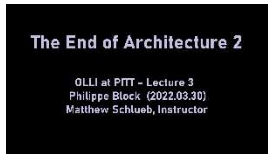
2022.03.30 Lecture Notes 

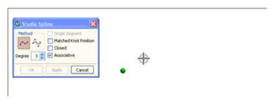
1pm

First lecture defined 'architecture' as tectonics: fitting, puzzling, crafting.

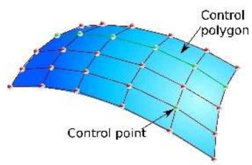
Zaha & **Gehry** chart the transition from a post-modern to the dawn of the computer applied to architecture.

Lou Ruvo Center for Brain Health
(Las Vegas, 2010)

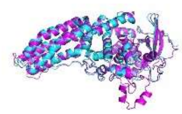
Beginning in mid-1990s and by mid-2000s we see the computational power applied to the manufacturing of customized structural members for the deformation of buildings designed by computer aided design program based on algebraic equations



to create NURBS (Non-Uniform Rational Basis-Splines); Splines; Meshes defining



surfaces of polygonal facets in non-rectalinear, non-right angle connections.
(Silicon Graphics workstations, 1989)



By the mid-2000-teens, computational power is modeling microscopic biology, breaking down molecules to parts to understand metabolic activity / protein folding, as well as the anatomic properties of building materials, creating more sophisticated study of material science.

Philippe Block and **Neri Oxman** chart this development, beginning with a more granular definition of 'tectonics', from Greek tetk [Ancient Greek tektōn (τέκτων) for an artisan/craftsman, in particular a carpenter, woodworker, or builder.
Contrasted with an ironworker, smith (χαλκεύς), stone-worker or mason (λιθολόγος, λαξευτής).
Tektōn (τέκτων) is derived from root *tetḱ- "to carve, to chisel, to mold."
[Sanskrit takṣan, literally "wood-cutter."]
Shaping materials (**wood, stone, metal**) to piece together,
to make an assembled whole (**wall or roof**),
an envelope (division), a membrane (modulator), a skin (interface).

■ **SUDU - Sustainable Urban Dwelling Unit**, Addis Ababa, Ethiopia, 2010
A series of tile vaulted structure prototypes to develop, design, construct 2-story, sustainable, low-cost urban dwelling units, of local low quality materials, built with minimal formwork, based on the current urban conditions and needs of Ethiopia.
To rethink traditional building methods and social space requirements, resulting in housing not dependent on imported materials for their construction and with a minimal carbon footprint.
Need to reduce global emissions, energy consumption, and material waste requires the systematic development of sustainable buildings at both large and small scales. Materiality, social space, water management, waste management, energy production and consumption, operation, and maintenance have to be designed to be the most effective and efficient.
Ethiopia, once called the granary of Africa, has a rich soil, which contains high levels of clay particles, possible source for material needed to build new structures. "Rammed earth" technology to construct the first level of the building, with a 60cm wide wall structure. Using a specialized technique, a small ring beam was constructed on top of the last layer, to ensure the structural strength needed to support the ceiling.
The first ceiling of the SUDU project is done using a tiled vaulting technique, designed and introduced for the first time in Ethiopia by the Block Research Group (at ETH Zurich). The technique, also known as **Guastavino** or **Catalan vaulting**, was introduced already in the end of the 19th century in many public buildings in United States. Robust, self-supporting arches and vaults using interlocking tiles and layers of mortar to form a thin skin. The tiles are usually set in herringbone pattern layout with a sandwich of thin layers of Portland cement. Unlike much heavier stone construction, these tile domes, or barrel constructions, can be constructed in place without additional support. Each tile cantilevers out over empty space during construction, relying only on quick drying cement, known as "Plaster of Paris", produced in Ethiopia, to secure it in place. With this technique, no scaffold is needed to construct the ceiling or dome, and only a string guide system is used to make sure the form is kept in an ideal structural line.
The second floor of the SUDU project is constructed with pressed loam stones produced on site, handled by local know how and a local workforce. This method

also allows for additional structural support, if needed, by hollowing out an internal formwork for small columns, which secures the building against lateral forces, since the area around Addis Ababa is seismically active. Again, no additional formwork is needed and a combined technique of loam stones and the option for a columnar structural support allows for a heterogeneous construction method, customizable according to local and regional requirements regarding seismic activity.
The roof construction follows again a vaulting technique, similar to the ceiling, but this time using bigger loam bricks. As the demands of a roof as an exterior element are different from those of a ceiling, it is covered with a special 10cm thick waterproof mortar, produced out of prickly pear cactus juice, salt, lime, loam soil.

1:25

Droneport Prototype - Venice Architecture Biennale 2016
Norman Foster Foundation and LafargeHolcim Foundation for Sustainable Construction that built a full-scale earthen masonry shell at the 15th International Architecture Exhibition "La Biennale di Venezia", curated by Alejandro Aravena.
Prototype for the "Droneport", a small airport for drones for the future Red Line project in Rwanda that seeks to create a drone network to deliver medical supplies and other necessities to places in Africa with limited access to roads.
A Tile-vaulted structure use of locally available non-fired soil bricks, minimizes the carbon emission of the entire building process and
With its tools for compression-only form finding, the structure is stressed uniformly by its own weight and has sufficient double curvature to be stable in compression under all other loading conditions, reducing the need to import large amounts of expensive materials such as reinforcing steel or cement.
A proof-of-concept droneport shell was at the 2016 Venice Architecture Biennale in less than six months, including only four weeks on site in Venice. Researchers of ETH Zurich, the Massachusetts Institute of Technology (MIT), and the University of Cambridge, and builders lead by master mason Carlos Martin Jiménez.
Sponsored by the LafargeHolcim Foundation for Sustainable Construction. Vault spans an area of 10 x 8 metres with an inner layer of clay tiles from Spain and two outer layers of "DuraBric", a naturally cured building block made of compressed earth and cement developed by the LafargeHolcim Research Centre in Lyon.

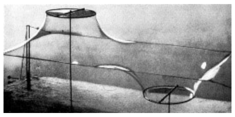
1:30

ETH Zurich Pavilion, New York City, USA, 2015
Commissioned by ETH Global, co-designed with Dirk Hebel's chair a compression vault, for the 2015 Ideas City festival in New York City, by the New Museum.
Built from compressed tetra-pack panels using New York's waste products, compressed into sheets of 9mm as its construction material, as a substance from which to construct new cities.
Waste belongs neither to the family of natural resources nor to finished products and has, until now, been a by-product, an (ideally) invisible part of our cities. The ETH Pavilion defines waste as a resource for the construction of our future cities.
The shape of the vault has been designed such that the stresses in the structure are predominantly compressive, allowing a considerably weak product to act as a structural material.

1:35

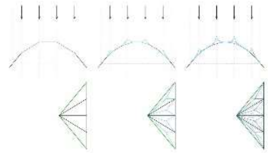
Josef Albers material studies at Bauhaus Dessau in late 1920s, then continuing at Black Mountain College in North Carolina later in century,
using material as the driving force in open ended creative design process.

Frei Otto at his institute at the University of Stuttgart from 1960s to 1980s, developed what he called 'form-finding' methods in a series of experiments with various material systems, from soap bubbles, sand, grid shells, cable nets, to study their inherent capacity to physically compute form to an equilibrium state, based on the system-intrinsic material behavior and extrinsic forces.

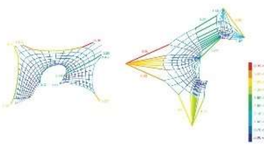


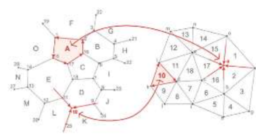
Architectural designs from bottom up, rather than top down determination of form,
Utilizing a computational design, simulation, fabrication of prototype models,
fusing structural calculation and physical architectural design.

Gaudí's Estereostàtic model for the **Colonia Güell church**,

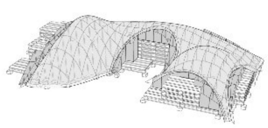


developed from Graphic-Statics method of 2D drawing calculation of form,
using length of lines to represent amount of loading force applied to the structure,
a method that can not be described / explained by modern mathematics.





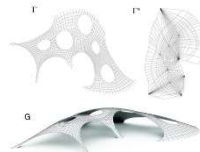
Thrust Network Analysis: A new methodology for three-dimensional equilibrium,
Journal of the International Association for Shell and Spatial Structures, 2007.
For generating compression-only vaulted surfaces and networks. The method finds possible funicular solutions under gravitational loading within a defined envelope. Graphical and intuitive method, adopting the same advantages of techniques such as graphic statics, but offering a viable extension to fully three-dimensional problems. Applicable for the analysis of vaulted historical structures, specifically in unreinforced masonry, as well as the design of new vaulted structures.
[Developed by Philipe Block for PhD (2009) at MIT, under Prof. John Ochsendorf.]



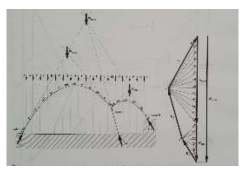
Form Finding to Fabrication: A digital design process for masonry vaults
Proceedings of the International Association for Shell and Spatial Structures Symposium, Shanghai, China, 2010.
Thrust Network Analysis (TNA), form finding through discrete force diagrams, for compression-only masonry shells. Representations of the geometry of the force (thrust) network for the use in structural and experimental modelling software and fabrication. Implemented in existing CAD software, offering fully interactive control of boundary conditions, the internal stress field and the weight distribution of the shell. Linked to a NURBS surface for continuous geometric information, the automatic generation of the shell volume according to its self-weight.

■ **MLK Jr. Park Stone Vault**, Austin, TX, USA, 2010-2013
Multi-purpose community space in urban development and transit-oriented district.
RhinoVAULT - Designing funicular form with Rhino

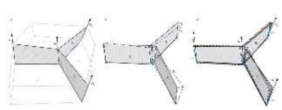
RhinoVAULT - Interactive Vault Design
The Rhinoceros® Plug-In RhinoVAULT
International Journal of Space Structures, 2012.



The equilibrium of funicular compression networks is represented by reciprocal diagrams, which visually express the force dependencies between different parts of the structure. By modifying these diagrams in real-time, the designer is able to explore novel and expressive vaulted geometries that are blurring the difference between shapes typically associated with compression-only forms, obtained e.g. with hanging networks, and freeform surface structures.


The project was exhibited at the 13th International Architecture Exhibition at the Venice Biennale 2012, titled "Common Ground", invited by **Patrik Schumacher**, partner at **Zaha Hadid Architects**, to add to their exhibition on shell structures.


Armadillo Vault, - La Biennale di Venezia, Italy, curated by Alejandro Aravena, 15th International Architecture Exhibition, May 28 to November 27, 2016.
399 individually cut limestone pieces, unreinforced and assembled without mortar, spans 16 meters, minimum thickness of 5 cm, proportionally as thin as an egg shell.
Funicular geometry stands in pure compression, while tension ties equilibrate form.
Each stone voussoir is informed by structural logic, need for precise fabrication and assembly. Planar on the exterior to avoid the need to flip the stones during machining. Their interior sides' doubly curved geometry was obtained through rough cutting. Rather than milling away the excess material left by this process, it was instead hammered off, leaving the resulting grooves as an expressive feature.

1:50 BREAK 2pm

■ **Cable-net and fabric formed thin shell**, Buda, TX, USA, 2014
Together with Escobedo Construction fabricated a small prototype of a thin shell using a cable-net and fabric formwork, standard shoring and scaffolding elements. Using both large cable nets with a secondary system of fabric shuttering as well as fabric directly as a formwork for concrete shells. Lightweight formwork systems reduce the need for seperate foundations of the formwork and allow unobstructed space underneath the shell during construction.
Scale the concept of fabric formworks to the size of large-span roofs and bridges, especially when applying a thin coat of concrete or mortar to form a shell structure.

2:05

■ **Beyond Bending** - Venice Architecture Biennale 2016
With Ochsendorf, DeJong & Block (John Ochsendorf being Prof. at the MIT, Matthew DeJong at University of Cambridge) with The Escobedo Group.
Potential to achieve efficiency and stability while curbing material waste.
Learning from the past to design a better future, throughout history, much of world's built structures are unreinforced masonry and often unclear how they still stand when conventional analysis tools have predicted their failure. There is much to learn from the architectural and structural principles that were developed.

By better understanding the flow of compressive forces in three dimensions, excess steel can be eliminated, natural resources can be conserved, humble earth materials can be reimagined for the future.
Combining past methods with new technologies and fabrication techniques, this installation advocates for the logic of compression-only forms, beyond the slab, beyond the dome, beyond free-form, and ultimately beyond bending.

Beyond Bending II - Sustainable affordable housing for South Africa, Venice, Italy, 2021
Collaboration between the Block Research Group (BRG) at the ETH Zurich, South Africa's Department of Environment, Forestry and Fisheries (DEFF) and nonCrete. As a part of the biennial architecture exhibition "Time Space Existence" organised by the European Cultural Centre (ECC), on display at Palazzo Mora (Room #05) from May 22nd 2021 until November 21st 2021.
The building industry is responsible for 40% of global resource consumption, over 35% of waste generated worldwide and 40% of human-caused CO_2 emissions each year. The global population to increase by 2.1 billion people over the next 30 years, not possible to continue, if we want to reduce greenhouse gas emissions, slow the depletion of natural resources and minimize waste production. Three quarters of a typical building's embodied energy attributed to its structural mass, a sustainable future of the building industry requires a shift in structural systems of buildings are designed, fabricated, and constructed.

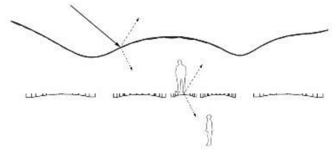
This exhibit presents innovative material and construction methods that have the potential to provide safe and dignified housing in South Africa in a more affordable and sustainable manner. By clearing and chipping biomass of water-thirsty invading alien plants (IAP's) as a substitute for sand and stone as aggregate, a more sustainable alternative to conventional concrete, a bio-concrete, can be produced, ensuring water security, restoring natural ecosystems and creating labor intensive jobs in impoverished communities. The lightweight falsework and shuttering of the formwork system can be fabricated by local basket weavers using local grasses and invasive reeds. Such a system not only further reduces the overall environmental impact of the building as well as the construction process, but also supports market-driven demand for sustaining local tradition and crafts.

■ **Striatus - 3D concrete printed masonry bridge**, Venice, Italy, 2021
Exhibited at the Giardini della Marinaressa during the Venice Architecture Biennale until November 2021
Project by the Block Research Group (BRG) at ETH Zurich and Zaha Hadid Architects Computation and Design Group (ZHACODE), in collaboration with incremental3D (in3D), made possible by Holcim.
Striatus is an arched, unreinforced masonry footbridge composed of 3D-printed concrete blocks assembled without mortar, 16x12-metre footbridge is printed in layers orthogonal to the main structural forces to create a “striated” compression-only funicular structure that requires no reinforcement.
Striatus places material only where needed, significantly reducing its environmental footprint. Built without reinforcement and using dry assembly without binders, Striatus can be installed, dismantled, reassembled and repurposed repeatedly;
Unlike typical extrusion 3D printing in simple horizontal layers, Striatus uses a two-component (2K) concrete ink with corresponding printing head and pumping arrangement to precisely print non-uniform and non-parallel layers via a 6-axis, multi-DOF robotic arm. This new generation of 3D concrete printing in combination with the arched masonry design allows the resulting components to be used structurally without any reinforcement or post-tensioning.
Compared to typical reinforced concrete flat floor slabs, this new floor system uses only 30% of the volume of concrete and just 10% of the amount of steel. The very low stresses within the funicular structure also enable the use of low-embodied-carbon concrete that incorporates high percentages of recycled construction waste. With an estimated 300 billion square metres of floor area to be constructed worldwide over the next 30 years, and floors comprising more than 40% of the weight of most high-rise buildings (10+ storeys), transforming how we design and construct our built environment to address the defining challenges of our era.

■ **MycoTree -** Professorship of Sustainable Construction at Karlsruhe Institute of Technology (KIT) and the Block Research Group at the Swiss Federal Institute of Technology (ETH) Zürich. Centerpiece of the "Beyond Mining – Urban Growth" exhibition at the Seoul Biennale of Architecture and Urbanism 2017 in Seoul, Korea curated by Hyungmin Pai and Alejandro Zaera-Polo.

MycoTree is a spatial branching structure made out of load-bearing naturally grown mycelium components. Its geometry was designed using 3D graphic statics, keeping the weak material in compression only. Its complex nodes were grown in digitally fabricated moulds.

Utilising only mycelium and bamboo, the structure represents a provocative vision of how we may move beyond the mining of our construction materials from the earth's crust to their cultivation and urban growth; how achieving stability through geometry rather than through material strength opens up the possibility of using weaker materials structurally and safely; and, ultimately, how regenerative resources in combination with informed structural design have the potential to propose an alternative to established, structural materials for a more sustainable building industry.



■ **Acoustic insulation through structural stiffness**

Shape of building structures also affects acoustics, especially in shell structures.
Guastavino's Akoustolith Tiles (1916) Cathedral Learning.
Building acoustics to minimize sound transmission in facades, roofs, floor systems and wall partitions. Transmission Losses (TL) are calculated for building components according to mass, thickness and the material properties of layers. Much research has also been done regarding the perception of noise by the human auditory system according to each sound frequency. This has yielded several noise rating systems used to classify rooms according to how much sound pressure is reduced by their building components. Rooms are required to have a minimum noise rating according to their function; for example, a concert hall requires a better noise rating than a restaurant or an office.
Acoustical insulation is often addressed by adding mass to the building envelope. Mass makes it more difficult for the sound energy to excite the envelope and to transmit sound vibrations from the outside to the inside or from one room to the other. Surfaces with a double curvature are much stiffer when compared to flat surfaces of the same material and thickness. Stiffness also makes it harder for sound energy to be transmitted through building elements, meaning that the added structural stiffness acts as additional acoustical insulation without requiring further mass, costs and embodied energy.
Research studies the relationship between the stiffness and the acoustical insulation properties of structural shells. Simultaneously optimize the structural capacity and minimize sound transmission. Generation of structural forms that allows for more accurate predictions of acoustical behavior, especially in shell structures, reduces the amount of materials required, and results in energy efficient construction.

Guangzhou Opera House by Zaha Hadid (Guangzhou, China, 2003-2010)

Heydar Aliyev Centre by Zaha Hadid (Baku, Azerbaijan, 2007-2012)

Walt Disney Concert Hall by Frank Gehry (Los Angeles, 1987-1991)

Pritzker Pavilion in Millennium Park by Frank Gehry (Chicago, 2004)
Park roof, transparent, yet sense of enclosure