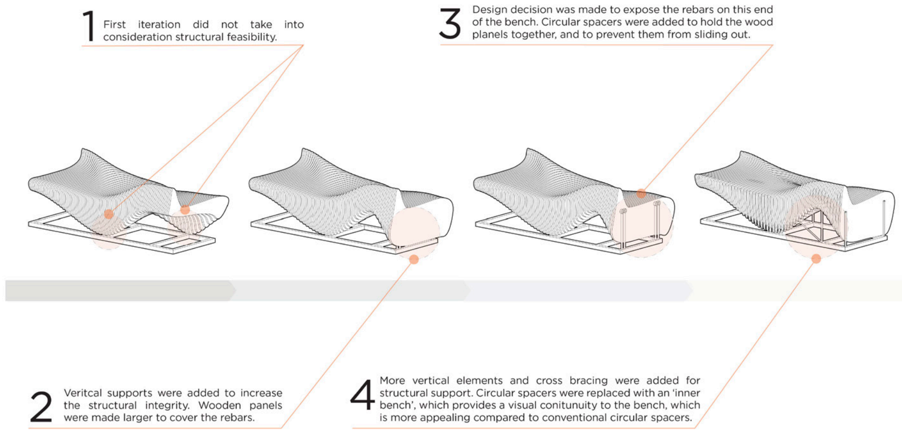


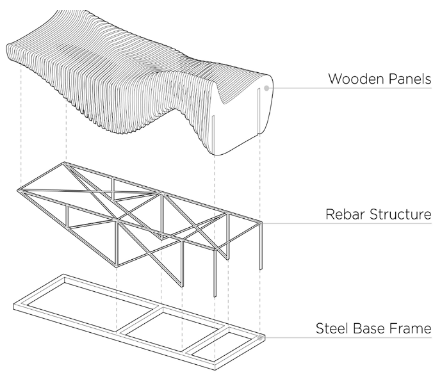
Karamba Rhino input

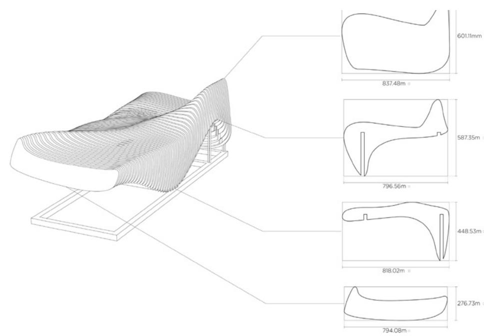


Karamba Grasshopper input

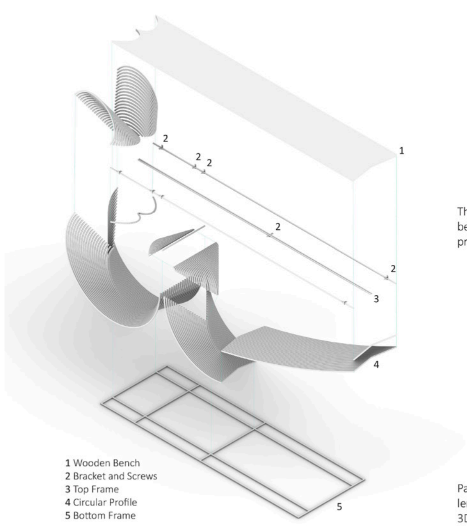
Chong Yuan Wen & Megan Riri Moktar & Natalie Ng & Tseng Yun Ching

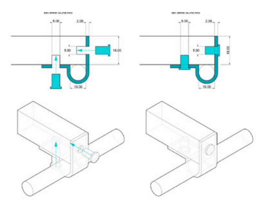




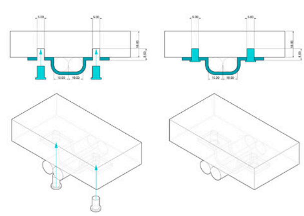


Keith Lim Jun Hong & Loo Wei Sheng Dixon & Nurul Nazeera Binte Yazid & Tai YuJie





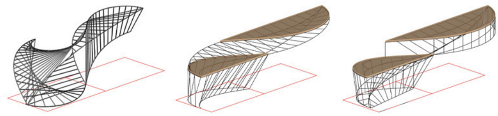
The perpendicular brackets are utilized along the longitudinal sides of the bench at eight main points. The brackets are 2mm thick wood coloured 3D printed plates secured by two M5 8mm screws.



Parallel Brackets are utilized along the two middle rods spanning across the length of the wooden plank. Similarly, brackets are 2mm thick wood coloured 3D printed plates secured by two M5 8mm screws.

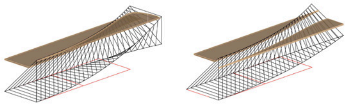
Lynus Lim Ming Jun & Melvin Wong Weijie & Tan Zhi Sheng & Kwang Kai Jie

Explorative Iterations
Elevating Wave



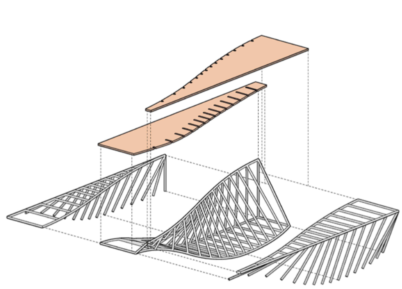
Using one directional curves and connecting them using straight lines to achieve hyperbolic waves. However, it is not consistent in design language and curves in too many directions.

Formed by connecting curves along the curvature of the bench. However, connecting point between the platforms not strong, a bigger base would be more ideal for stability.

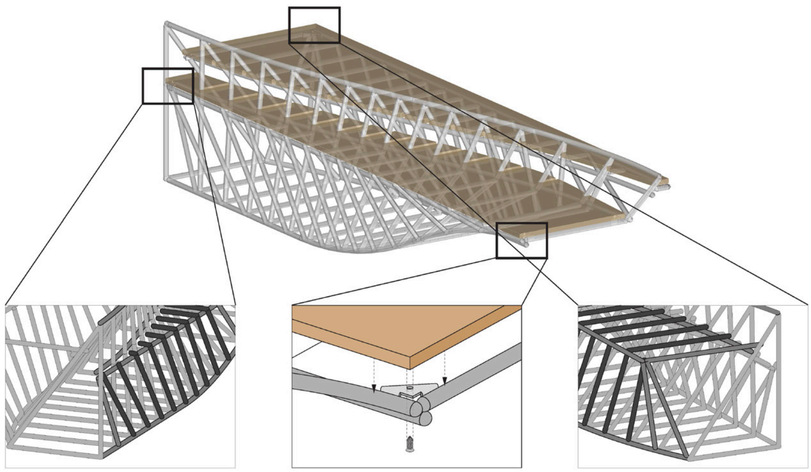


Formed by the twisting of a triangular cross section to differentiate between 2 distinct levels. Shape of bench follows the curvature of the frames.

Expolded View

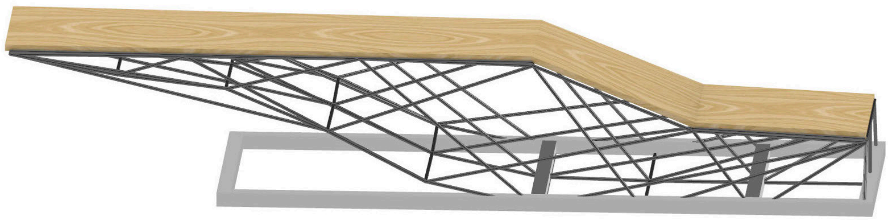


The Benchmark
Schematics

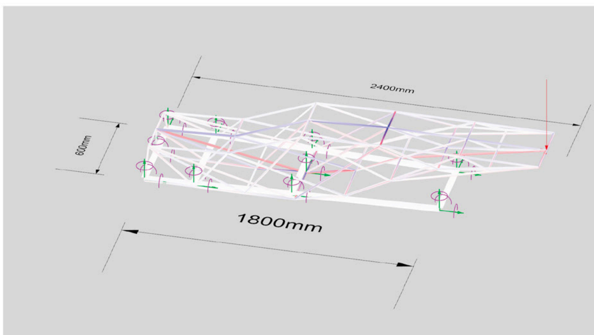


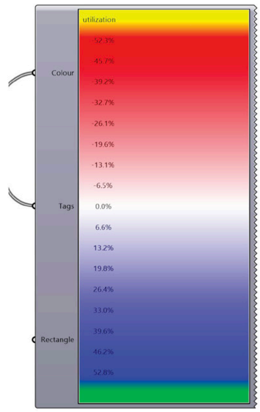
Yang Funing & Grace Teo Yu Cheng & Muhammad Syafiq Norkhalim & Kwan Wai Hin

Multi - BENCH



KARAMBA: FULL MODEL

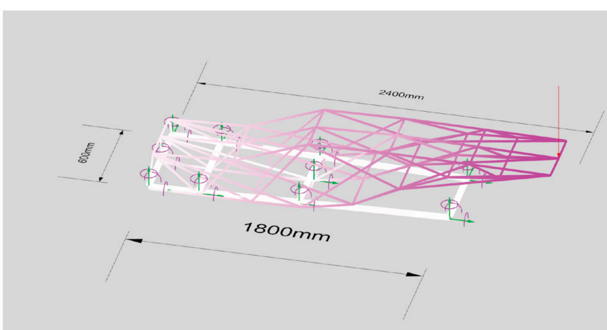


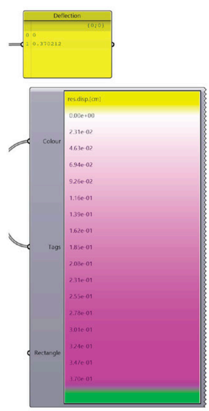


Karamba model testing the loads of self weight, live load, and both x and y-axis swaying.

Utilisation:
-52.7% to 52.8%

KARAMBA: DISPLACEMENT

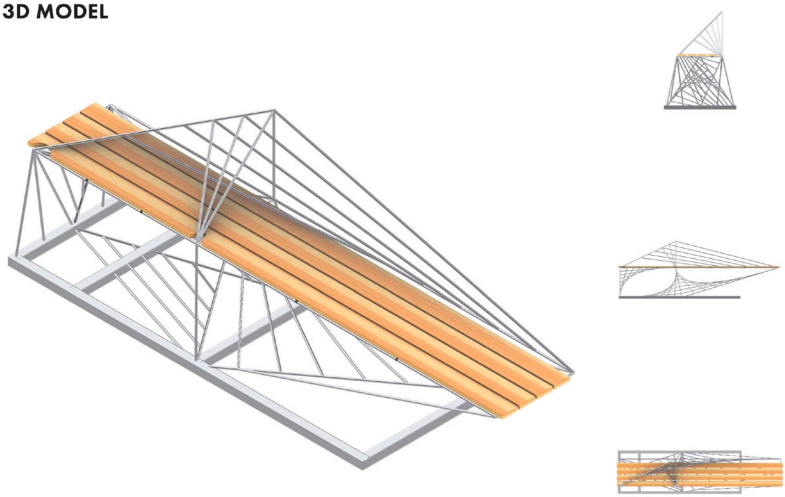




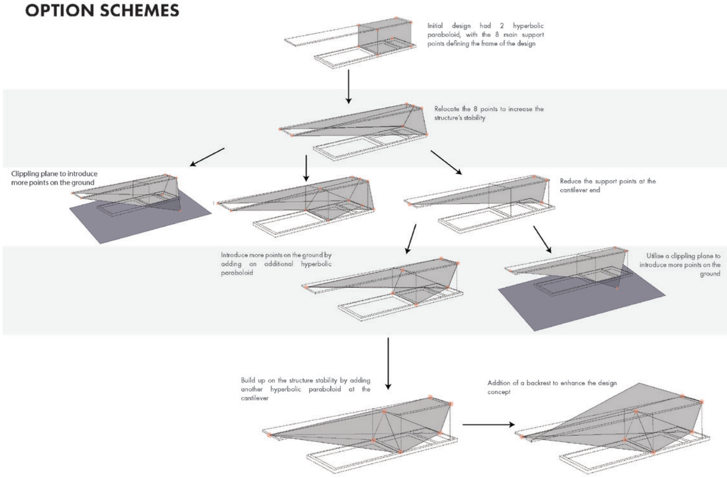
Deflection is 3.7mm, which is under 1/200 of the length.

Chua Bing Lun & Chew Cheng Wee & Han Xianhe & Yang Yu Bing

3D MODEL



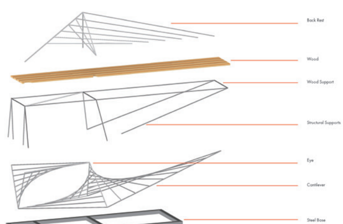
OPTION SCHEMES

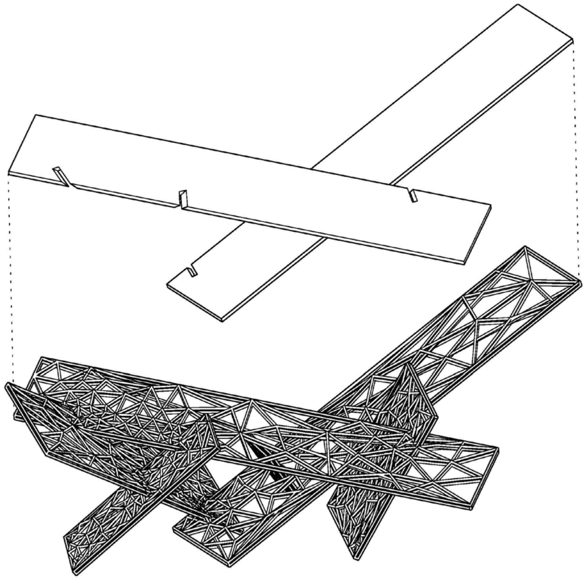


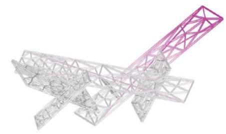
METHOD OF FABRICATION

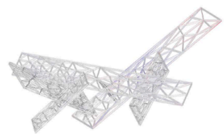
ASSEMBLY ANALYSIS

The design of the bench was categorized into smaller subcomponents. After fabricating each individual subcomponent, a specific sequence of putting together all the subcomponents is followed in a chronological order - Steel Base, Eye, Wood Support, Structural Supports, Cantilever, Back Rest, Wood.

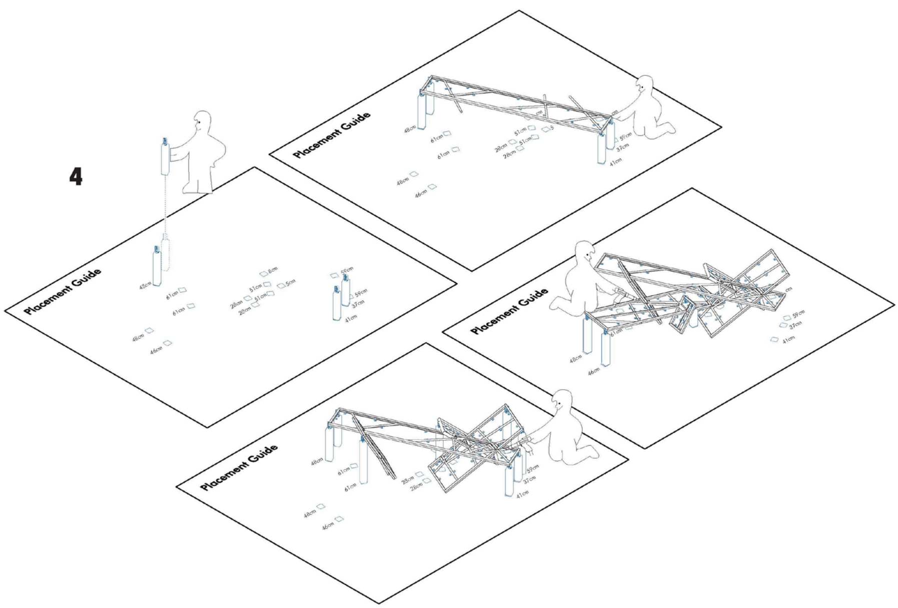




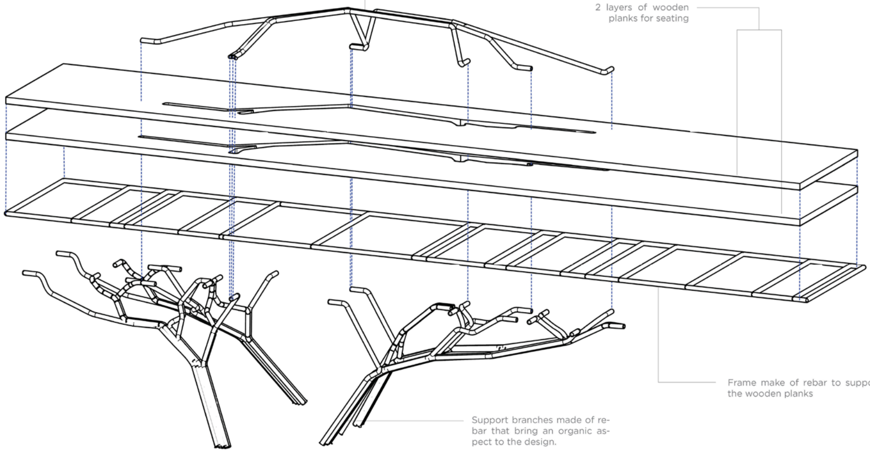


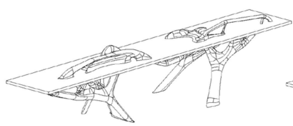


rebar diameter: **10mm**
wood thickness: **18mm**
total displacement: **19.3mm**
maximum utilisation: **55.5%**



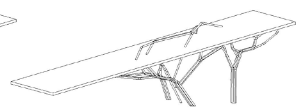
Chew Yunqing & Koh Fang Yun & Elizabeth Lum & Matthew Tsou_Page





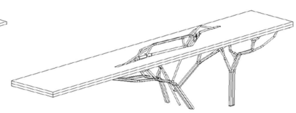
1

Chosen Generative design Iteration



2

Extraction and tracing of the supports from the generated design as close as possible to maintain similar utilisations and rationalities as created from generative design, simplified for manufature.



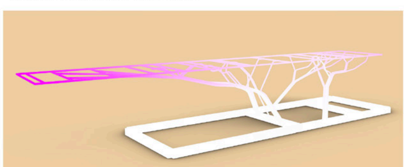
3

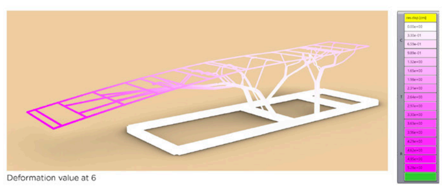
Creation of holes through the bench for the backrest, strengthening supports through increased bundling of rebars.

KARAMBA ANALYSIS

DISPLACEMENT

The maximum dispacement of our bench under all the load cases combined is 2.8cm at the edge of the centilevered end. This is consistent with our concept of a bench that displays reactive properties where users sit on it.





Deformation value at 6

AXIAL STRESS

The maximum axial stress reached for elements under compression forces is -2.03e+01 kN/cm² and +1.95e+01 kN/cm² for tension forces. Most stress is observed in the branches that supports the centilevered ends.