Summary	Context	Course	Date
Digital Design and Fabrication	Undergraduate Education	Architecture Term 5	2014 2018

Developed by

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Adapted by

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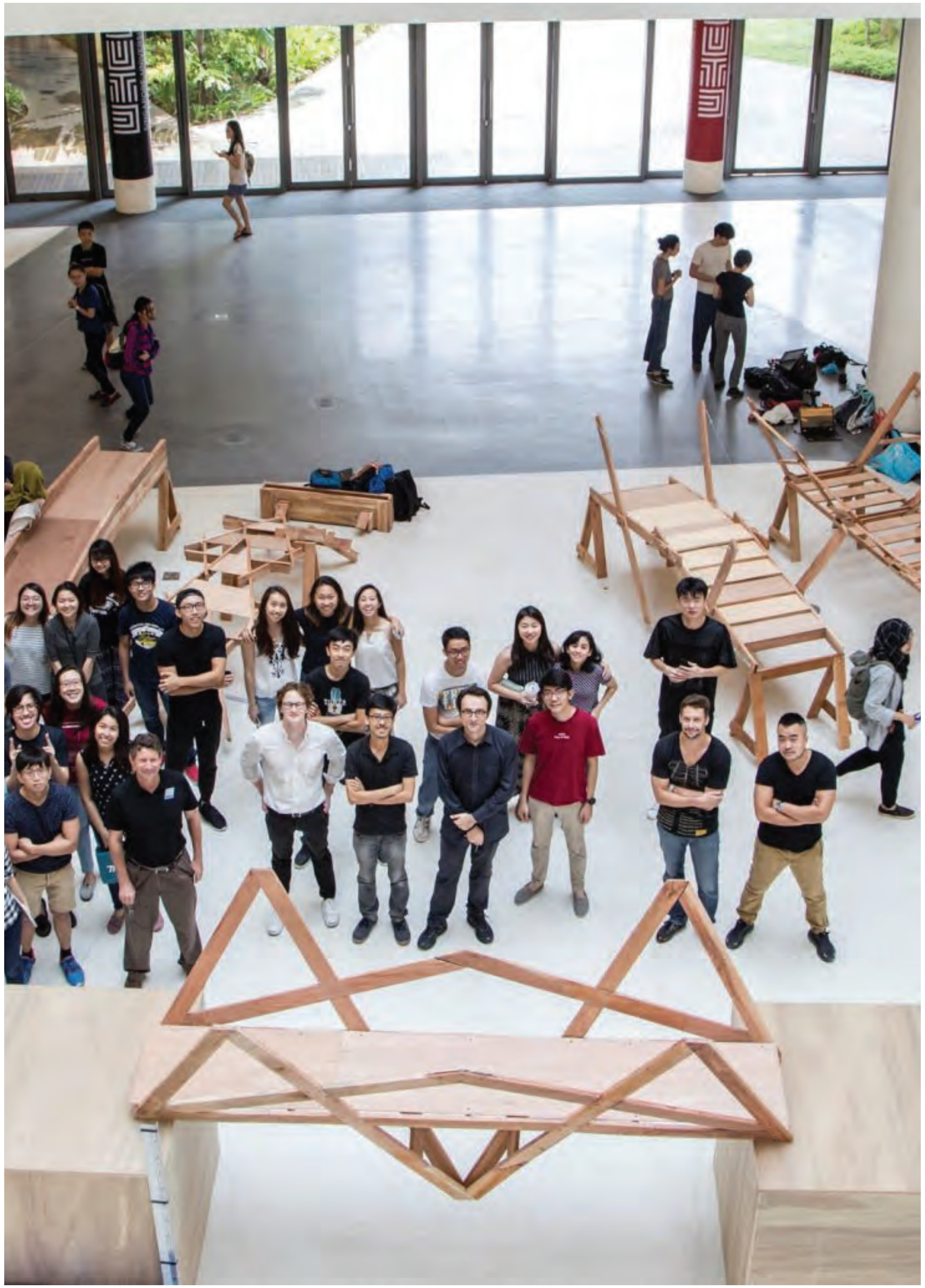
<Description>

Digital Design and Fabrication investigates the transformation of conceptual design to physical artifacts through manufacturing within contemporary digital media. Situated at the threshold between virtual and physical, design information and objects, it is comprised of design computation methods and material fabrication techniques.

The course introduces advanced concepts of design computation such as imperative and declarative techniques of design description and analysis for fabrication, computer aided design and manufacturing work flows and technologies of materialization such as conventional fabrication protocols as well as rapid prototyping and numerically controlled manufacturing.

<Overview>

Digital Design and Fabrication is offered to about 60 to 90 undergraduate students every year. It is a 5th term course overall but only 2nd semester within architecture. The course approaches design thinking bottom-up from the perspective of materials and fabrication processes, from the physical world to the realm of concepts. It aim to assist students to develop sensibilities and aptitudes in the physical dimension of design processes and products.



<Learning Objectives>

(a) Apply concepts of parametric modeling and computer scripting to create, represent and document architectural design for production. (b) Apply methods of part-assembly workflows, understand material and manufacturing design complexity, and select appropriate methods of production. (c) Apply conventional and computer numerical control manufacturing methods to create physical prototypes that communicate the design intent. (d) Apply computer aided design and manufacturing methods to design, produce and present a small-scale installation.

<Measurable Outcomes>

(a) Evaluate methods of digital fabrication using various technologies quantitatively such as material use / waste and production time requirements; and qualitatively such as aesthetics. (b) Demonstrate understanding of design description, documentation and production methods and technologies, their capabilities and their limitations. (c) Respond to transformation of design information through representations, provisioning for precision and tolerance. (d) Demonstrate the potential for creative adaptation between original design intent and final outcome from design to production.

<One Million Cuts>

The very first assignment of the course asks students to design and fabricate an artifact, using the laser cutter and veneer wood, by performing no less than one million incisions. This rather abstract challenge inquires for opportunities innate to digital media to design, using computation, and fabricate, using computer-controlled machinery, objects that could have never been possible to be either drawn or manufactured by human hand at any other point in history. Students are already familiar with laser cutting from previous courses in digital media and representations. Nevertheless, they perceive the technology as a utility for producing physical prototypes without appreciating its capability for transforming materials with accuracy and speed unattainable by using conventional media, nor inquiring for opportunities to design exactly at the threshold between human and machine aptitudes. The objective of presenting an abstract design inquiry is aiming at the development of comfort with open-ended design briefs beyond conventional problem-solving activities. Instead, it motivates students to approach design from a personal expression perspective and develop commitment to their own design work.

Student Credits

01 Ryan Teo
02 Tan Gee Yang
03 Bianca Gill
03 Clifford Kosasih
03 Melissa Ho
03 Timothy Lum
04 Hendriko Teguh
05 Ling Ban Liang
06 Caleb Ng
07 Ian Soon
08 Natalie Chen

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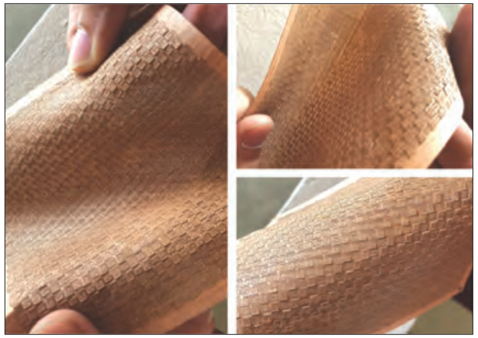
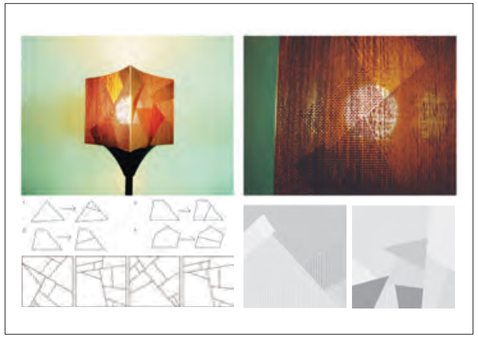


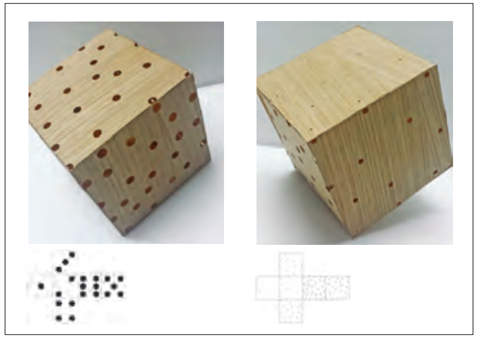
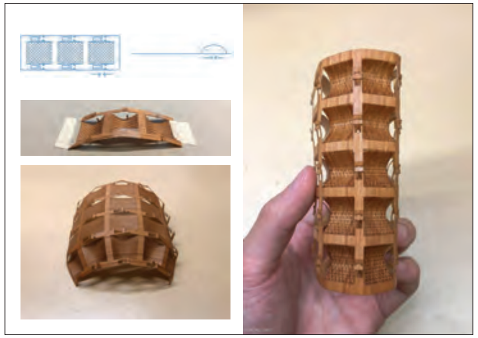

<Generative Casting>

Generative Casting computationally it derives from the theories of formal languages, rule-based design and shape grammars. It introduces affine transformations, symmetry groups and the concept of permutations.

Originally, the assignment asked students to design a massing model for a building and fabricate a prototype using laser cutting laminate mold and cement casting. Due to complexity of building form design, it was later simplified. The latest version asks students to design a 2.5D tiling pattern, fabricate a mold by CNC machining Styrofoam and cast a number of tiles in plaster of Paris.

As part of engaging students to experiment with material, they are also asked to produce ten small scale samples mixing any other material with plaster and create a new composite material + process. Their final design then is fabricated using the new material formulation.

The challenge of the assignment is to attempt to control a wet fabrication process, generally considered as of low accuracy, using a high-precision manufacturing method such as CNC milling. Yet the end produce for any casting process is no better than the care and effort expended in the preparation of the formwork; something that it is not merely ensured by the computerized fabrication method.

Generative casting begins the transition from materials towards tectonics and assemblies. It asks students to consider not only the geometry of one element by itself but as an arrangement of potentially numerous parts which they have to come together. Those inevitably will define conceptually and physical boundaries at their joints which may be as critical, or perhaps even more, than the individual shape of the element.

Student Credits

01 Bianca Gill
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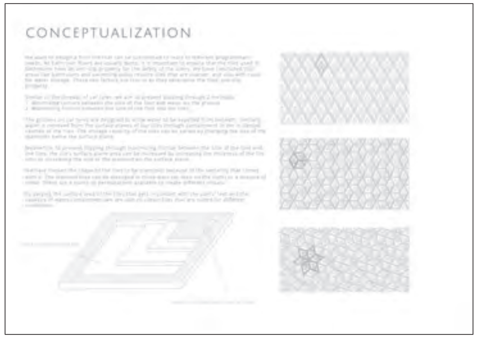

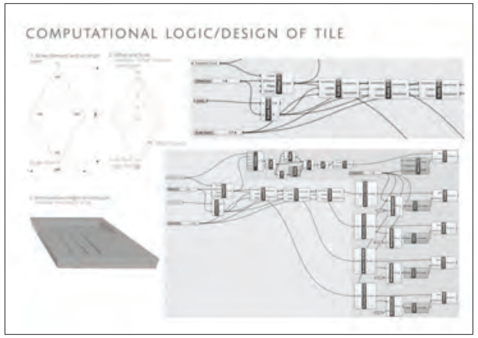

<Planar Joints>

Planar Joints was the first assignment of the course. Its objective was to introduce a quantitative perspective in materials and assemblies beyond affective properties; and transfer focus on architectural tectonics.

It asked students to design a puzzle-type joint from a single 400 x 100 x 12 mm plywood blank using CNC milling. The fabricated joints were tested using the Instron Universal Testing instrument against tensile loads.

The concepts of accuracy and tolerance are fundamental to the design and fabrication of architectural details and assemblies. Variations due to material sourcing, logical design flaws as well as fabrication errors are amplified when parts have to interlock with one another.

Planar joints took a design-oriented and experience-based approach to the mechanical behavior of materials and assemblies in compliment to knowledge introduced in building technology of structures. The tensile behavior of plywood was thus not of primary interest but the inseparable relation between material and geometry.

As an introduction to Computer Aided Manufacturing the assignment presented parametric machine G-code generation from within the Computer Aided Design environment. The goal was to demonstrate how to take full control of complex machinery through computer programming.

Student Credits

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02 Tracy Tan
03 Chin Wen Ao
03 Jade Kwok
03 Louise Chia
03 Li Yen Ong
04 Lawrence Kam
04 Faizah Ja'affar
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05 Faizah Ja'affar
06 Mellisa Lee
06 Yehezkiel Willardy
07 Lawrence Kam
07 Faizah Ja'affar
08 Amanda Mak
08 Millicent Nhu
08 Mihn Chau Nyugen
08 Chin Yih Soh

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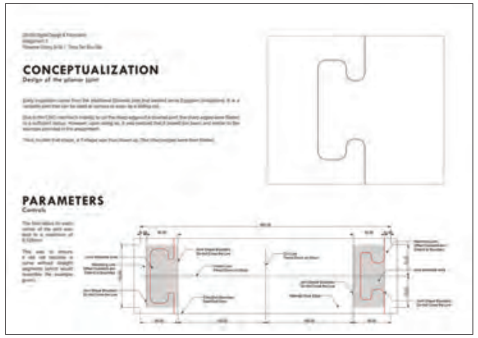

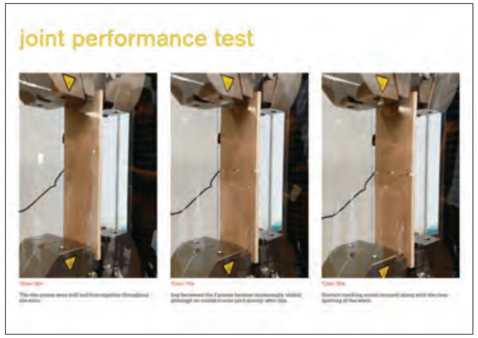

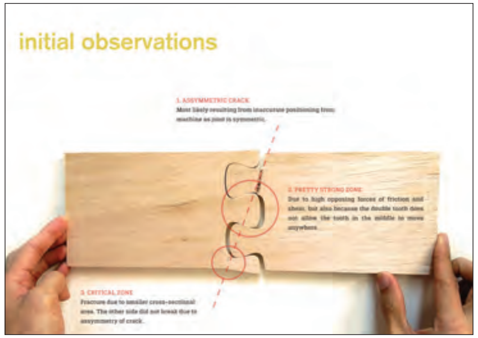

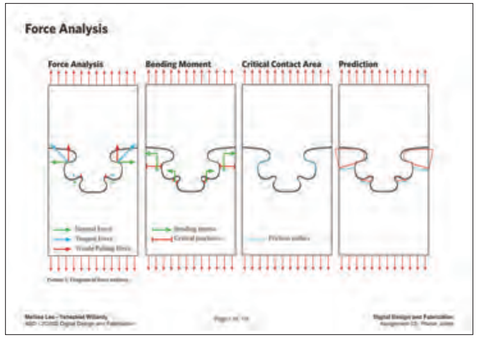

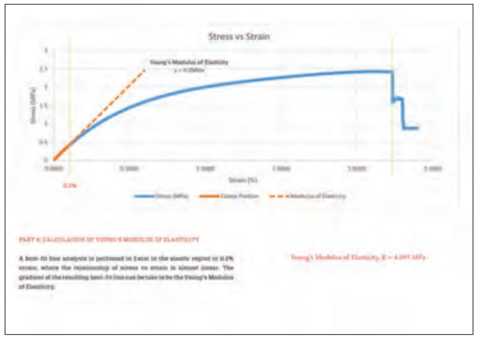

<Spatial Joints>

Spatial Joints is the last short assignment before mid-term. It asks students to design a grid-shell node and fabricate in aluminum using the water-jet cutter. Associated tutorials introduce engineering solid modeling principles, such as relational and constraint-based parametric methods, which have also recently been adopted for the design of architectural details in the industry.

The students receive a center-line geometry specification expressing the top of the beam for a shell structure. They need to design a four-edged node with fixed angles between members locally on a conic surface. While much easier compared to arbitrary geometries conics require 3D thinking for how to change planes via orthogonal actions.

This assignment aims to convey how downstream production constraints, such as an efficient 2D fabrication process, may be considered upstream in design. Students can thus understand the implications of geometric thickness in details, considering assembly sequencing and geometric as well as mechanical restraints. Aluminum being relatively more challenging to conform or correct requires careful consideration for accuracy and provision of tolerances.

While this spatial joints is perhaps the most technically challenging assignment in the course, it has also been consistently one of the most creative and interesting for students.

Student Credits

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02 Denise Lee
03 Maria Lee
03 Jean Lee
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04 Ian Soon
04 Emma Lim
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05 Althea Chan
05 Poon Weng Shern
05 Odelia Shane Tan
05 Rebecca Tan
06 Daniel Tay
06 Chantalle Goh
07 Wai Man Chau
07 Ian Soon
07 Emma Lim
07 Hui Sin Ong
08 Gee Yang Tan
08 Hui Yee Lim
08 Bojun Zhang
08 Rui Chen

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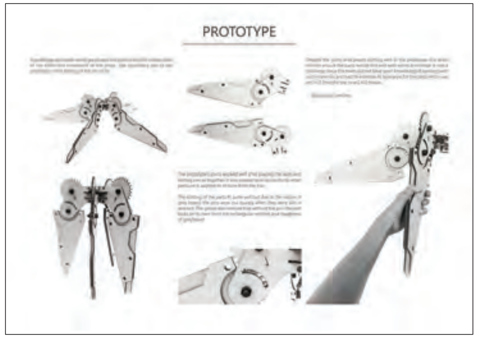

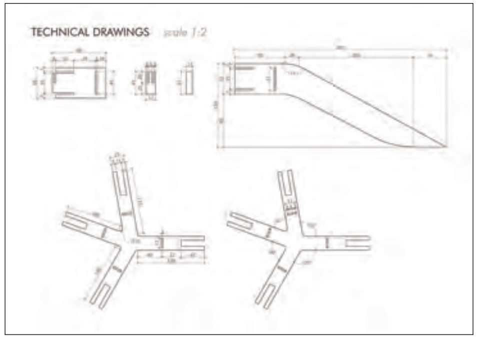

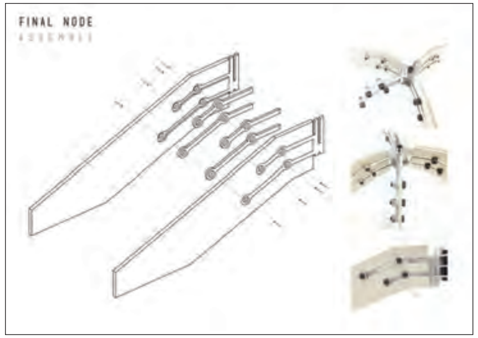

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01 Kady Ho
01 Yanhan Lim
01 Dana Yang
01 Elizabeth Yang
02 Willa Trixie Ponimin
02 Yu Jie Tan
02 Endy Fitri
02 Rebecca Ong
03 Denise Lee
03 Gabi Quek
03 Sze Min Neo
03 Wen Zhen Seah
03 Zayar Lin
04 Chris Pambudi
04 Hyosoo Lee
04 Si Kai Chen
04 Wei Ann Low
05 Kerin Kua
05 Eileen Wong
05 Yi Lei Cheong
05 Yin Yin Ong
06 Dionne Teo
06 Wan Rong Lim
06 Iffah Khairani
06 Jean Paddila Yap
07 Sin Hnin Phyu
07 Wentao Zhu
07 Chuchu Zou
07 Clarissa Lim
08 Xinhui Neo
08 Xingling Ng
08 Shanquan Thia
08 Ivan Deviano

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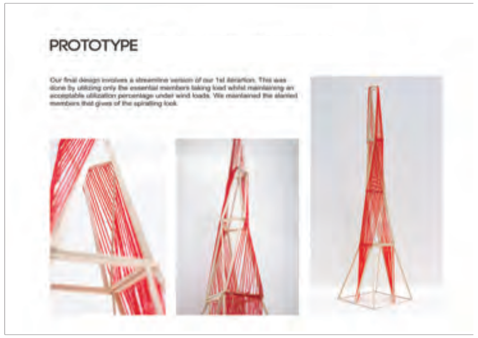
<Design Prototypes>

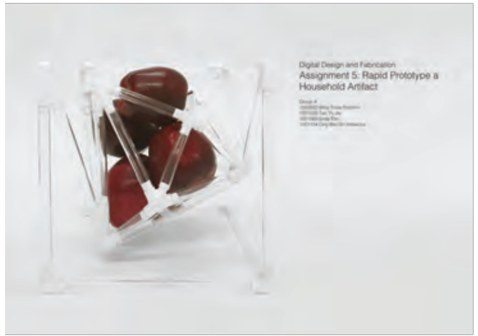
The prototyping assignment is part of the term project and its content vary based on the thematic of each year. The objective is to create a proof-of-concept physical prototype of the much larger scale end of term project.

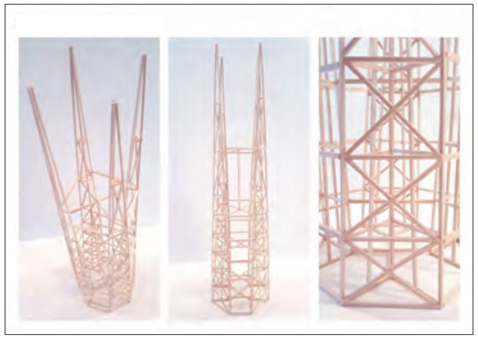
Initial iterations of the assignment aimed at introducing rapid prototyping modeling principles using low cost and widely available FDM 3D printers. Yet by now 3D printers are so widely available and commonly used as the laser cutters. Therefore, it is no longer critical to introduce them formally with an assignment but cover technical aspects rapidly and focus on opportunities for design.

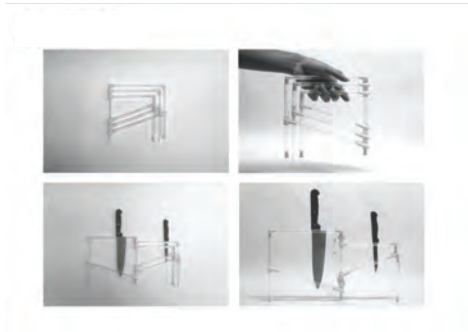
Indicatively, a past assignment asked the students to create an acrylic and PLA product design. The goal was to understand the ability to situate geometric complexity of an assembly at the node while using standardized material products for linear geometries. In addition, as the term project used similar techniques, it was important to understand the production logistics implications of using additive manufacturing for large-scale designs.

Overtime the direction of the assignment shifted from the notion of visual prototyping towards performance mockups. The objective here was to produce an object that can faithfully capture some of the systemic and structural aspects of a much larger object. The prototype could then allow for assessing the effort in production, accounting for complexity of assembly and of course mechanical characteristics such as bending and buckling.









<Kinetic Artifacts>

Architecture artifacts are designed often as conceptually and perpetually static. Time and the passing thereof, in architectural design is considered as the unvoidably long periods from concept to construction and the life-cycle of built space.

It is most often approach precautionary, with measures against deterioration by weathering, ensuring structural static immobility etc. The goal of this assignment is to bring time in the foreground; both in concaptual design, digital media representation and physical artifact sense. The brief of this challenge is to design and fabricate a "design machine".

Students learn kinematic modeling via advanced solid modeling applications. Those often include such features as planar 2D and spatial 3D geometric constraint solvers and simulation engines, which can be employed for design of objects in motion.

Students are introduced to theory of kinematic mechanisms including transmission, gearing and cams. Each team is supplied with 12VDC power supply and a single high torque 30RPM motor. Use of motion pictures is naturally the appropriate medium for presenting the devices created.

Student Credits

01 Simon Rocknathan
01 Naomi Wong
01 Jeanette Lee
01 Li Ying Song
02 Christy Chong
02 Ng Yun Shu
03 Looi Siao Si
03 Dixon Loo
04 Srtui Niranjan
04 Syed Faizaanull
05 Michelle Wijaya
05 Koh Jie Ying

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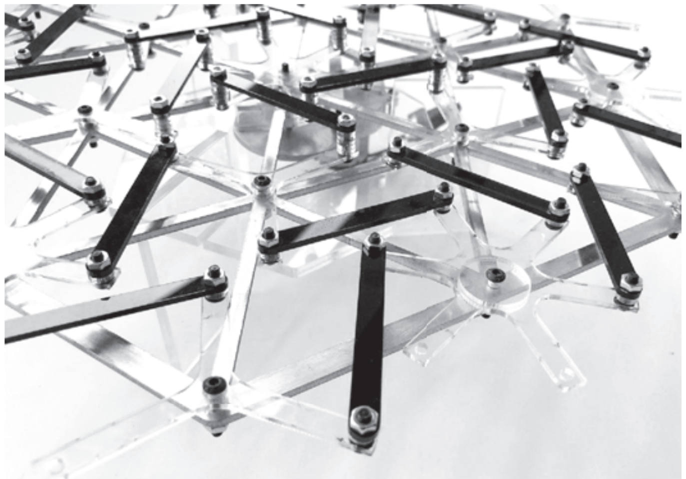
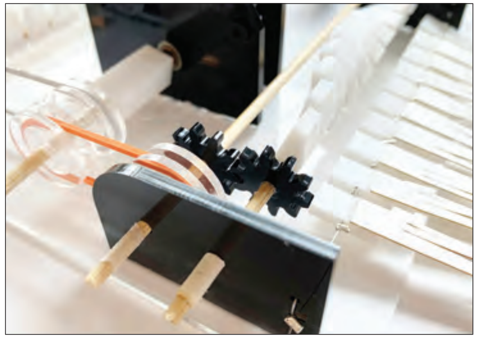
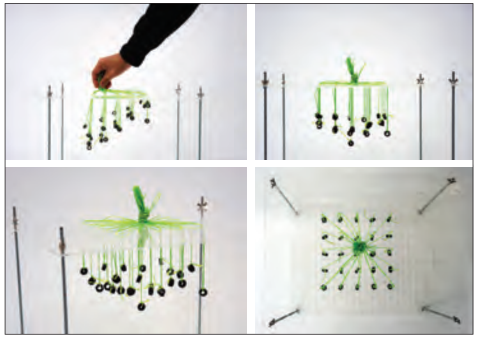
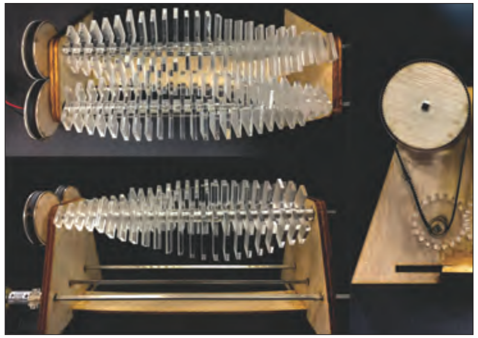
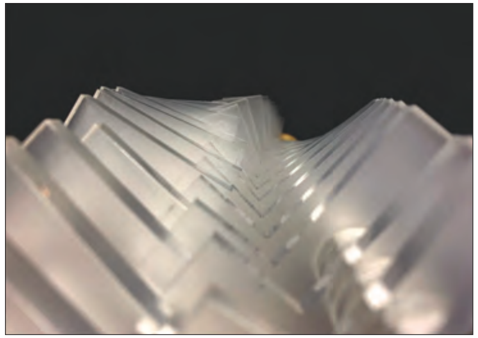










<Design and Production>

The term project typically spans the second half of the semester. Students in teams of three to five, engage in a large-scale campus design and fabrication exercise. The design thematic of each year is new based on material and fabrication availability and logistics.

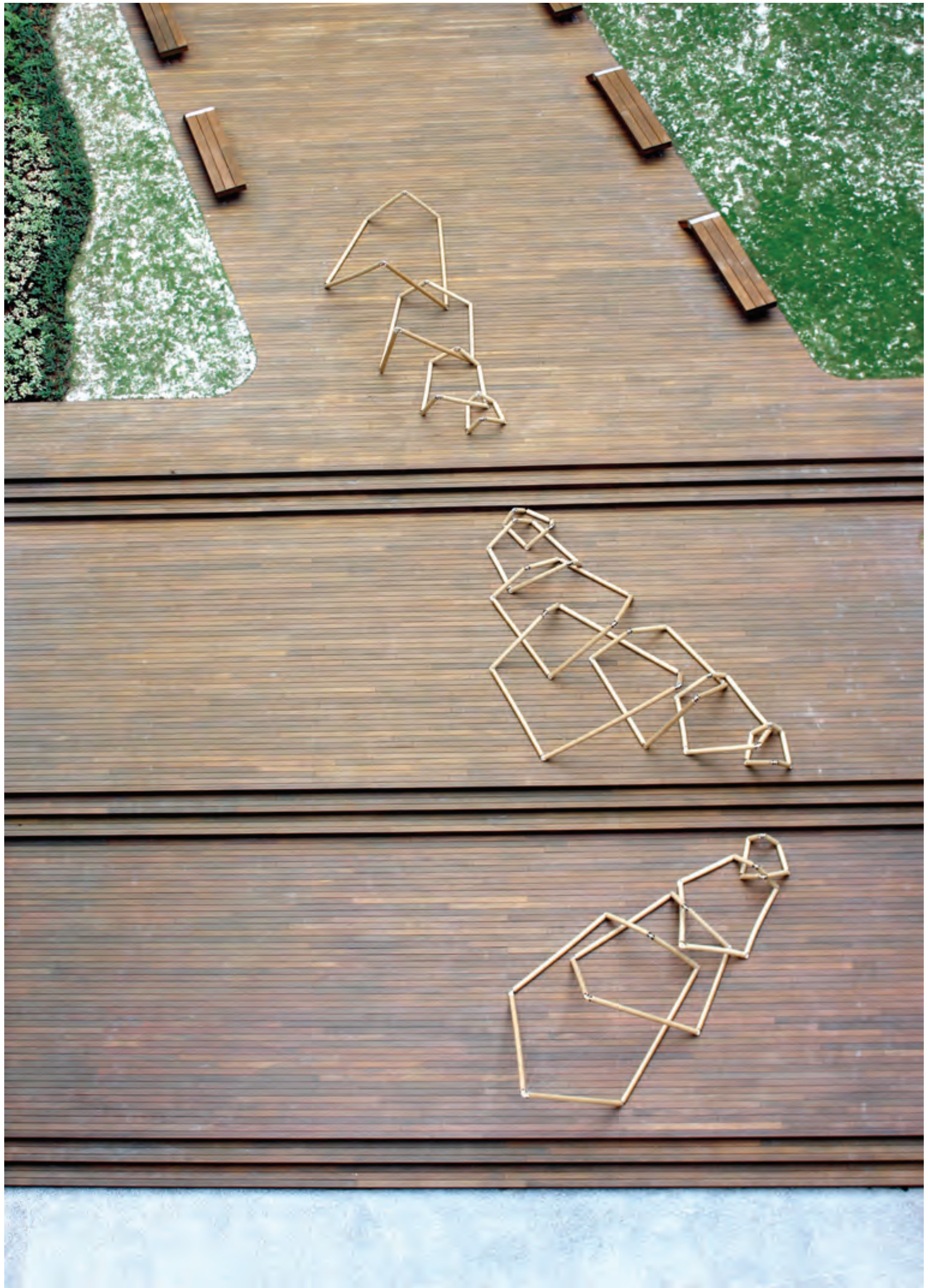
Early iterations of the assignment asked students to select a location and design an in context installation with the only consideration to improve the built environment and the constraint of limited material resources. In recent iterations the term project is offered jointly with the building technology course on architectural structures. As such the component of material performance evaluation become also integral.

Designing and building at real physical scale and context is an experience that requires hands-on engagement with the materiality of the place; as the end-goal is larger than an individual it reinforces collaborative work; the intellectual and physical efforts are rewarded by the sense of accomplishment; the importance of forming a vision and planning ahead of time prior to production becomes vividly evident; understanding and containing design complexity without compromise becomes essential; theoretical knowledge acquired through lectures and books becomes tangible; the profound interaction of materials and geometry is evidenced; observing people's reaction to one's work is invaluable feedback.

Student Credits

01 Aerilynn Tan
01 Diana Yeo
01 Aunn Ning Lim
01 Rachel Lau

01



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Course 2014

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03 Jenn Chong
03 Shirley Kwow
03 Khin La Pyae
03 Lena Toh

02
01 03

The thematic of the 2nd iteration of digital design and fabrication 2015 was Tubular Structures. Sixteen teams of three to five members, of total 64 undergraduates, were commissioned to design and build installations on the newly opened East Cost Changi campus.

The material of the year was cardboard tubes with 100 mm diameter and 2.4 m length. They were cut to size using conventional wood working techniques. Joints were created using plywood and laser cutting. While the intent of the course was the design of grid shell type of structure the variety of student designs exceeded expectations.

Computational design preparatory course work included the design of linear element assemblies using solid modeling techniques. In addition, focus was placed on resource optimization. The problem of one-dimensional cutting stock, a classic in computer science and operational research, was introduced and students were challenged to find an algorithm that could reduce the waste cut outs. The concept of heuristic search and best-fit methods was then used as a practical method to production planning.

Course 2015

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02 Xian Zhe Koh
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02 Yehezkiel Willardy
03 Auerial Chan
03 Hui Jie Ee
03 Chloe Tan
03 Yen Lin Tan

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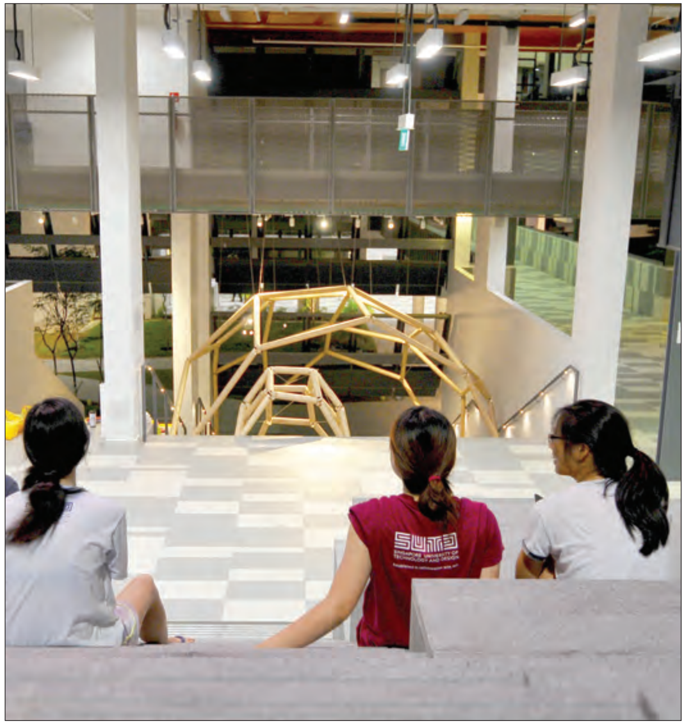

In 2016 the thematic of the term project was "Small 3D printers / Large-scale artifacts". Sixteen team of four students, total of 64 undergraduates, designed and built lattice grid structures comprised of tropical timber dowels and 3D printed joints.

One of the main challenges in the adoption of additive manufacturing for architectural scale designs is the limitation of speed and size of current technologies. Nevertheless, it is possible to strategically localize design complexity at the nodes of spatial lattices and use stock linear and planar elements to span larger scales.

Students were introduced to rapid prototyping techniques and the production of parametric geometries at varied incidence angles. Thus they were able to create designs where all nodes could be different from one another and also extract cutting schedules for the linear elements from their 3D models. The concept of cutting-stock best fit heuristic optimization was reused from the previous year to minimize material wastage.

Course 2016

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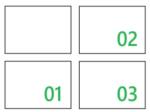
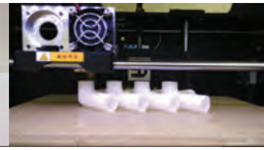
02 Lisa Koswara
02 Inez Ow
03 Joei Wee
03 Clara Hanna Goh
03 Nicole Soh
03 Christopher Wicks





The design for a 4m long bridge was the first combined assignment between digital design and fabrication and the architectural structures courses. Sixteen teams of four students, total of 64 undergraduates, designed, analyzed and built bridges using tropical hardwood. The material was salvaged from road clearances in provision of safety.

The design of a bridge is a highly challenging activity as it requires understanding of materials, assemblies and physics. The use of high-density timber, circa 0.9 kg/m3 made it very evident that increases in material use was in detriment to the structural characteristics of the design. Thus an equilibrium or optimum needs to be found.

As a joint course assignment, architectural structures introduced parametric finite elements analysis and digital design and fabrication focused on translating design to production specification. This was critical for this assignment as the fabrication techniques used were conventional wood working methods. The designs exhibited in the campus center and load tested up to 200 kg in static load against limiting 10 mm of deflection.

Course 2017

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01 Jin Xi Ng
01 Samuel Ho
01 Truman Ng
02 Jia Ying Soh
02 Jia Wen Heng
02 Abhipsa Pal
02 Natasha Yeo
03 Michael Yeow
03 Elizabeth Teo
03 Samantha Tang
03 Pei Ru Tan

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01 Hui Yee Lim
01 Caleb Ng
01 Dion Teo
01 Samuel Halim
02 Eunice Lim
02 Jing Ren Tan
02 Weng Shern Poon
02 Sally Tan
02 Joshua Tan
03 Caleb See
03 Jeniffer Gautama
03 Michelle Gouw
03 Odelia Tan

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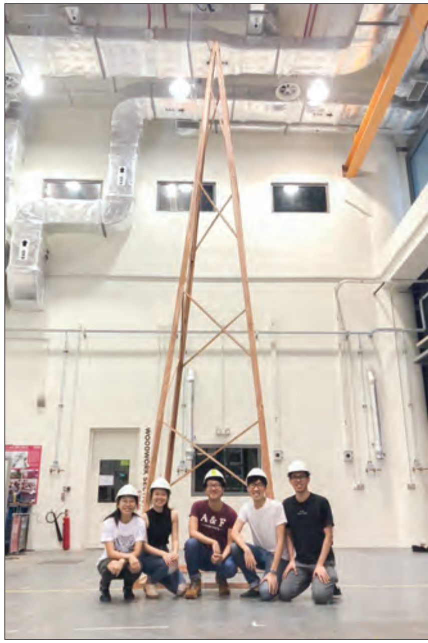
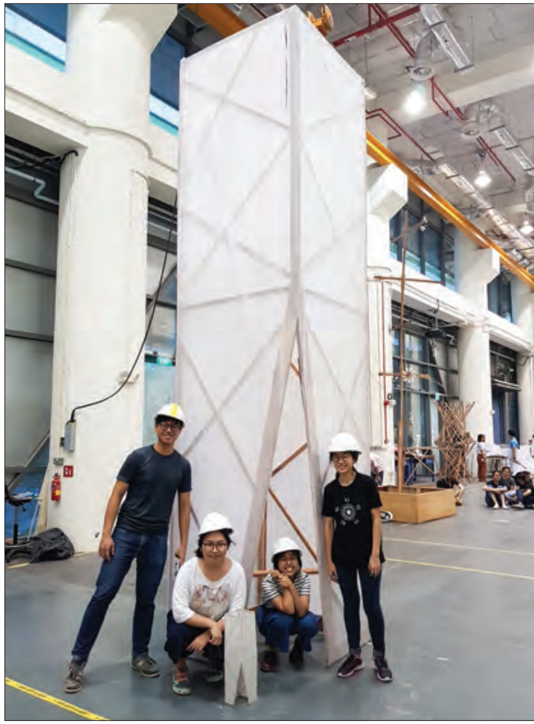
A unique design for a tower structure was the thematic of the term project in 2018 offered jointly by the digital design and fabrication and the architectural structures courses. Twenty teams of about four students each, 87 undergraduates in total, designed, analyzed and built tall structures, some of them over 6m, in the fabrication laboratory of SUTD.

The method and material of fabrication was, as in the previous year, wood working using road clearance salvaged tropical timber. The key challenge of this year was in construction sequencing which was critical for the assembly and erection of the structure. In addition, the concept of buckling under self-load was equally a concept that was less accessible compared to bending.

Use of scaled prototypes was instrumental in accessing the mechanical behavior of the structures, complimenting structural analysis models using computational methods. Students' ambition to create the tallest structure meant that in some cases the use of fabrication laboratory's crane was the only solution setting the towers upright.






The topic of 2019's joint term project was the design of a public canopy or pergola structure spanning 1.5 by 3.0 meters. Structurally the design aimed at cantilevered forms. The material used was 2mm plywood fabricated and assembled using standard wood-working techniques. As a result all designs were highly light weight given their overhead placement. The ease of transforming the thin planar material into three-dimensional geometries gave rise to wide variety of designs.

Nevertheless, the similarity of light-weight plywood to common architectural prototyping materials such as paper and cardboard, and use of laser cutting for fabrication, allowed students to mentally drift away from provisioning for actual construction often operating with significant loads and complexities arising in assembly. On the other hand the ease of moving from design to production, which for this year was the most rapid, allowed for variety and a highly effective and enjoyable experience.

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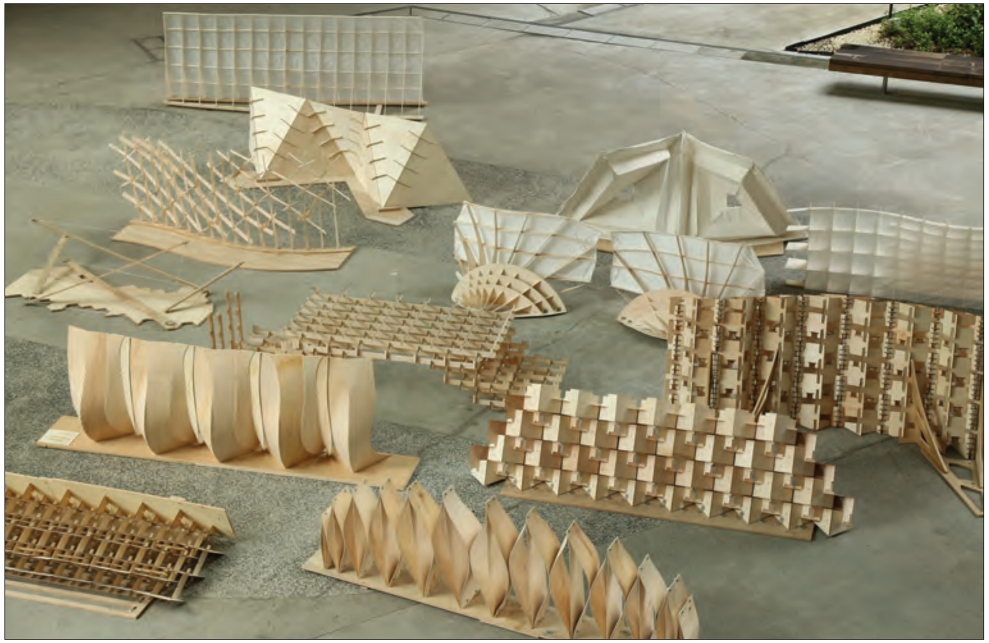

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01	02
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The design of a cantilevered bench for public spaces was the design challenge of 2020. The material selected for building the artifact was 10mm diameter reinforcement bars used for concrete construction. The fabrication technique was shielded metal arc welding. This was the first time to introduce a jointing heavy approach to fabrication requiring significant effort in training and health and safety precautions. Despite the extensive planning due to the Convid19 epidemic the term project was transformed to a virtual design assignment. Emphasis was placed on the methods of upstream design optimization for pre-fabrication ie. design for manufacturing and assembly. Fabrication was substituted with copper wire soldering.

While the physical outcomes of this very special year in our lifetime were clearly lacking in contrast to previous iterations of the course, the deliverables demonstrated a higher degree of proficiency in digital methods. Projects employed generative design / topology optimization, experimental design / response surface modeling, genetic or evolutionary systems optimization as well as methods of computational geometry rationalization. Surprisingly, social distancing measures instead of detrimental, proved highly influential in establishing digital conduits for design communication which were perhaps more effective than physical interactions.