International Course on Architectural Design | Master Program
INDUSTRIAL DESIGN AND ARCHITECTURAL DIGITAL FABRICATION

SYSTEMS AND COMPONENTS DESIGN

ON FORM INVESTIGATION
ASSEMBLING AND JOINING STRUCTURES

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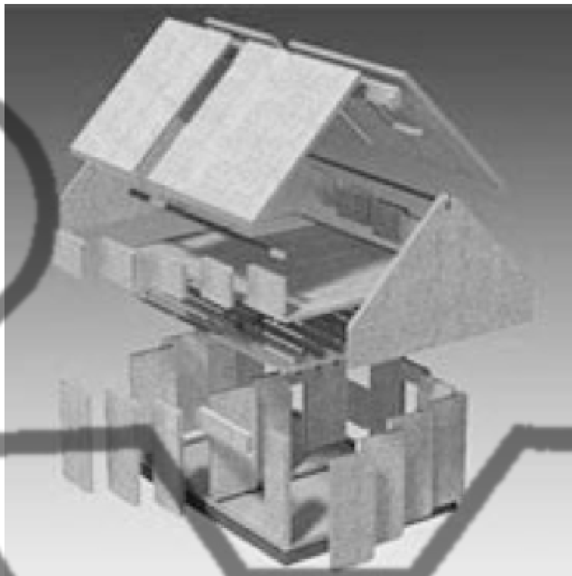
This document contains some examples related to the study of structural forms with particular reference to the union of the parts that compose the architectural system of a construction.

The material is conceived as a resourse to support the course *Systems and Compontens Design*, a disciplinary contribution of «Technology of architecture» to the integrated laboratory *Architecture and Structure Design Lab* (1st year)

prof. Giuseppe Ridolfi, PhD | 2015 |rev 2017



Building is a big entity that needs to be assembled in different parts and phases.

ON FORM INVESTIGATION
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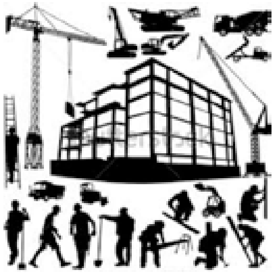
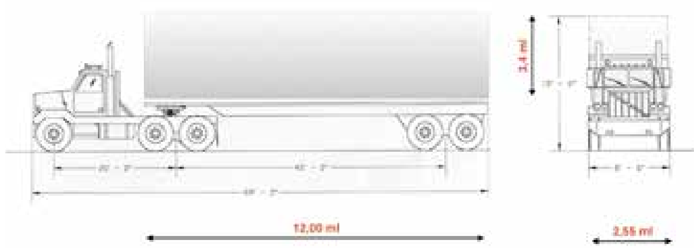
Building is a big entity that needs to be assembled in different parts and phases. Parts that have their materiality, dimensions, weight and performances. All these characteristics affect modality and strategy to build. Dimensions and weight need to be considered for transportation and manoeuvrability.

Elements that exceed normal dimensions allowed for trucks transportation (2,55 m width; 3,4 m heigth, 12 m lenght) cannot be used to build. Elements with a weight that exceeds the normal capacity of a man require the use of equipment for handling. Also dimensions that cannot fit the human capacity needs specific tools and machines, sometimes very expensive.
Dimensions has to be carefully considered for the constraints that may be present on the building site or during the construction phase because other elements already made may prevent their positioning.
If the behaviour of each element is very important when the building is in use, its performances is also very important for the construction process. The assembling and joining peculiarities of each elements represent an important issue affecting the strategy of conceiving building projects regardless of the adopted structural type.





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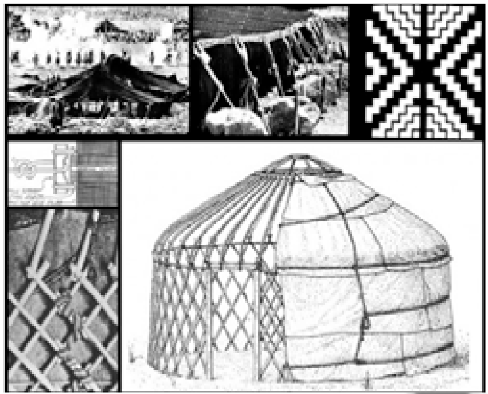
using gravity and friction


using stretching and tightening

Some ways of building

Excluding excavation one of the main way to build was *stacking*: piling materials or elements exploiting their friction characteristics and weight and later, using their capacity to be bound by a third material.

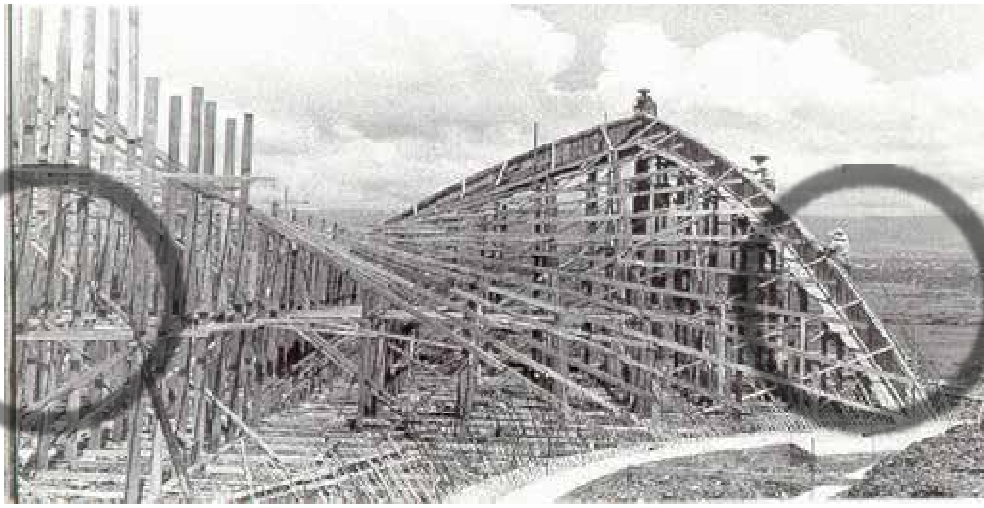
Another archetype of building systems is *weaving*, where materials have inherent characteristics to be bent and stretched. Usually, in this systems light elements are preferred, where in the first one the heaviest are most used.

At the beginning of the 1900 the industrial production of concrete allowed another way to build: we can recognize this new approach as *casting*. Casting concrete represented a very new significant opportunity for the art of architecture, but we have to recognize that *weaving* was still the strategy and the technique under this new way of production.

In fact, the traditional execution of this technology required that builders must prepare the mold before pouring concrete and these mold, the formworks, were made by assembling wooden boards and beams. It is well known that, in the past, the best workers for concrete structures came from the shipyards or from areas where wood technology was widely used.

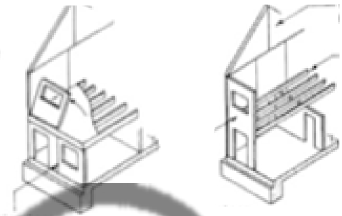
The other material that emerged from the industrial revolution was the iron, used in its different percentage of carbon: grey cast iron, mild steel, steel and today in other alloy combination with different characteristics such as the Exten, Mar-Ten e Triten types where the CorTen, patented in USA in the 1933, is the most famous one.

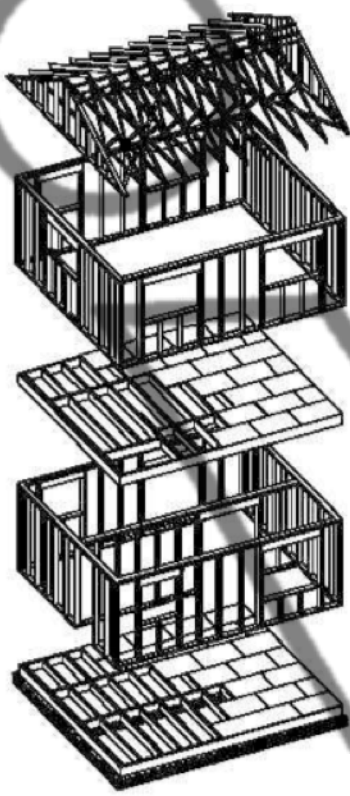
For it's nature and performances it's clearly evident that also for iron the assembly strategy was weaving. In fact, since the beginning and without any scientific knowledge, designers and constructors approach this new material applying wooden techniques to arrange elements and to assemble them.



Felix Candela's shells under construction. The complex formworks show the importance of weaving and wood technology

Bridge on River Severn by Abraham Darby III, 1779. A clear example of weaving and how, without scientific knowledge, designer applyed the rules of thumbs from other technologies: in this case from the construction of stone arches since cast iron has the same structural behavior of stone.





Building structure typologies and peculiarity of their elements.

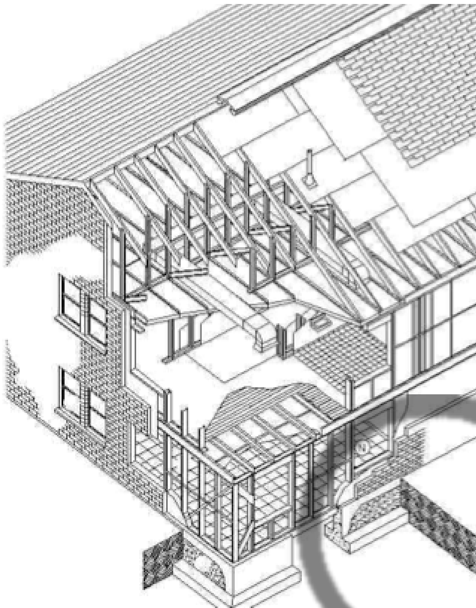
The effects of these two strategies (stacking vs weaving) can be clearly observed also on the structural design approach. We can differentiate two structural typologies: the *platform type* and the *continuous pole type* where the former is more suitable to be realized using-stacking, the latter using weaving.

The construction of a platform building, also known as «box structure», proceeds floor by floor with some advantages and disadvantages. For example, it can provide a safe surface for workers. Floor can be used as a place to assemble walls or other elements and from there to tilt the entire unit into place; it can also offer a good barrier for fire stopping. As disadvantages we can list the fact that the walls present discontinuity and do not work optimally when the structures must have a prevailing vertical development. This kind of approach has good applications in housing, when the plans lay-out is repetitive and their span are not very long.

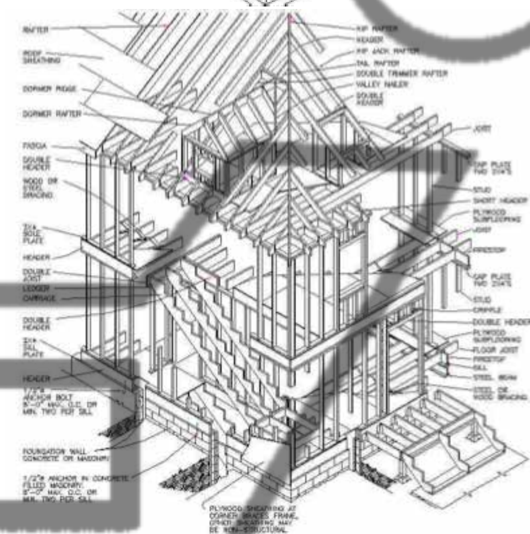
The long pole (or «continuous post») structure type is mainly used for buildings where the vertical elements prevail in their continuity, and the horizontal ones are placed after the vertical components are in position. This kind of structure has good applications for tall building, wide façade or where a large space is required. In the history a good example of this technique were the *stavkirke* mainly located in Norway where tall and straight trees were available. Another example of this technique was the famous «Balloon-frame» that a popular suggestion, reported by the architect John

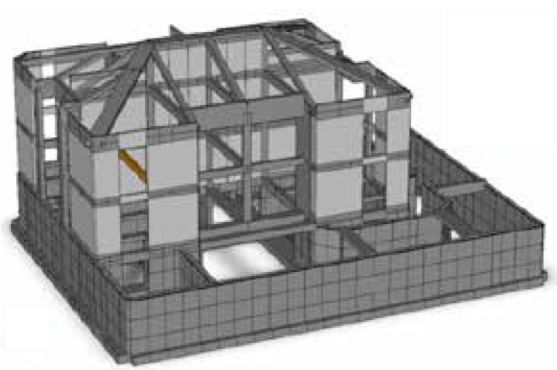
M. Van Osdel, indicates in the Chicagoan carpenter George W. Snow his inventor.

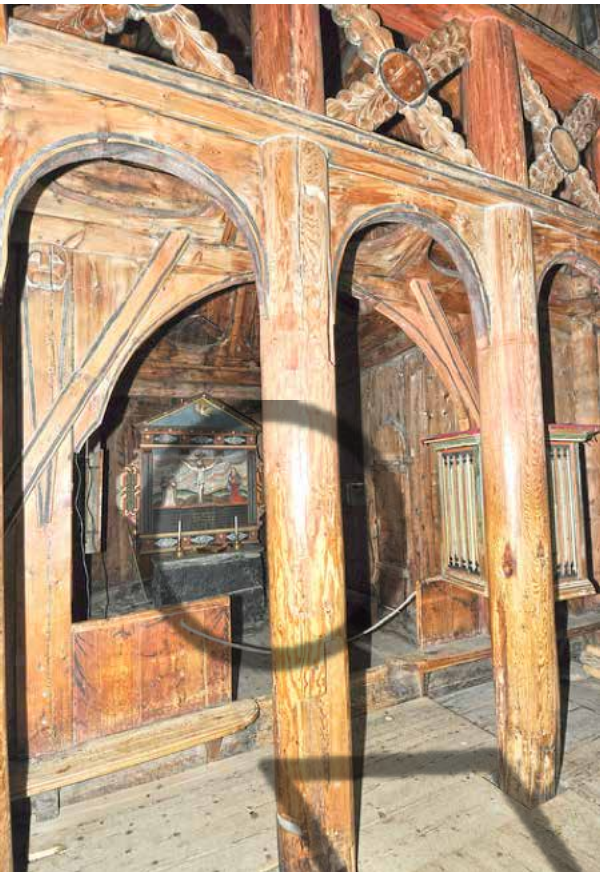
Also in this kind of building, the vertical elements run uninterrupted and the horizontal joists are attached to them but with important differences compared to the old *stavkirke*. The differences were the fastening system and the elements used. In fact, the balloon frame introduced smaller, standardized timbers as structural elements and machine-produced wire nails as joining system. They replaced heavy poles and the sophisticated technique of dovetails in order to reduce time, material, expertise and costs in construction. With nails and light elements, few people not very skilled was able to realize the skeleton of a house in less than a week where the old systems, based on tenon and mortise or *blockbau* technique, required heavy wooden logs and expert craftsmen. The adoption of standardized light timbers made possible the entry of a new type of construction: the *framing structure,* a structural approach that later was widely adopted in the technology of steel and concrete. Le Corbousier was one of the most noted architect to recognize its value, coding this new system with the well known Maison Domino.

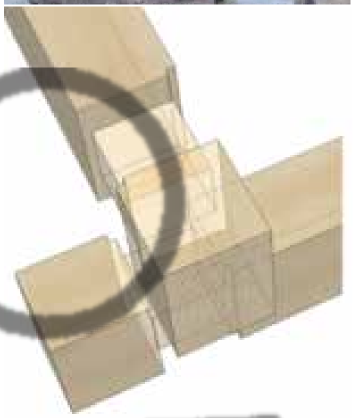


PLATFORM (box) TYPE



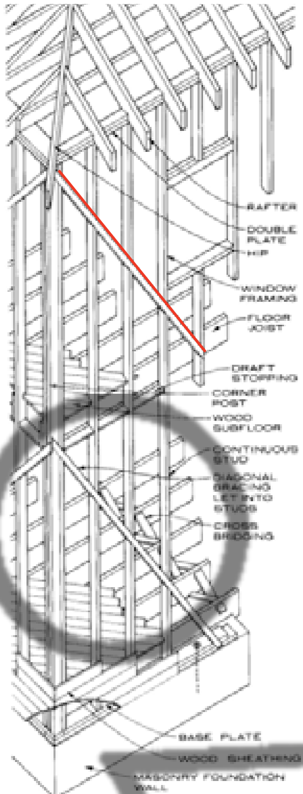




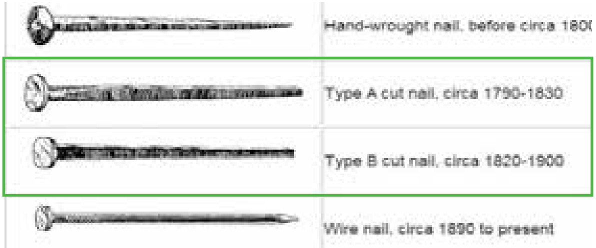


opposite page:
Stav-Kirke
continuous long pole façade

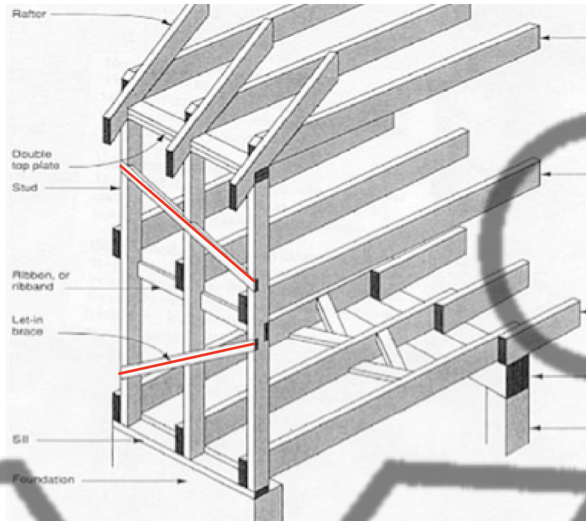
this page:
block bau detail
dovetail interlocking scheme
heavy frame wooden building



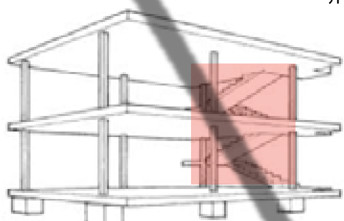
Ballon Frame, 1832



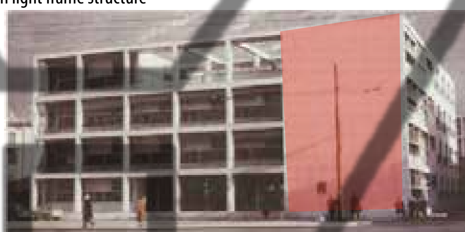
Examples of machine cut (or square) nails



Typical bracing in light frame structure

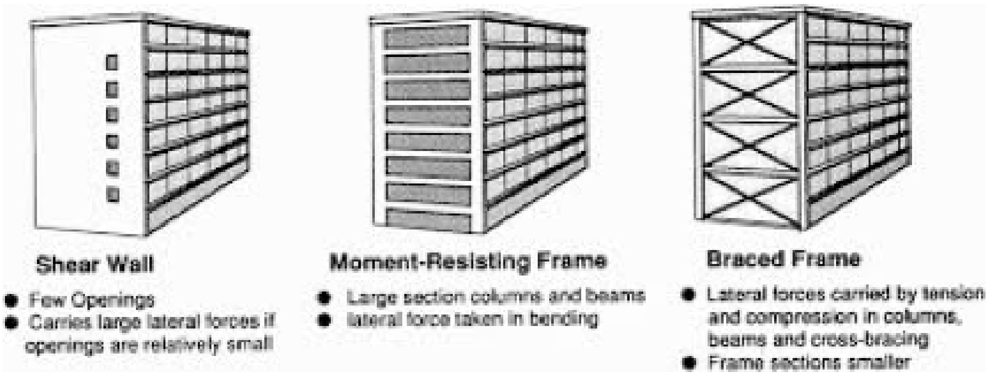


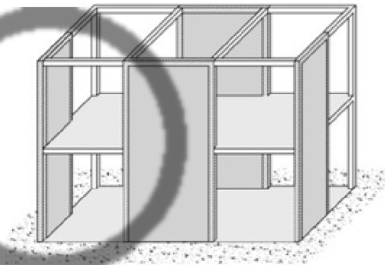
Maison Domino 1914-15



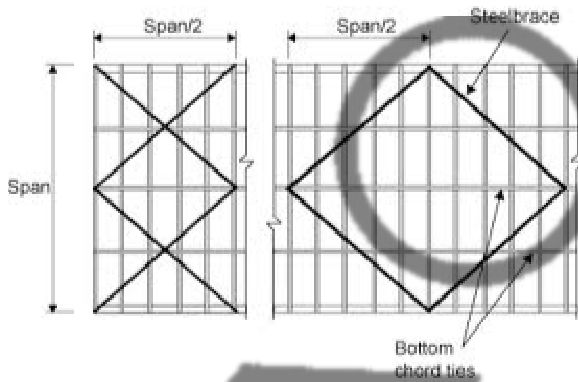
G. Terragni 1932-36

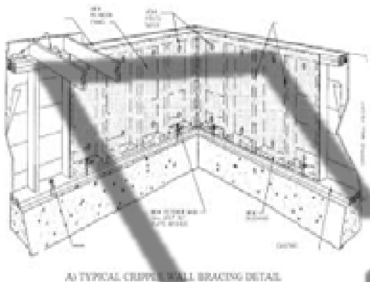
Different bracing devices



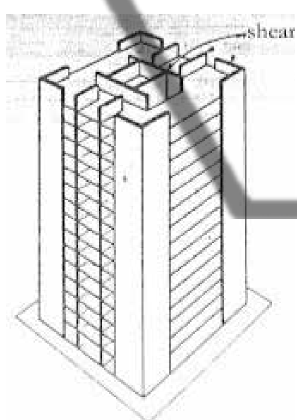


overlapping rigid boards to the frame elements.

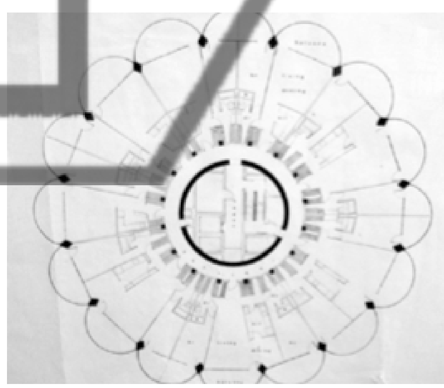




St.Andrews cross-bracing



shear walls type



shear core type Bertrand Goldberg , Marina City Apartments, 1959-64

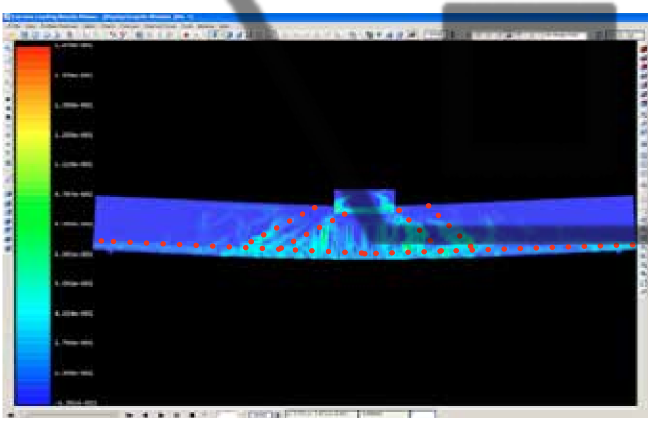
One of the most important aspects to take in account in designing framing structure is the *bracing* to prevent the horizontal movements.

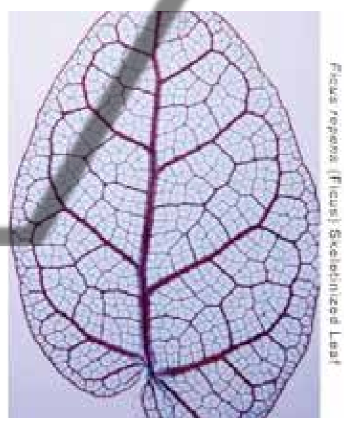
Maison Domino is a clear example of a framed structure but, because the vertical elements are massive and reduced in number, the right definition for this type is *heavy framing structure* in opposition of the *light framing structure* of the «Balloon frame» where the vertical elements are in great number, reduced in section and uniform.

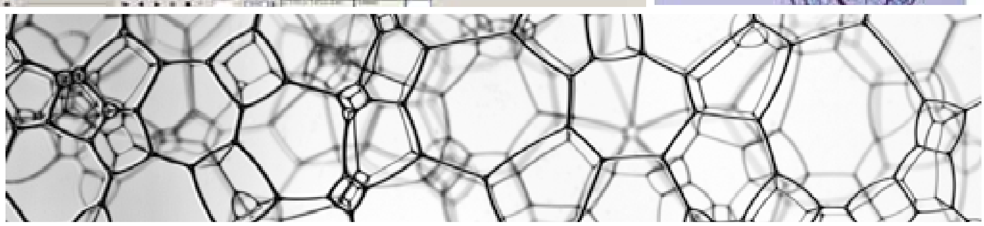
One of the most important aspect to take in account in designing framing structures is the *bracing* to prevent the horizontal movement of the construction. For this purpose, designers can put in place a number of devices such as: triangulations in between some part of the vertical elements, St. Andrews cross-bracing, isolated rigid element in conjunction with the frame elements such as shear walls and shear core, or overlapping rigid boards to the frame elements.

Discrete vs Continuous Structural Elements.

The framing approach is a structural strategy that is widely adopted in nature. It corresponds to the principle of displacing the material where it is needed and removing it where it is not required. Framings, trusses, spatial structures belong to this kind of family: structures made of *discrete* elements. This kind of structure are in opposition to another type: structure made of *continuous* elements represented by masonry or concrete bearing walls, precast panels of different constitutions and materials. Although the structures made of discrete elements have obvious advantages of lightness and a bet-



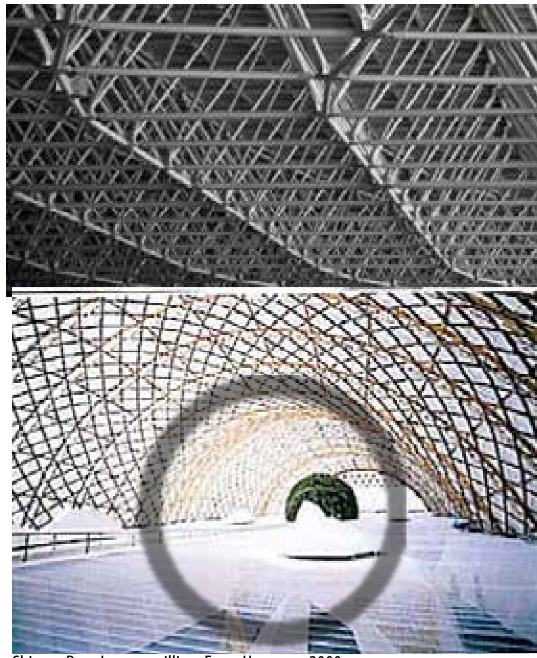


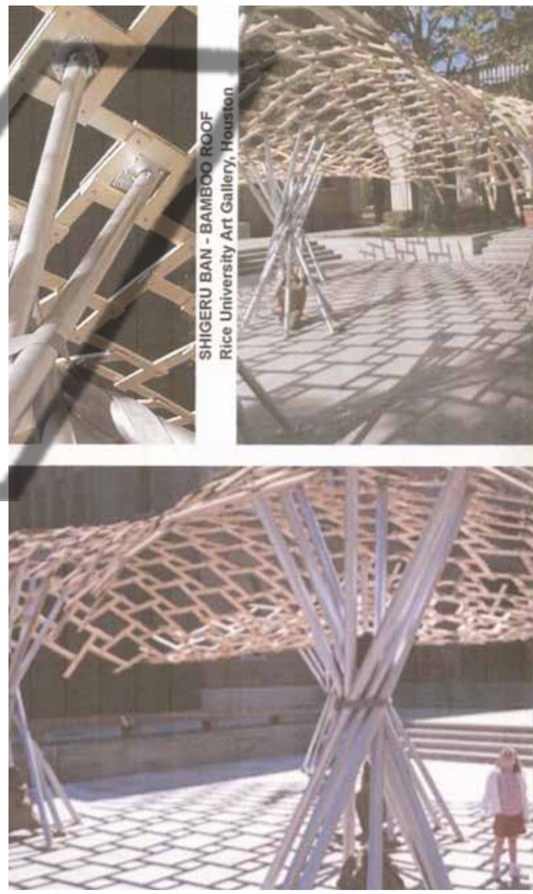


ter ratio of performance and weight, structures made of continuous elements are still widely used for various reasons. Some of these reasons are based on the less complexity to produce them, or on the fact that the continuity of their surfaces can offer, at the same time, bearing and envelope functions.

In last years one of these kind of systems is the Cross Laminated Timber (CLT) or briefly Cross-Lam (Xlam) a new generation of engineered massive wood product started from 1990 in Austria and Germany, that has been gaining popularity in residential and mid span buildings. This technology offers rapidity and easiness in assembling, good thermal and sound insulation, good fire resistance and a standardized technique for the connection of its elements. The X-Lam is also high valuable for its high level of prefabrication allowing the application of the state-of-the art CNC manufacturing technologies and, as a consequence, an effective implementation of the file-to-factory process and a very high accuracy in production.
(http://www.forestprod.org/buy_publications/resources/untitled/summer2012/Volume%2022,%20Issue%202%20Mohammad.pdf)

Anyhow X-Lam system, precast panels or masonry bearing walls, need to be conceived and assembled in conformity with the platform approach.
In contrast, the discrete structural elements can be used both by following the patterns of the platform and the long pole type.
The discrete structural elements become absolutely essential when you want to cover large spaces. Although through recent advances in material technology continuous structure can be used to cover wide spans, the use of discrete elements for structural purpose is still more convenient from many points of view. First of all,


Shigeru Ban, Japan pavillion, Expo Hannover 2000

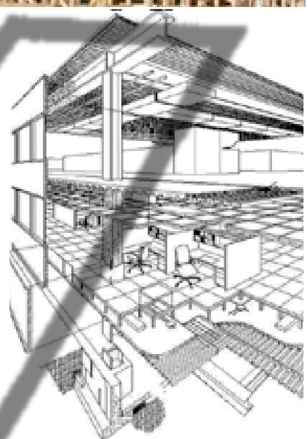


the lighter weight of his elements and, for large-scale works, the possibility of splitting its constituents to reassemble them in the construction site.

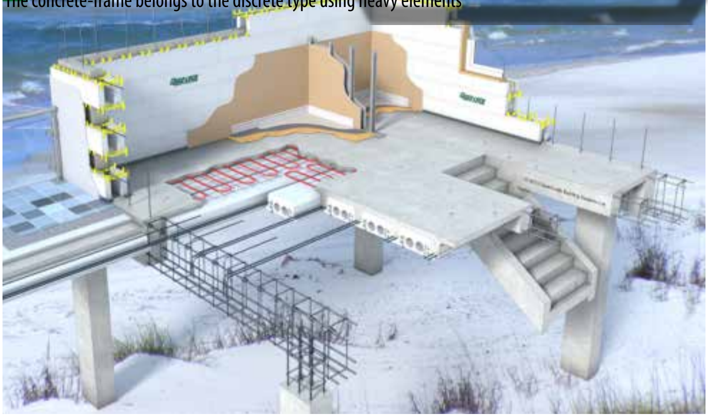
Advanced materials are widely referred to the technology of concrete using high performance steels or pre/post-stressed reinforced concrete but many other innovations have been introduced in construction. Some of these new materials are

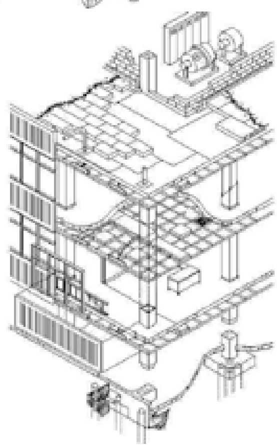
The wood-frame can use light or heavy elements

The metal-frame can use light or heavy elements



The concrete-frame belongs to the discrete type using heavy elements

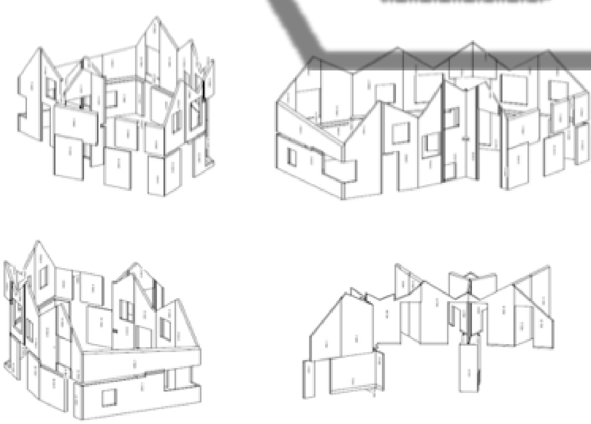




light alloys, metal foams and non-metallic or composite materials with high structural performance derived form aircraft and automotive industries.
Some other of these futuristic materials are microstructure of polymers, glass fibre reinforced plastic (GFRP), ceramic matrix composite (CMC), polymer matrix composite (PMC) and metal matrix composite (MMC).

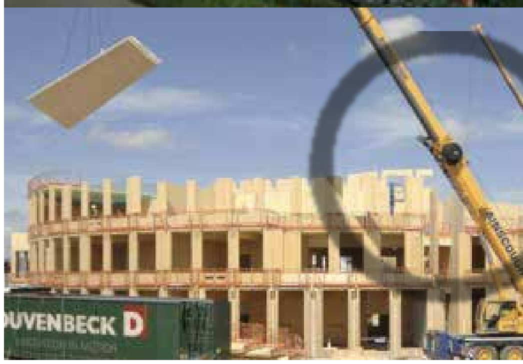
STRUCUTRAL INSULATED PANELS

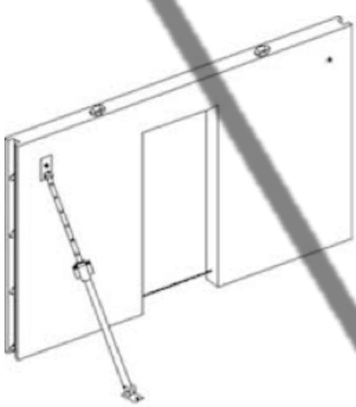
CROSS LAMINATED TIMBER (CLT) / CROSS-LAM (XLam)

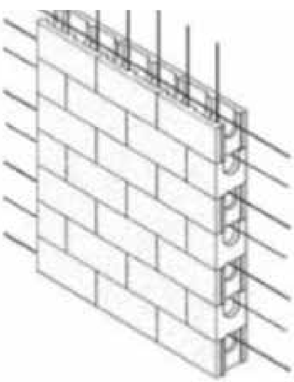


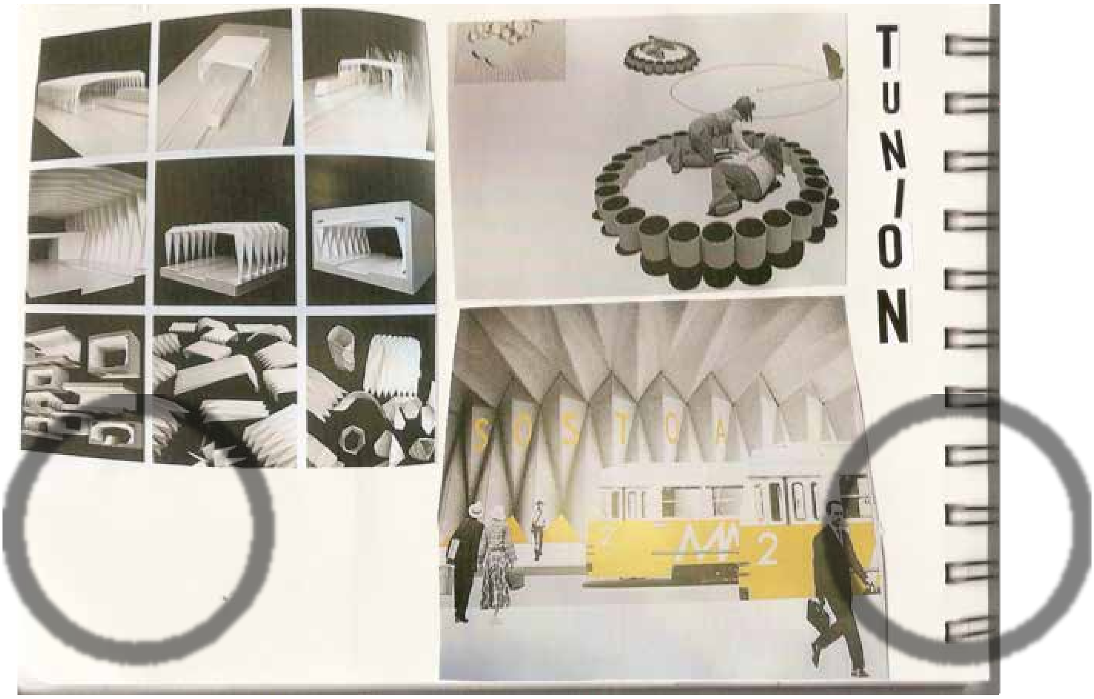
Cross Laminated Timber (CLT) or briefly Cross-Lam (Xlam) is a new generation of engineered massive wood product started from 1990 in Austria and Germany, that has been gaining popularity in residential and mid span buildings. This technology offers rapidity and easiness in assembling, good thermal and sound insulation, good fire resistance and a standardized technique for the connection of its elements. The X-Lam is also high valuable for its high level of prefabrication allowing the application of the state-of-the art CNC manufacturing technologies and, as a consequence, an effective implementation of the file-to-factory process and a very high accuracy in production.

Progetto Sofie (Ivalsa) durante le prove di antisismicità







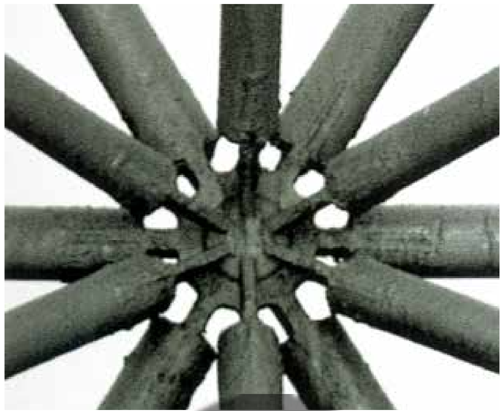

TUNION
SOSTOA
2

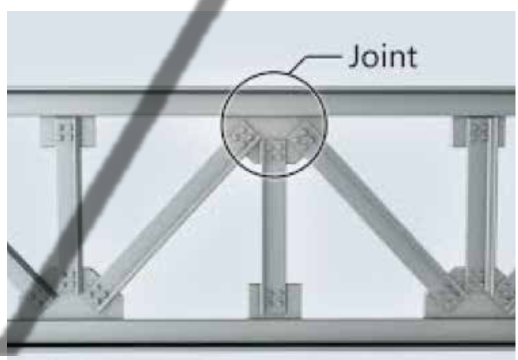
Joining different building structures.

Discrete and continuous structural elements required different assembly strategies and different kind of joining.
The most important aspect to take in consideration is that joining can be *linear* or *punctual*. The former is naturally related to the continuous structural elements and the latter to the discrete ones.
It is well known that joints can be rigid or have some degrees of freedom letting the related elements to have some movements. It is also well known that constrained joints are not always equivalent to a better assurance for the stability of the construction. A rigid structure can be a disaster under the forces induced by earthquake, wind or thermal dilatations. A constrained joint can be a problematic issue during the construction phase; in kinetic building it is absolutely a non sense!

Having said this, we have to consider that the linear joining tend to be rigid with less opportunity for the relative movements of the construction members.

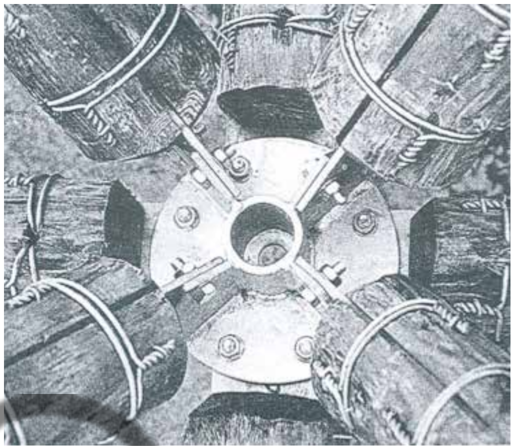
Both types of structure (discrete/continuous) can be assembled directly joining their parts or using a *third* element.
In discrete structural elements this third entity is the *node* where the truss member are converging and joined.
Node can assume different shapes and work in multiple ways. Can be a plate, a sphere, or other shaped object designed to assemble structural elements in different geometrical configurations. During the time many kind of nodes have been developed and used in space truss or in planar truss as well.
One of the most famous historical examples are related to the research of Buckminster Fuller

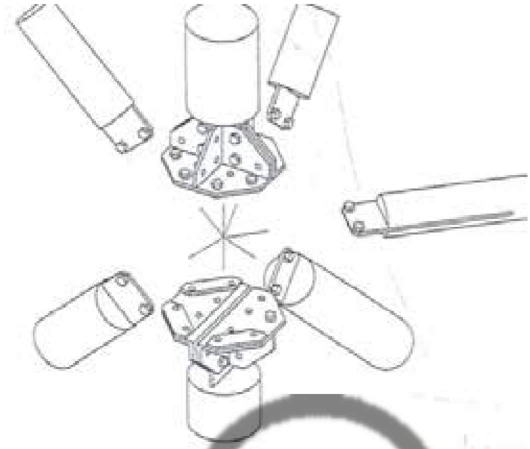


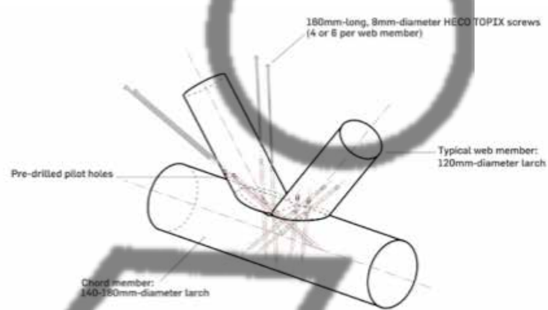


S.Ban, Artek pavillion " Space silence", in UPM ProFi a paper plastic composite 2007

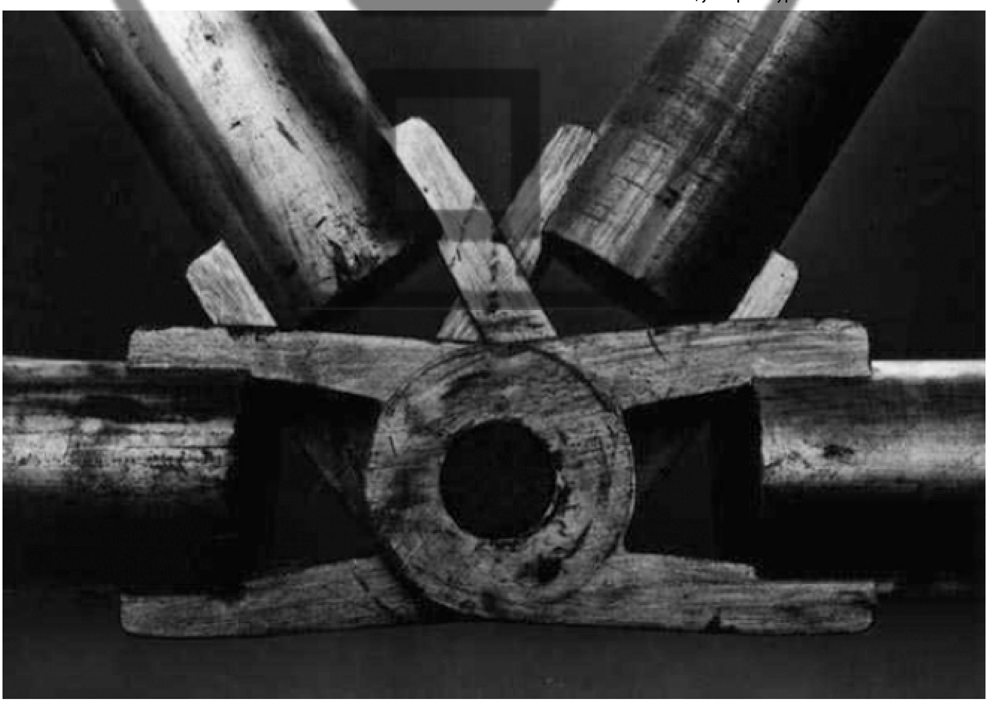
(1895-1983) that realized his first experiment in Black Mountain College or to the work of Konrad Wachsmann (1901-1980). From these early experiments many industries have developed and patented their own solutions. Some of these most famous and widely used systems are: Vestruct, Mero, Pan… All these systems are now able to offer large opportunities for different applications even if many designers and researchers are still puzzling for new solutions and spatial configurations of the final result.



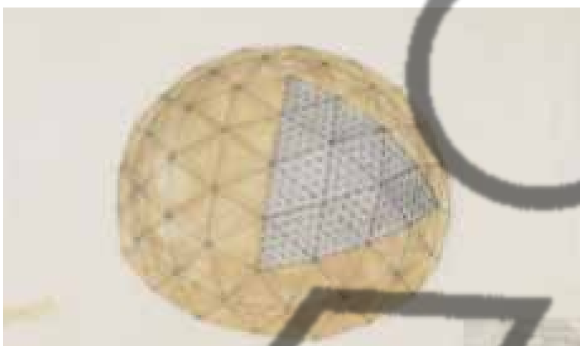




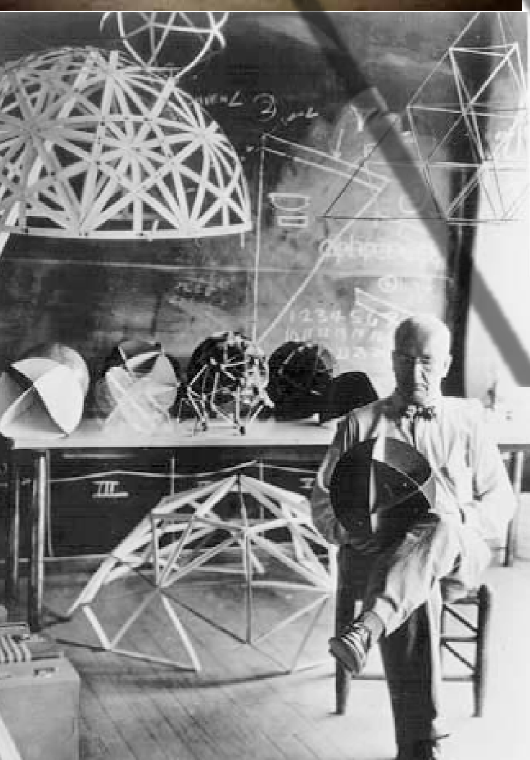
Konrad Wachsmann, joint prototype

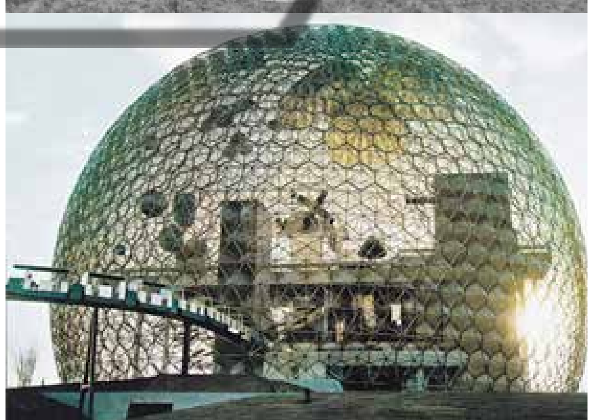


A US Navy helicopter moving a 16,5 m diameter dome 16.5 m,1954



B. Fuller geodesic for ford motorr company,1952-53



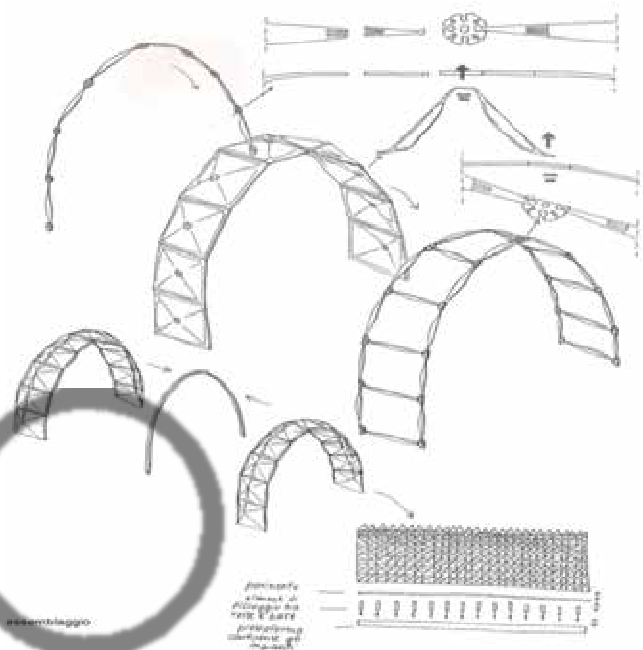


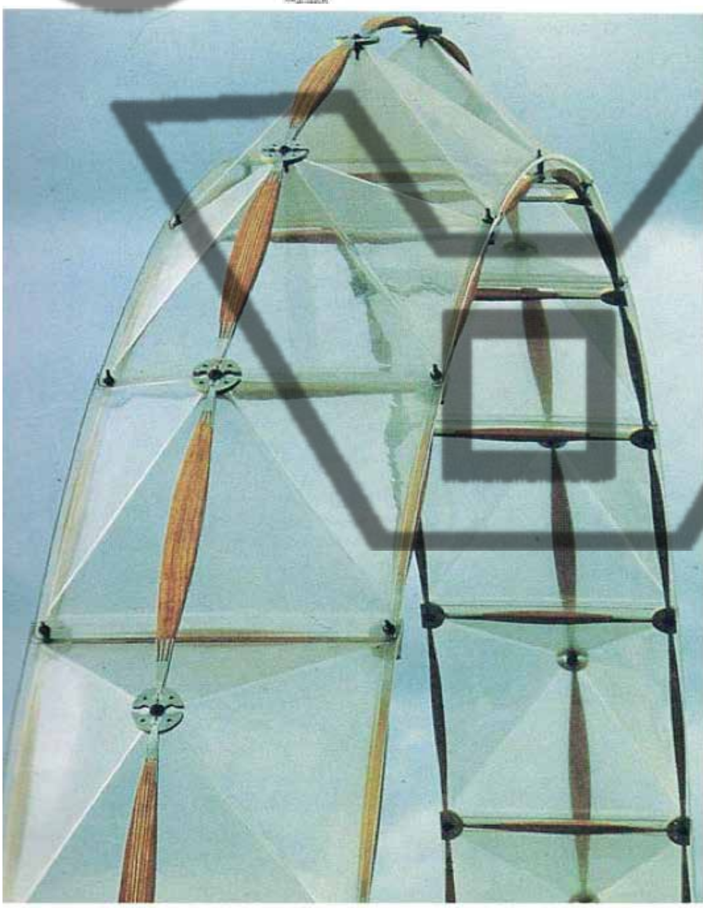
Fuller, @ Black Mountain College, 1948

B. Fuller, USA Pavillon, Expo Montreal,1967

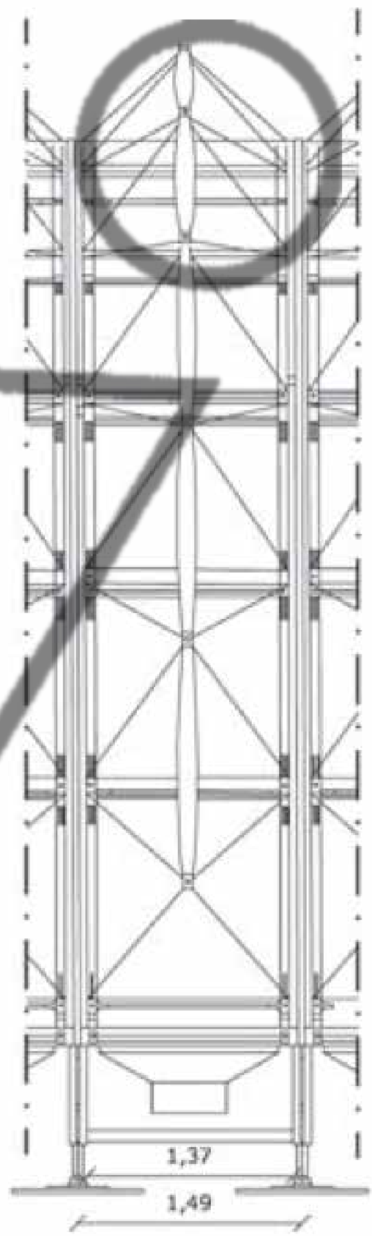

PAN
VESTRUT
MERO

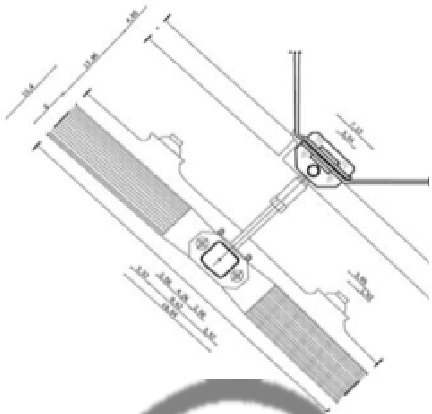
Renzo Piano, IBM travelling pavillion, 1983-86

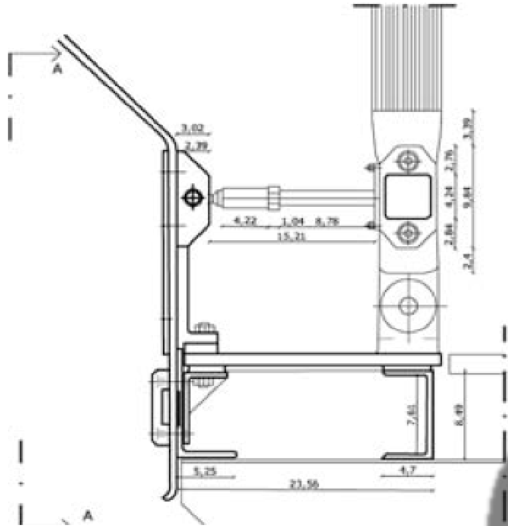


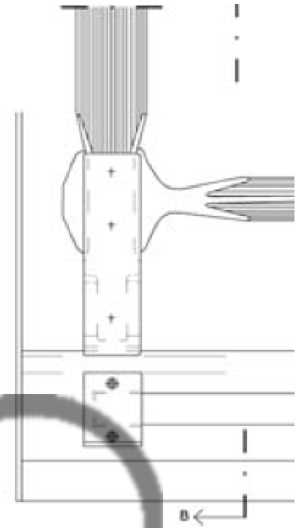


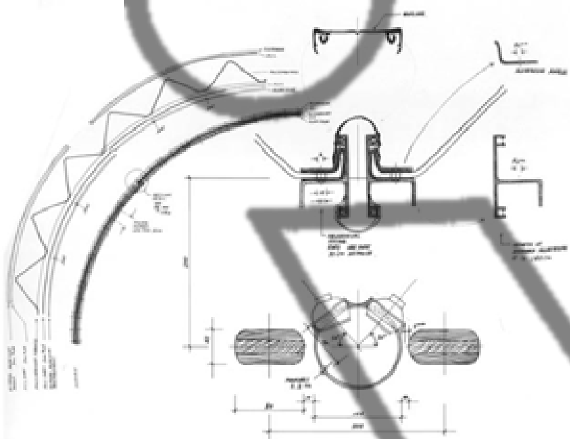
Prova di montaggio di un'arco della struttura

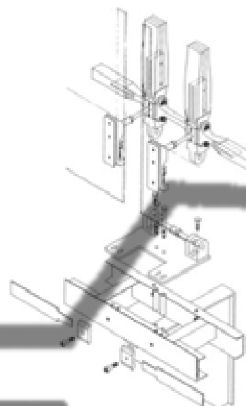








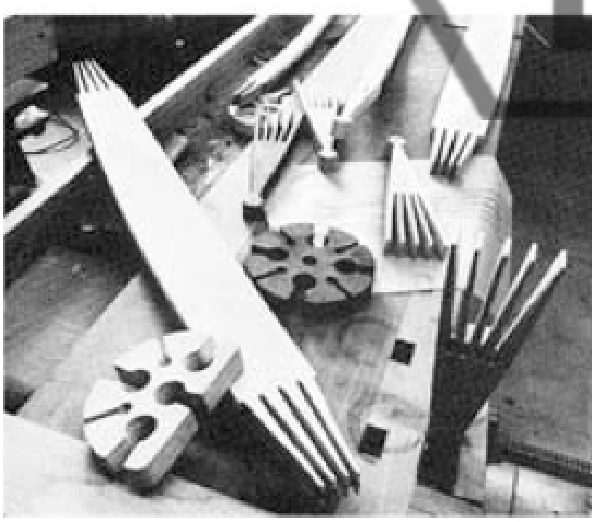


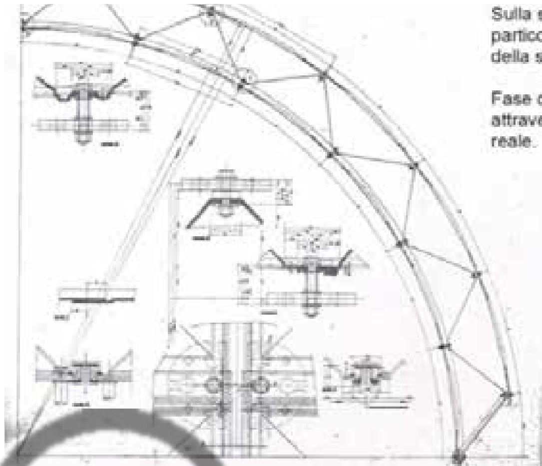


La progettazione si è svolta attraverso una profonda cura dei dettagli che sono stati riprodotti a scala sempre minore.

Sulla sinistra:
modelli di studio delle varie cerniere e incastri.

In basso:
schizzi originali di alcuni dettagli e ricostruzioni tridimensionali dei nodi.

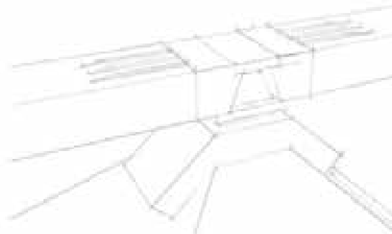




Sulla sinistra:
particolari di alcuni nodi della struttura.

Fase di studio in laboratorio attraverso modelli a grandezza reale.

Particolare attacco superiore della piramide in policarbonato, scala 1:10



Schizzo prospettico del particolare

Fase della lavorazione e del montaggio delle aste in legno lamellare

Fase di montaggio a terra delle piramidi in policarbonato

Fasi di montaggio del padiglione: il basamento e il sollevamento degli archi

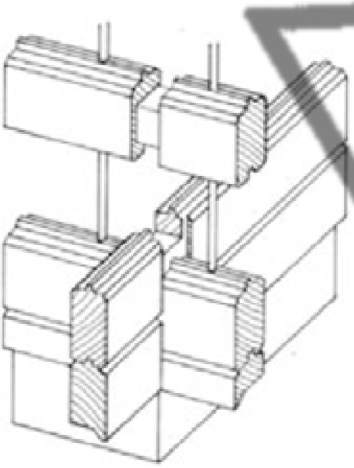
Foto di gruppo a montaggio dell'arco completato

1:

Joining technology

Joining wood. Structure using continuous members less frequently can be joined without using a third element. The technology of the wood is one in which it is possible to realize joints without the third junction element through the use of interlocking.
Over time wood crafts has developed an entire universe of joints for light or heavy structural use:

- tenon and mortise
- tonguen and groove
- lap or halved joint
- through housed
- stopped rebate
- half-lap
- finger (or box) joint
- beveled scarf joint



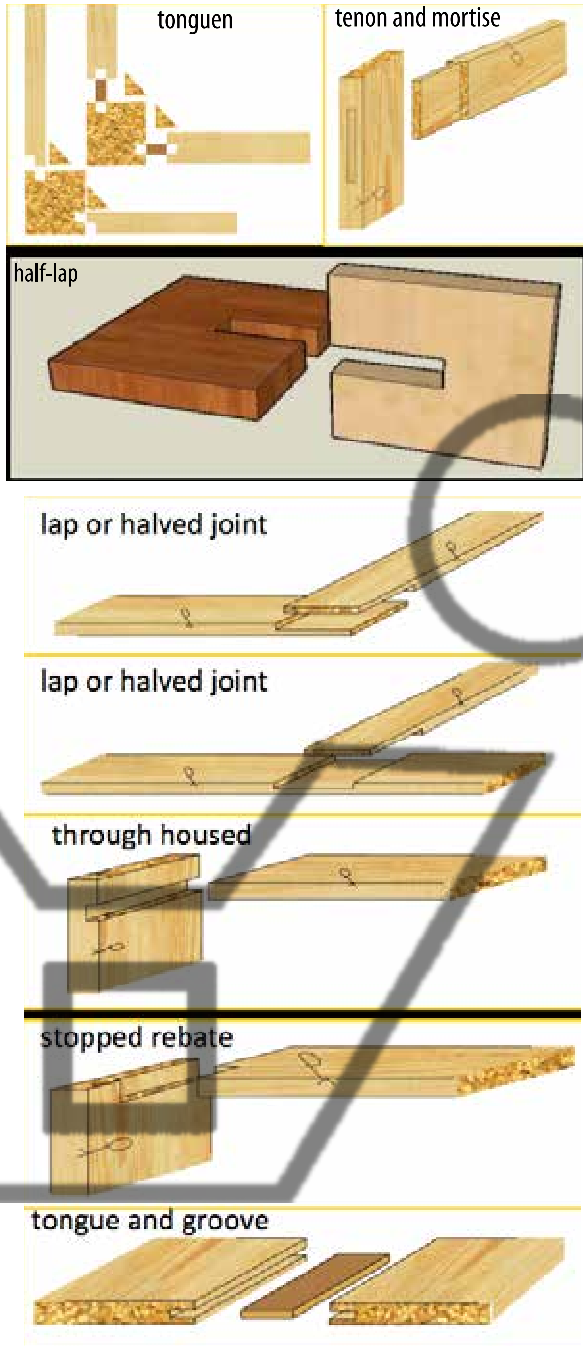
But in fact, very rarely this kind of connections is made without the use of third-party components. Normally these third elements are pins, nails, adhesives, and bolts that become the primary means of fastening in other kind of joints such as:

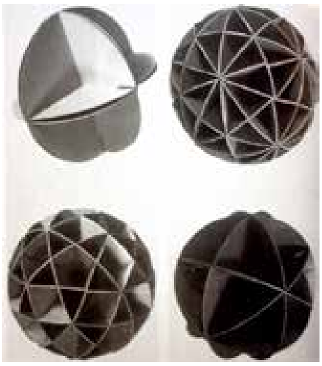
- butt join
- miter join

For joints demanding heavier structural performances, is always required the use of a third element. Normally this element is a metallic plate with different shapes (L, T, C) or more complex ones such as post caps, joist hangers.

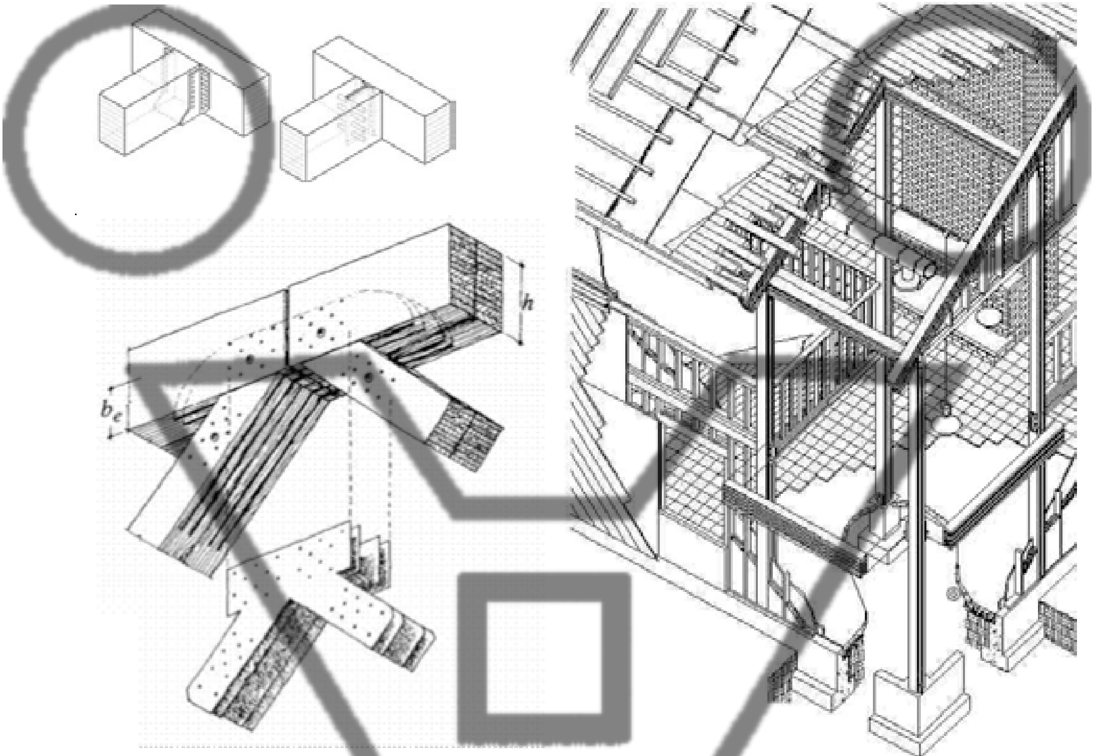
Joining Metal. As written above, at the dawn of metal structures, the assembling strategies for this kind of technology were closely related to the connections used by wood carpenters. In this analogy nails were replaced by rivets: a round ductile steel bar clinched, after heating, in prepared oversized holes. This technology is no longer used and has been replaced by bolts, high strength structural bolts or, for higher resistance, the High Strength Friction Grip (HSFG) less expensive and noisy then rivets.

Currently bolts are the most used system to combine elements regardless of their nature. In particular bolt connection is widely used in the connections to be realized in the construction site and absolutely necessary if the structures need to be disassembled. After many years of experimental application, with the First World War a new connecting technology

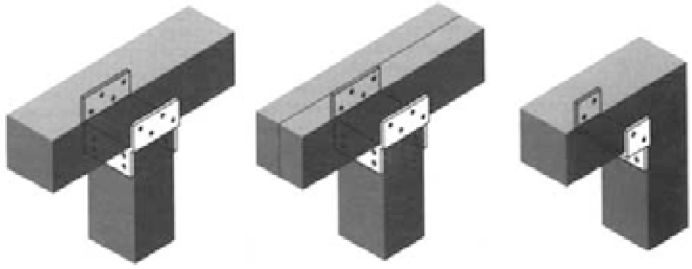


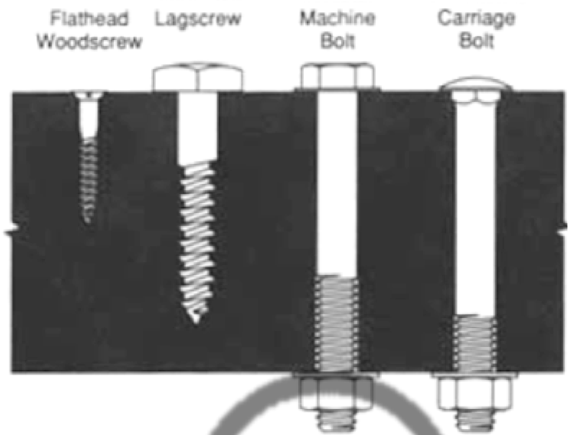


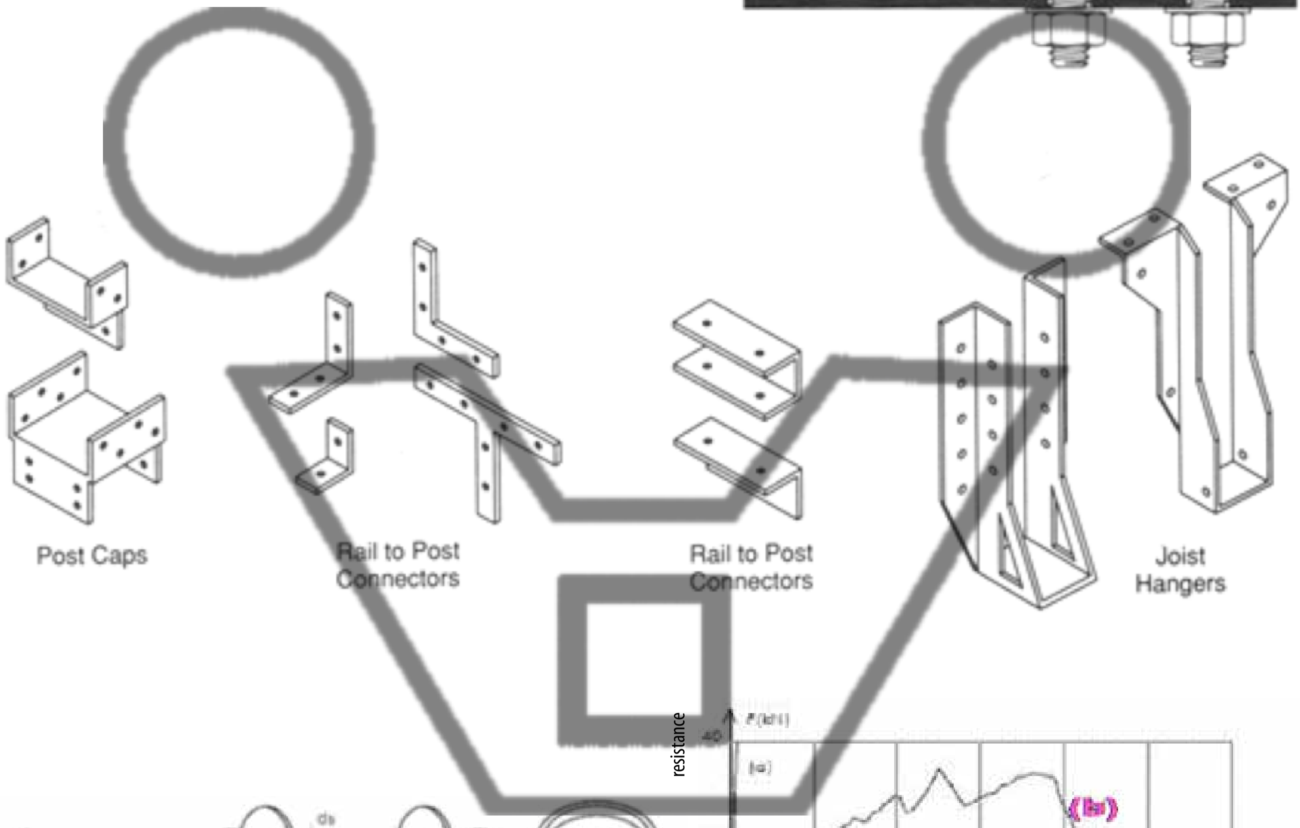
Special hidden fastener

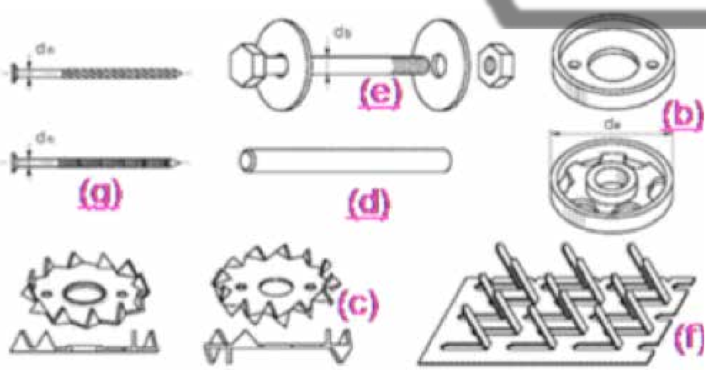


for metallic elements was widely developed and perfected: the welding technology for the fabrication of different kind of weapons, ships and then airplanes. This technology can be realized using electricity combined with consumable or not consumable electrodes; gas, where the most common is the oxyacetylene; more recently the laser and the ultrasonic technology used, the last one, to connect thin sheets or wires by vibrating them at high frequency and under high pressure; explosion welding, used for joining dissimilar materials by pushing them together under extremely high pressure. Because the required high level of control, this kind of joining technology is mainly realized in factory (*shop connections*) and restricted in the construction site (*field connections*) when a perfect rigidity and sealing is required.





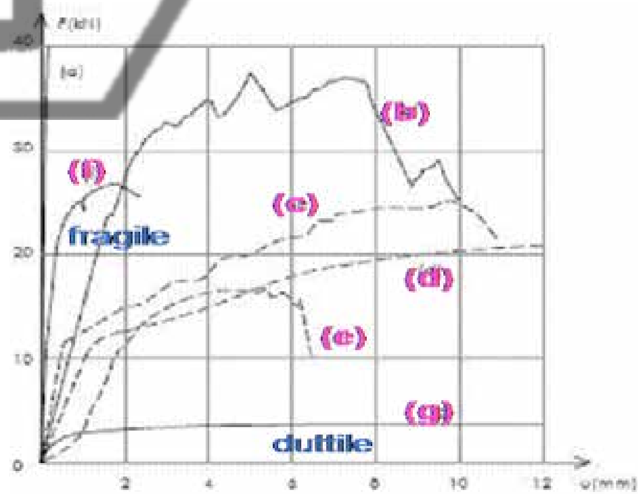




toothed washers

toothed plates

resistance



elongation

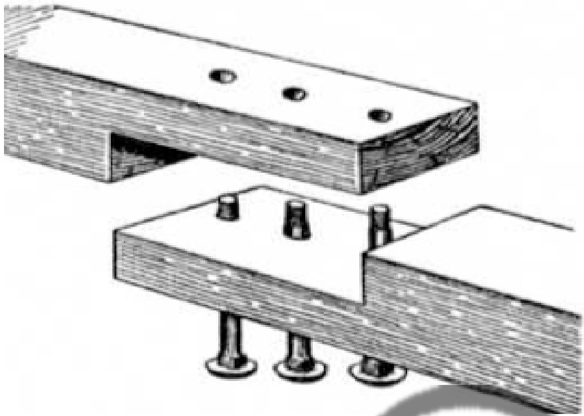
Joints and geometry

Joining can be placed to allow different configuration of structural elements.
The first and maybe most difficult is the co-planar connection because the structural behaviour is not supported by the shape. In fact, when the elements are crossing each other or dislocated in the space, the geometrical configuration can give an important contribution to the structural performances. For this reason the best behaviour of the co-planar joints is achieved when the elements are working under traction forces.

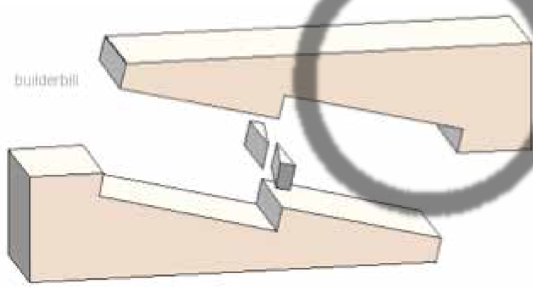
beveled scarf

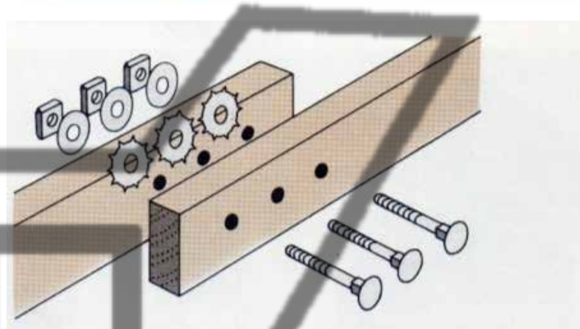
For co-planar connections can be used *finger joints*, *bulbed joints* but normally overlapping plates are required. Plates can be located on top/down position, along the two lateral faces or at the end of the two elements to be joined. In case of «I» profiles these kind of plates are respectively called *cover plates, web plates, end plates. End plates* form a kind o junction known as «flanged junction».

For massive wooden elements, plates can be inserted inside or using other sophisticated fastener devices oc-

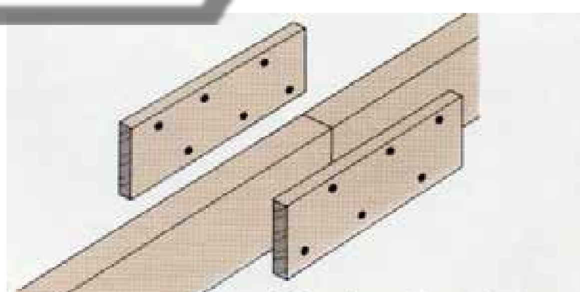


bevelded scarf



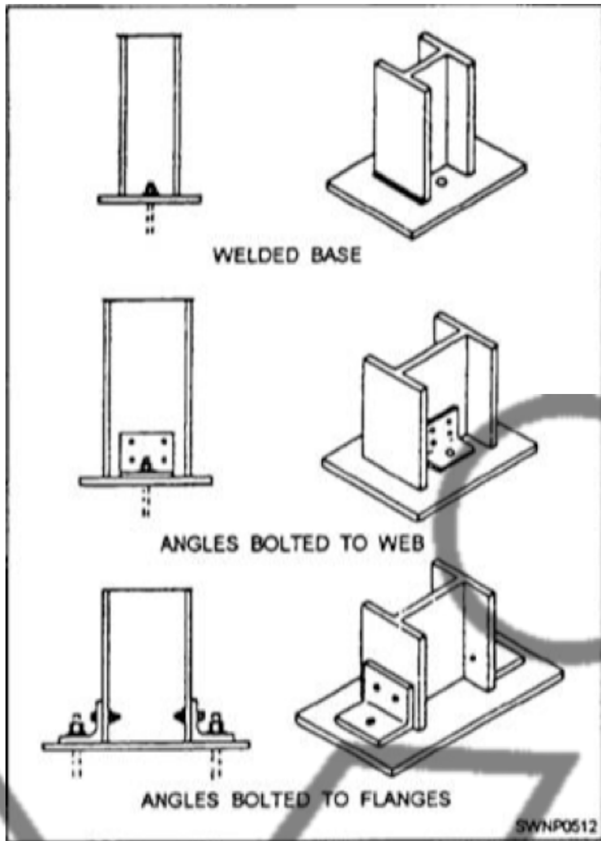


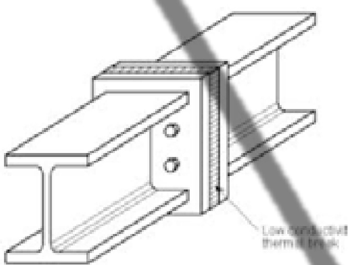
Bolted joint. Coach bolts and timber connectors give a strong face-to-face joint. Insert the connectors on the bolts between the two pieces of wood, and use washers under the nuts.

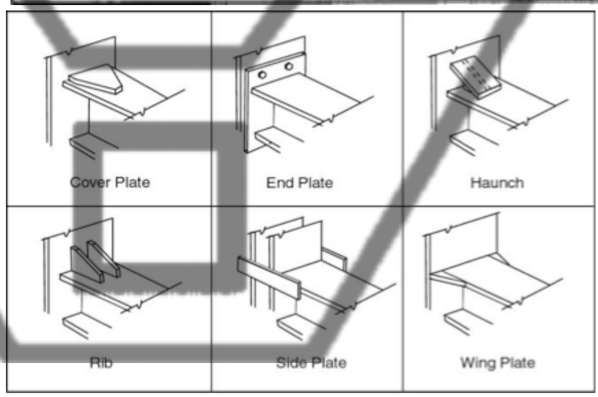


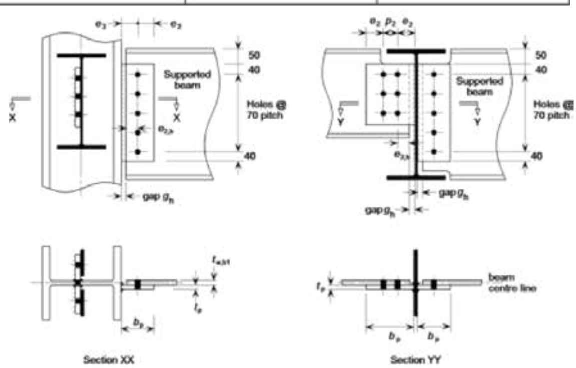
Joining plates. 'Sandwich' timber meeting end-on between two wooden plates of the same width. Glue the joint and stagger the screws to prevent their points clashing.

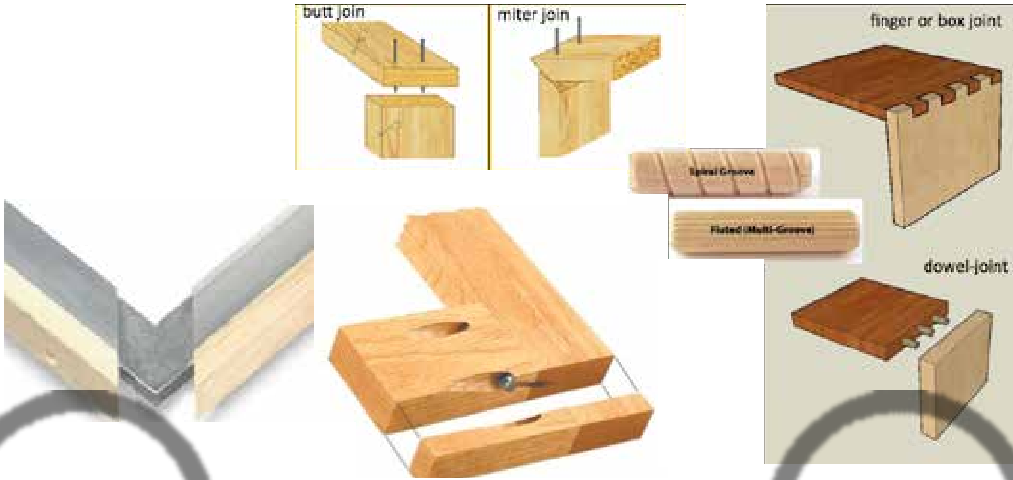
culted inside the section of each member. Normally, this fastener are metallic devices that works in traction, inducing forces that squeeze one against the other elements to be connected.
When the junction are used to connect columns or pilaster to girders, or more in general to realize an orthogonal junction, plates can be integrated or replaced by angular elements, fins, or T elements.
In wood elements this kind of joint can be realized using butt join, and miter join reinforced by nails, bolts or dowel pins.

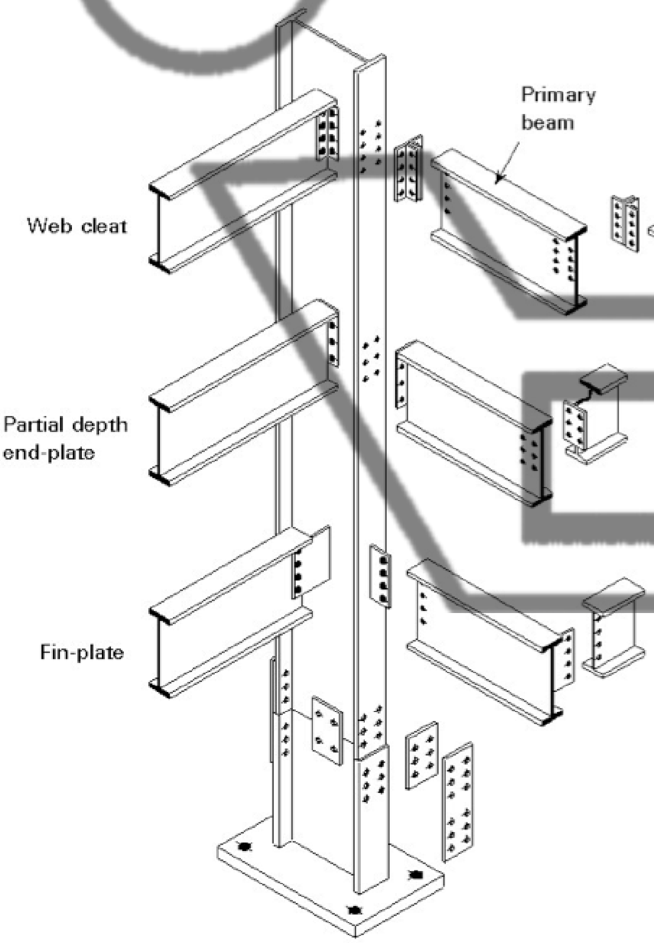












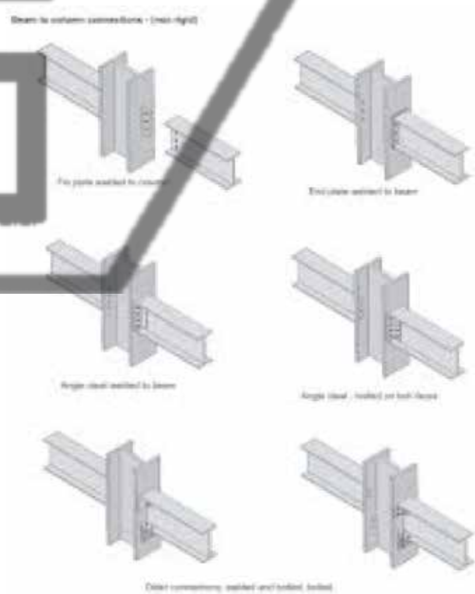
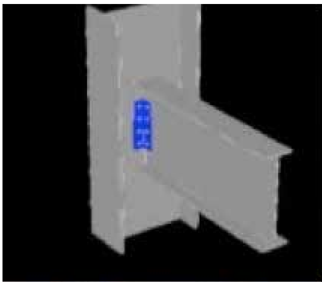
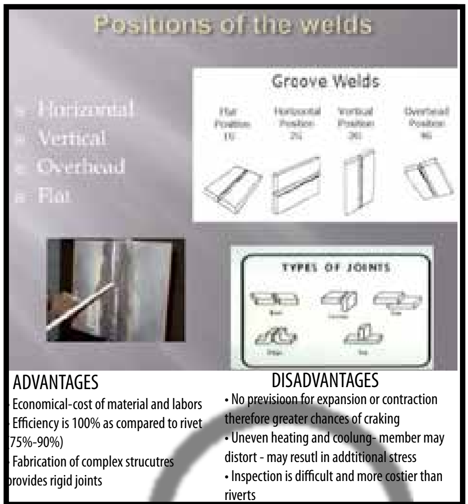
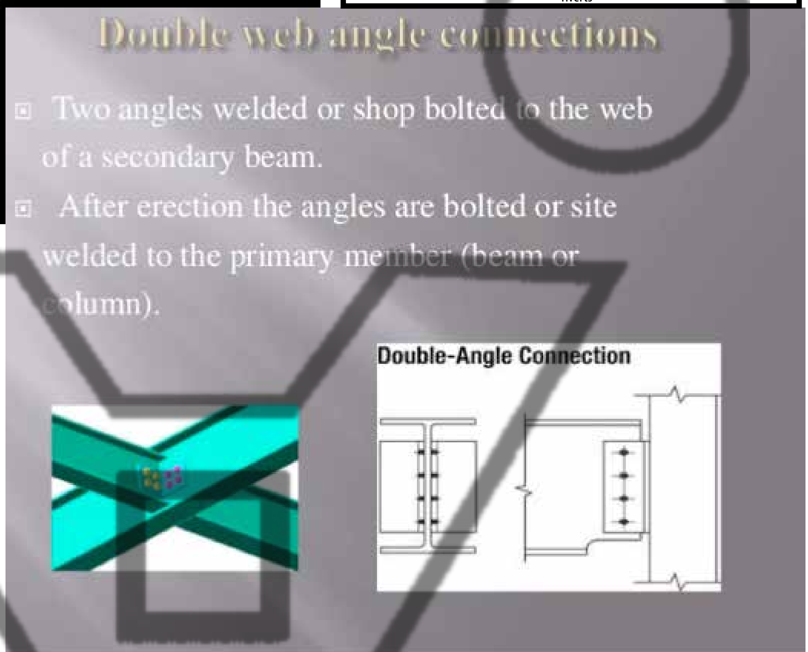
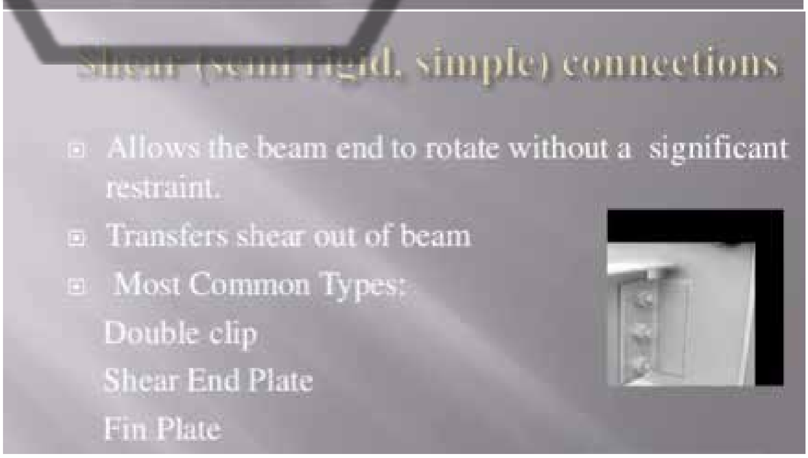


Figure 11 Types of simple connection.

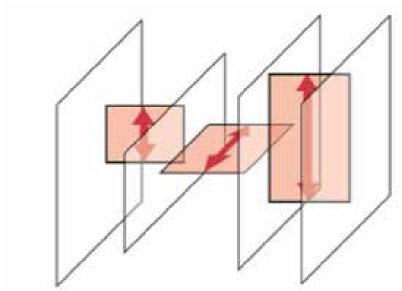



Positions of the welds
Horizontal
Vertical
Overhead
Flat
Groove Welds
TYPES OF JOINTS
ADVANTAGES
Economical-cost of material and labors
Efficiency is 100% as compared to rivet 75%-90%)
Fabrication of complex strucutres
provides rigid joints
DISADVANTAGES
• No previsioon for expansion or contraction therefore greater chances of craking
• Uneven heating and coolung- member may distort - may resutl in addtitional stress
• Inspection is difficult and more costier than riverts

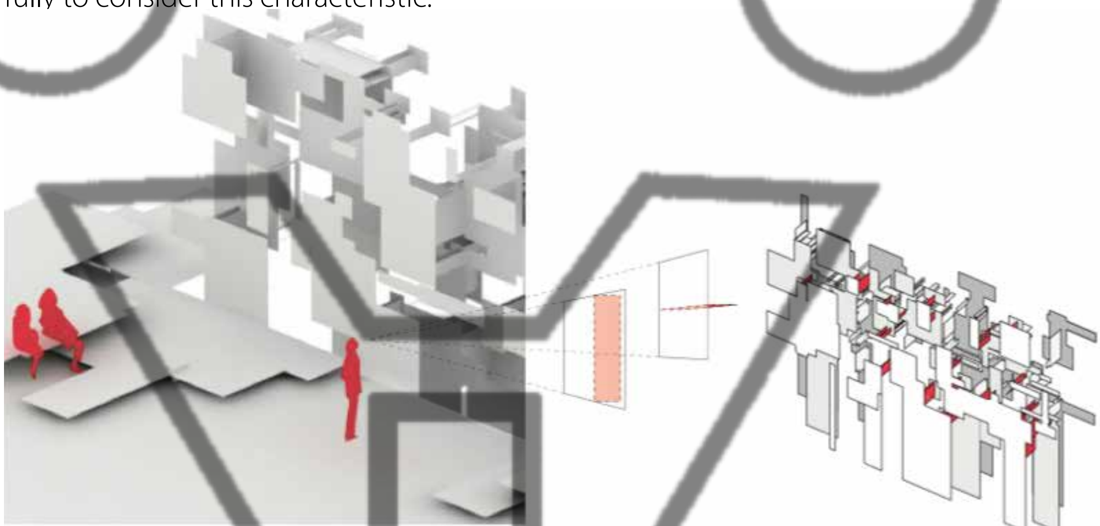

Double web angle connections
Two angles welded or shop bolted to the web of a secondary beam.
After erection the angles are bolted or site welded to the primary member (beam or column).
Double-Angle Connection


Shear (semi rigid, simple) connections
Allows the beam end to rotate without a significant restraint.
Transfers shear out of beam
Most Common Types:
Double clip
Shear End Plate
Fin Plate

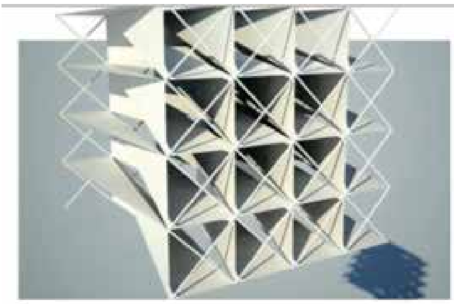
Assembling and joining two-dimensional structural elements.



A specific field of investigation can be referred to structural elements where one dimension is prevalent in section. We can define them two-dimensional elements meaning that the thickness, compared to the length and the width is less relevant or irrelevant such as in textile structures. These elements can be blades, metal sheets, plywood, membranes, etc. For their nature these kind of elements have a very low stability under lateral forces and structural design has carefully to consider this characteristic.

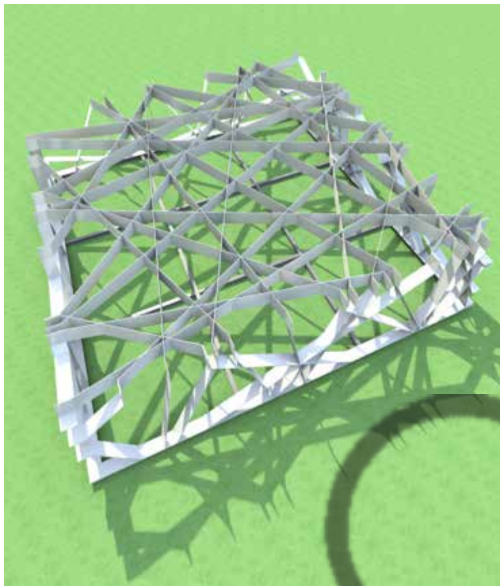


Kengo Kuma, Ceramic Cloud, Reggio Emilia, 2010.

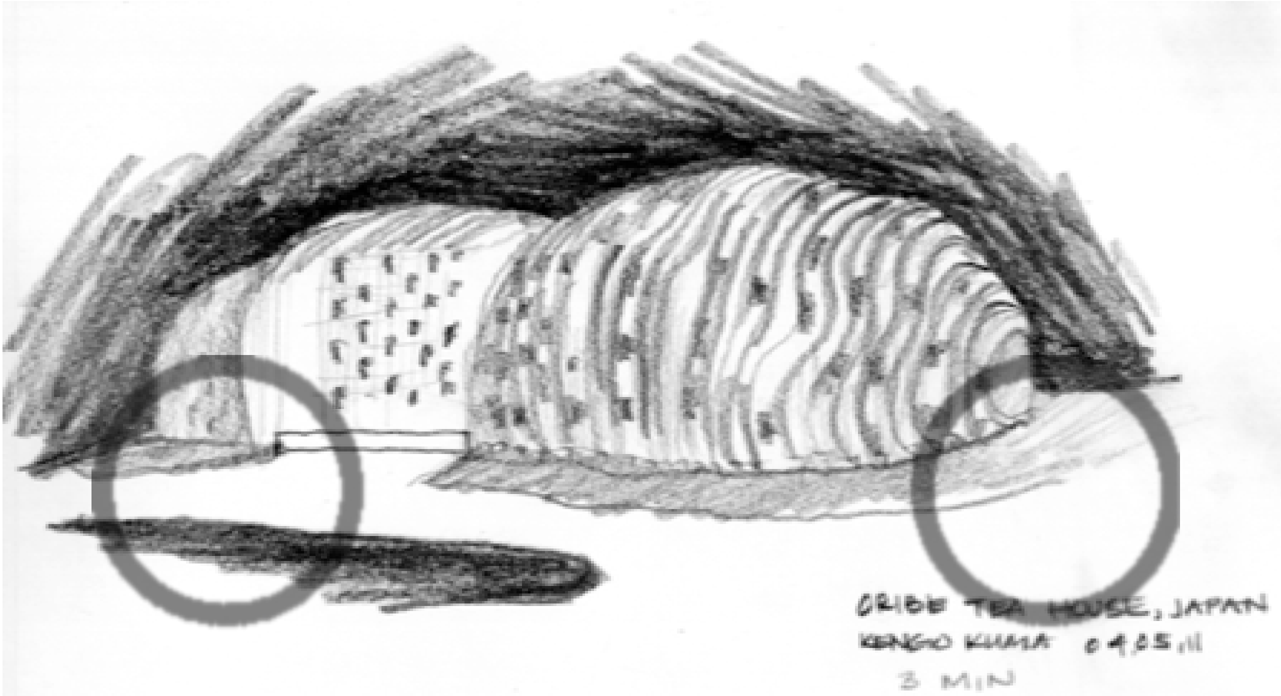


01 Reframe system sample with tension cables

02 Reframe system strips of material consistency marked in cyan



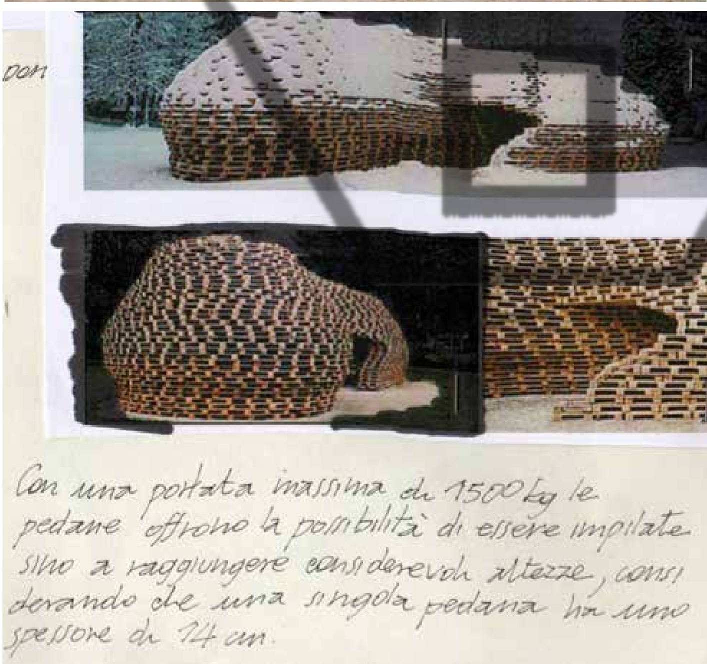
Toyo Ito+Cecil Balmont Arup, Serpentine Gallery Pavillion, 2002



Kengo Kuma, Oribe Tea House, 2005

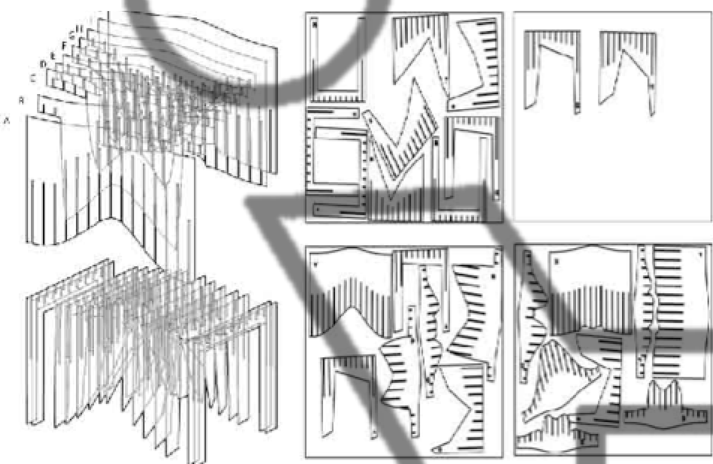
To give them a resistance form a useful strategy is changing its original planar condition, for example, by *folding* or *bending*. But if you want to maintain the original planar configuration of each element it's absolutely required to cross them and joining them orthogonally or in the space.
One of the emerging structural approach is *waffling* a kind of discrete structure where elements are crossing each others in order to realize a kind of skeleton. With this strategy is possible to realize in many different forms with high accuracy since CNC manufacturing technology can be easily applied.
Another similar approach is the *sectioning* approach where the whole shape of the construction is literally cut in many slices and reassembled using a third element between them.

Matthias Loebermann, Palettenpavillon, 2010

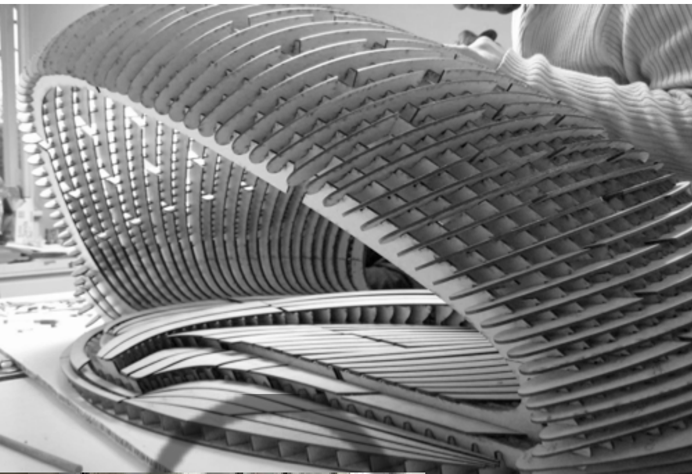


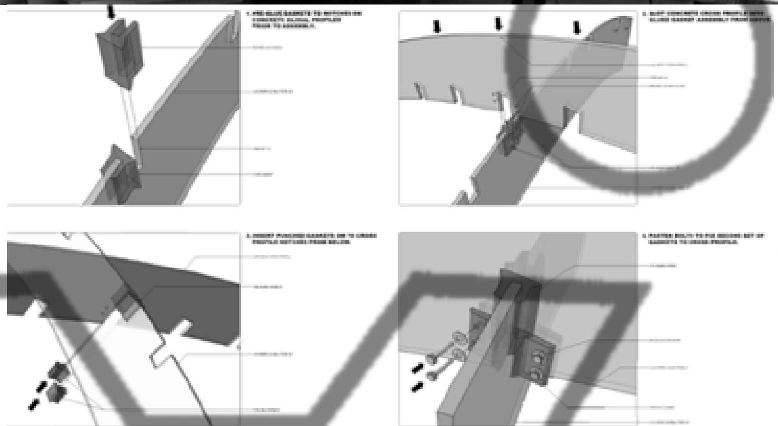
Even in sectioning is possible to use laser cutting or milling cutting technologies in order to realize customizing shapes fitting a high variable geometry. For example, using waffling or sectioning is possible to realize domes or other spatial structures with planar elements that in the past were only possible using struts made of tubular metal elements or wooden timbers.

With the precision offered by laser cutter or other cnc technology is now possible to realize a very complicated components and joints as well such as special hub connectors to organize two-dimensional elements in the space. These hubs, are normally made as a tree-dimensional objects but it's also possible to conceive planar hubs able to connect two-dimensional structural el-

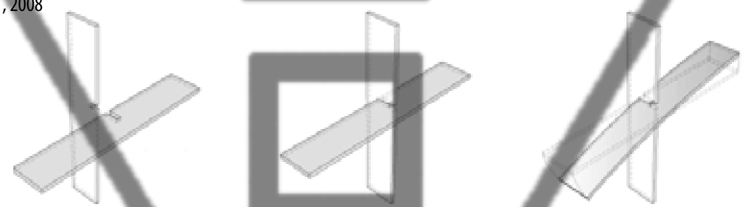


Advanced Architecture of Catalonia (IAAC), Fab Lab House, 2010

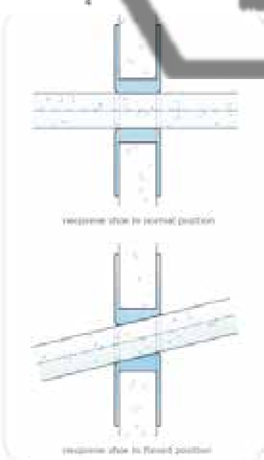


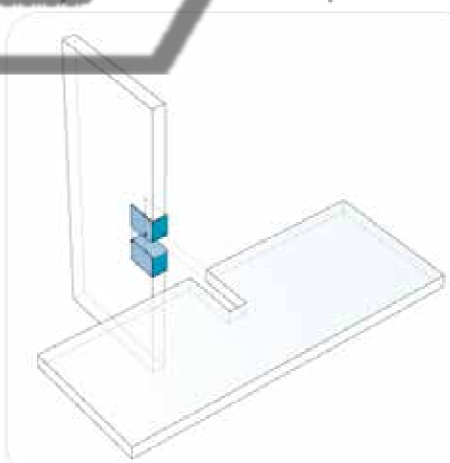


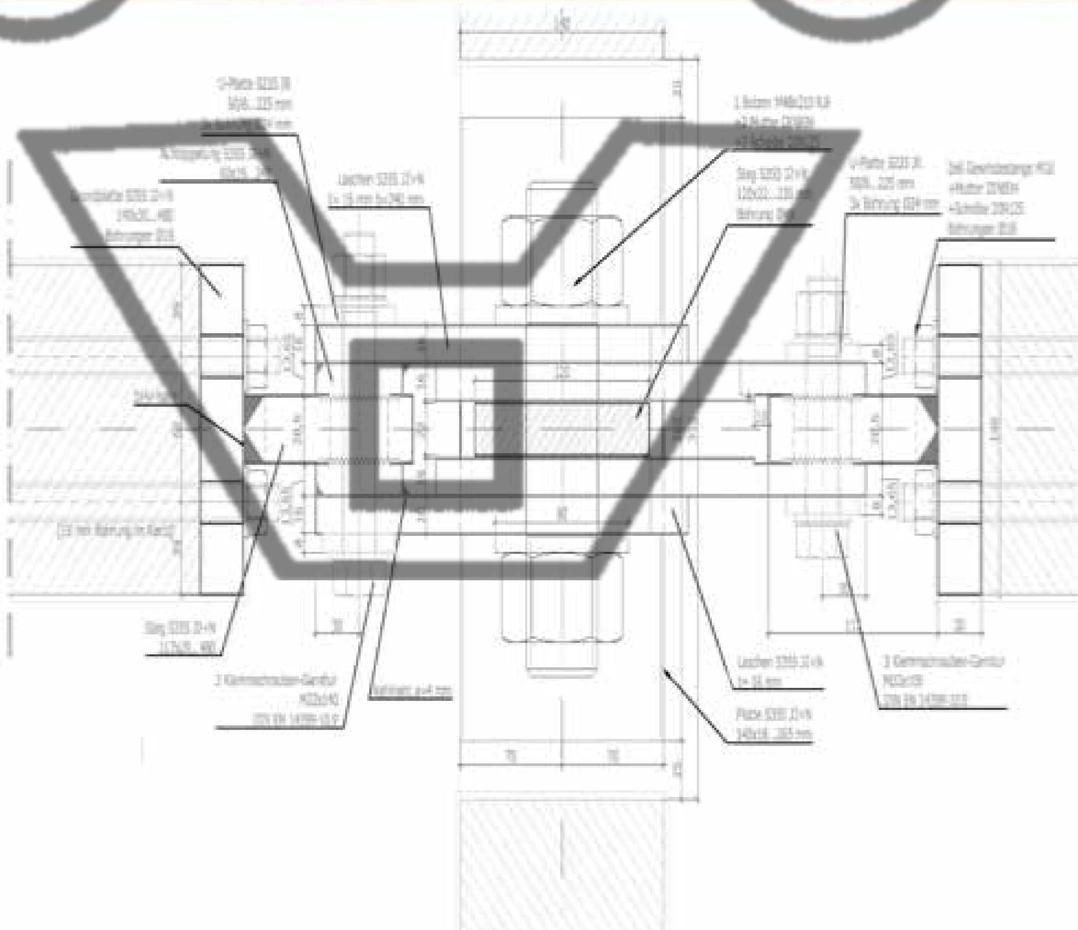
Alan Dempsey and Alvin Huang , (c) Space Pavillion , 2008



1_Giunto in neoprene in posizione normale | 2_Giunto in neoprene in posizione inclinata | 3_Giunto morbido in neoprene montato nell'incavo del profilato primario dentellato, per fornire una presa, e ridurre lo stress nella struttura quando i profilati sono flessi | 4_Il profilato primario strutturale è dentellato a metà della profondità del profilato secondario | 5_I profilati primari e secondari sono incastrati l'uno all'altro |6_I profilati primari e/o secondari sono inclinati al fine di creare una struttura completa

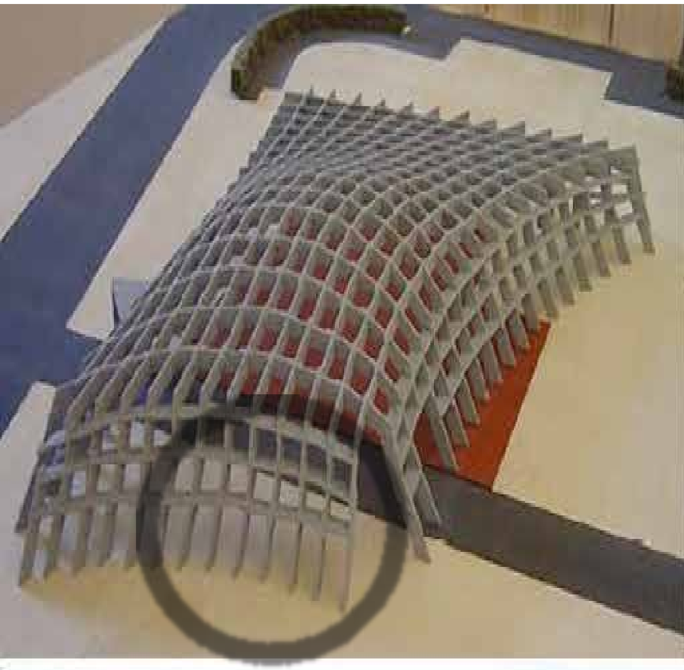




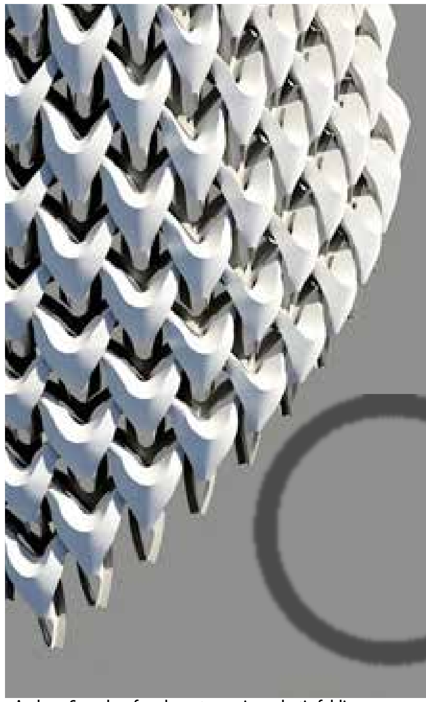


ements in the space with costs, of course, much lower. In some application that not required an high structural performance, these planar hubs can be also realized avoiding structural bolts and combining specific shaped pieces of wood with pins, chocks and wedges, sometimes in a very complex system of interlocking.
For the realization of three-dimensional components (whether they are joints or elements to connect) the casting system is still largely used. Traditional manufacturing techniques, related to the production of concrete components (also reinforced), are now complemented by other production technologies that derive from the manufacturing industry. Under the generic term of *molding* (sheet or bulk molding compound, injection molding, infusion, vacuum printing,..) today it is possible to realize elements of high complexity that can be repeated in large numbers or in a limited number that can allow different geometric configurations even with double curvature. To assemble this kind of components an effective strategy can be represented by the *three-dimensional tessellation*.

Alvaro Siza/ Eduardo Souto De Moura/ Cecil Balmond Arup,Serpentine Gallery Pavilion, 2005



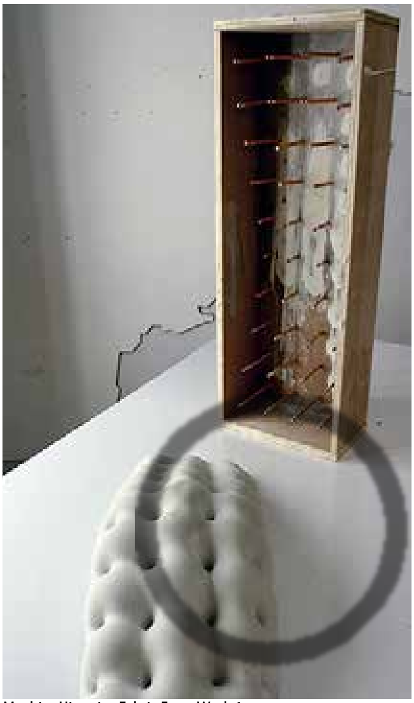
Parametric Studies_Zaha Hadid

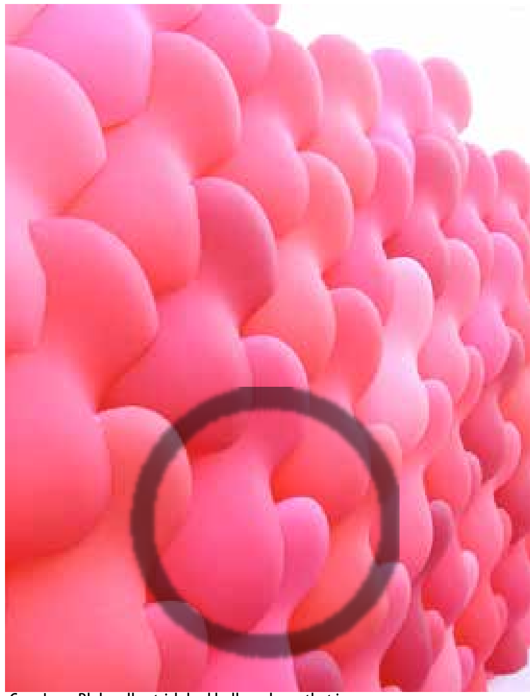


Andrew Saunders facade system using robotic folding

Natural Embellishment, Prosolve 370e a decorative architectural module coated with a superfine titanium dioxide (TiO_2), a pollution-fighting technology that is activated by ambient daylight. Installed at Torre de Especialidades, Hospital Manuel Gea Gonzales (Mexico)

Vent Block



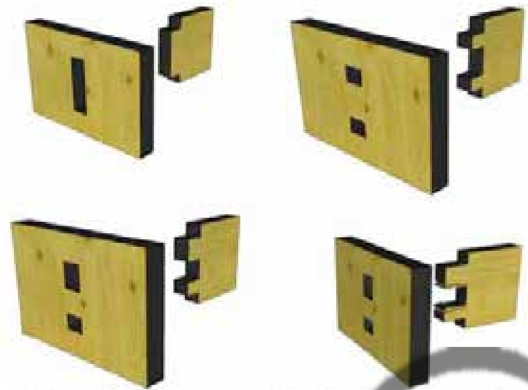



MachineHistories Fabric Form Work 1.
An experiment in casting using material properties and gravity as a form finding technique.
Materials: Hydrocal Gypsum, Spandex, Plywood and pencils

Greg Lynn Blobwall. a tri-lobed hollow shape that is mass produced through rotational molding.

BIG | Bjarke Ingels Group, Serpentne Pavillion

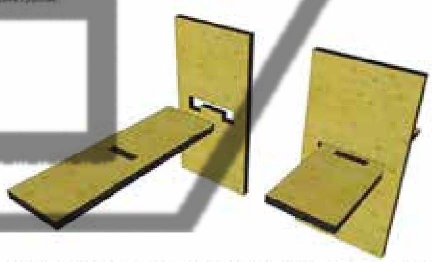

TEE „T" JOINTS



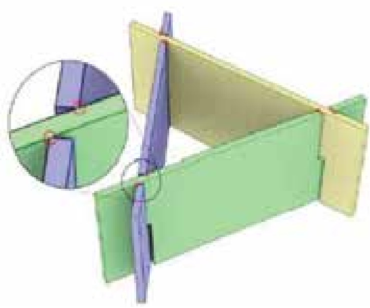
Here is a simple "mortise and tenon" type joint. We can split the "mortise" and "tenon" into two slots and tabs (or into as many slots and tabs as we like). If we break the symmetry of the slots and tabs, the joint becomes biased. And if we extend the tab a small distance past the thickness of the stock, we can add easily add snaps or detents that catch on the far side of the slotted part.
Fasteners in the plane of one of the pieces can now be introduced. The captive square nut joint is seen on a number of commercial products featuring CNC-cut parts, for instance the Thingformer vacuum former kit and several popular 3D printer kits.

This particular configuration was the subject of a nomenclature debate here on the blog not too long ago, though I don't think any sort of consensus was achieved. Interesting possibilities include "captive nut joint," "bedframe joint," and "Petts joint" (which is my personal favorite, because it observes Stigler's Law).
There are almost certainly other clever ways to incorporate metal fasteners or other bits of common hardware in this type of joinery that I haven't seen, and/or that have not been invented, yet.

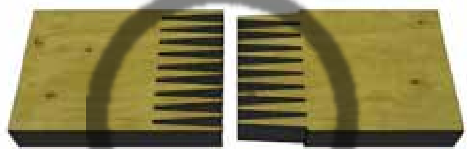
...and/or to the slotted member, as shown here. Note, in this case, that it doesn't matter if the profile of the catch is hooked or rounded. Once the catch pops into the slot, it'll be very hard to get out. For the reversible version, move the slot and the catch out to the edge of the stock.
Finally, in the case of "T" joints, if one member is narrower than the other, a full-width slotted arrangement becomes possible.



Such joints may be useful especially for shelves or other upright applications where gravity can be exploited to keep the pieces engaged, and may be biased or otherwise modified like the "T" joints described below.

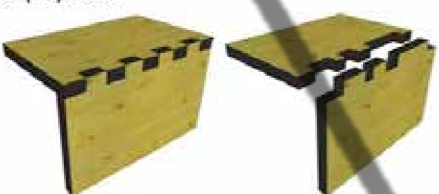


COPLANAR „I" JOINTS

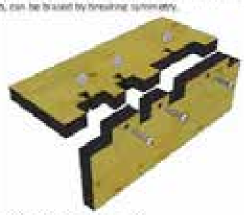


Here, for instance, is the classic "finger" joint, used to join members in the same plane for gluing.

Corner ("L") Joints

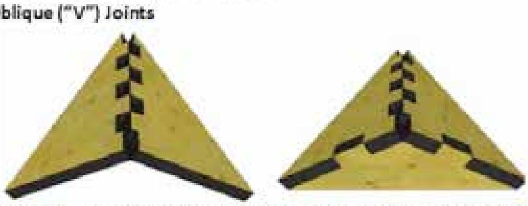


This arrangement of interlocking tabs and slots at a ninety degree angle is, of course, ancient and rudimentary. Most people call it a "box joint." It, too, can be biased by breaking symmetry.



And it is just as amenable to the bolted captive-nut arrangement.

Oblique ("V") Joints

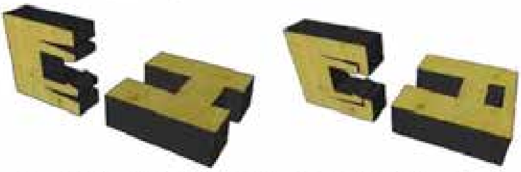


Though the captive-nut joint doesn't really work unless the two parts are at right angles to one another, generally the "L" joints can be pressed into service for acute or obtuse angles, as well.

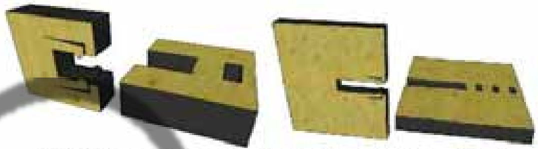
The bottoms of the slots no longer index closely against the surface of the stock, but if the members are held in alignment by some other means, for example by glue or the introduction of a third panel (as shown to right), it may not matter.

Cross ("X") Joints

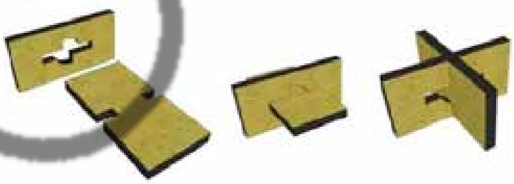
Here's a version of the basic slotted "edge lap" joint in which one side has an integral snap-lock feature. The snap hooks are accessible from the end of the joint. Insert a small flat-blade screwdriver, pry a bit, and they can be popped loose and the joint opened again.



But move the hook and the catch away from the edges of the stock, and the snap-lock action becomes "irreversible." Note that both pieces of stock could include both hooks and catches. I'm only showing "one sided" snapping joints for clarity.

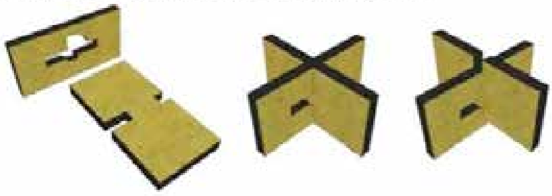


Replace the hook with a bulge and the snap becomes a detent. The part will "stick" in place but can be removed with sufficient force.

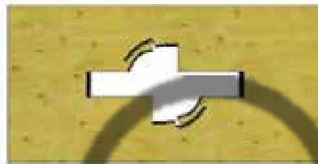


The detent could catch in one position, or many.

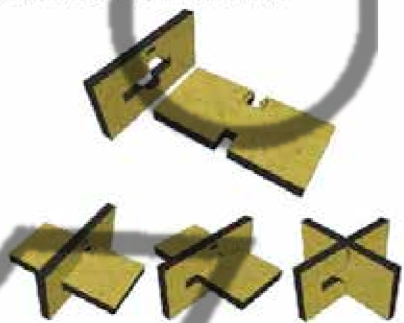
Here's a more unusual "X" joint that uses a radial interlocking motion to seal the deal.



A biased version is also possible. Here's a similar joint with the symmetry broken shown disassembled (left), assembled in favored orientation (middle), and assembled in its "disfavored" orientation (right).

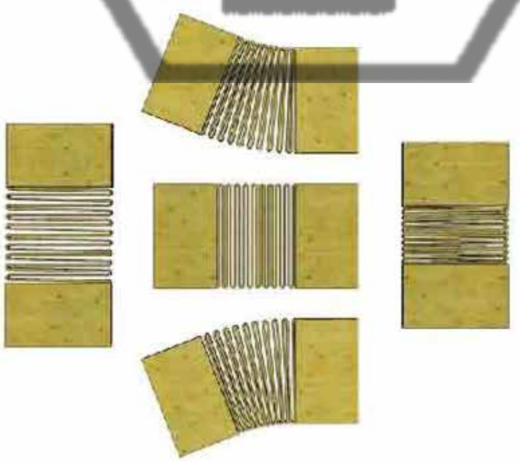


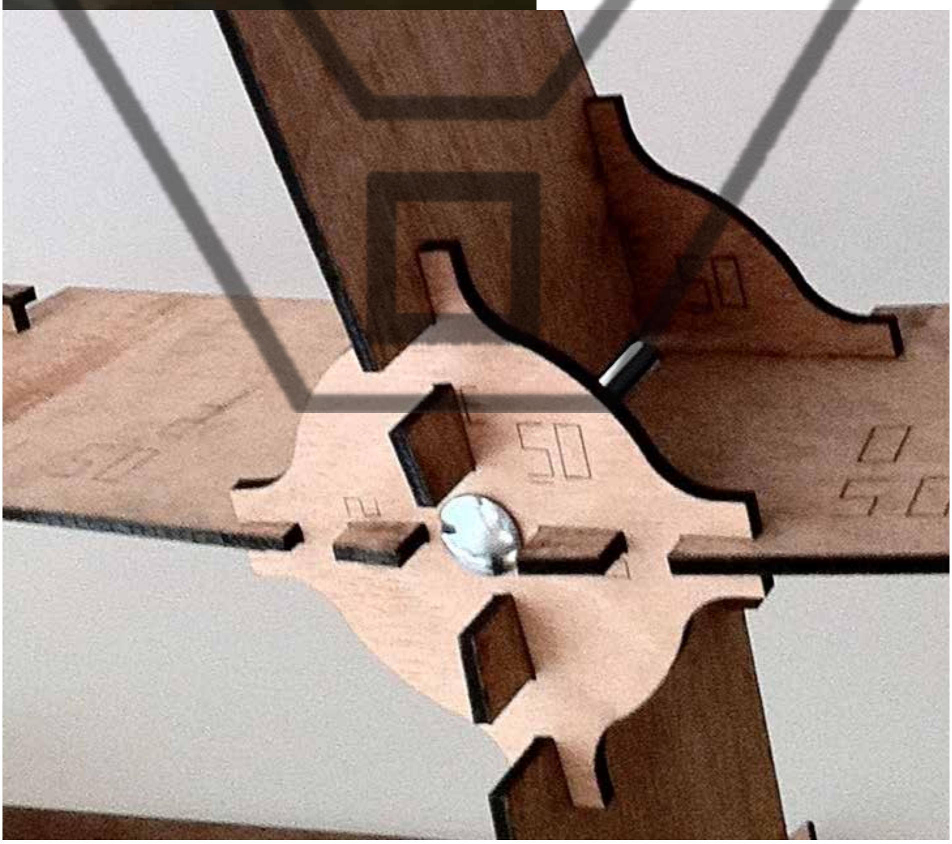
Locks or detents can be added to the stationary member, as shown above...

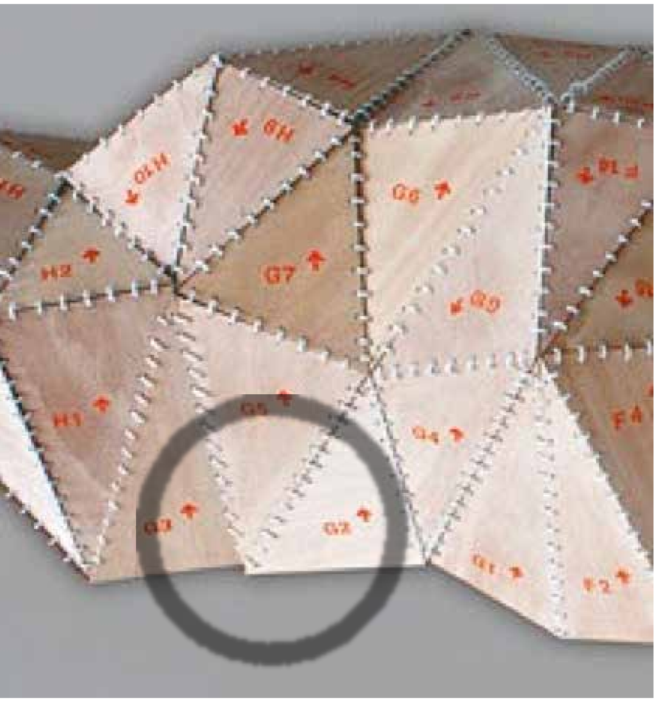


FLEXURES

Though not strictly "joints," there is a class of clever CNC tricks that meet our criteria for inclusion here (two or fewer members, all-the-way-through cuts at 90 degrees) that are designed to exploit the natural elasticity of the panel material itself to create living hinges, springs, and other dynamic flexing elements. We have already broached the subject of integral flexures with our discussion of catches and detents, above.







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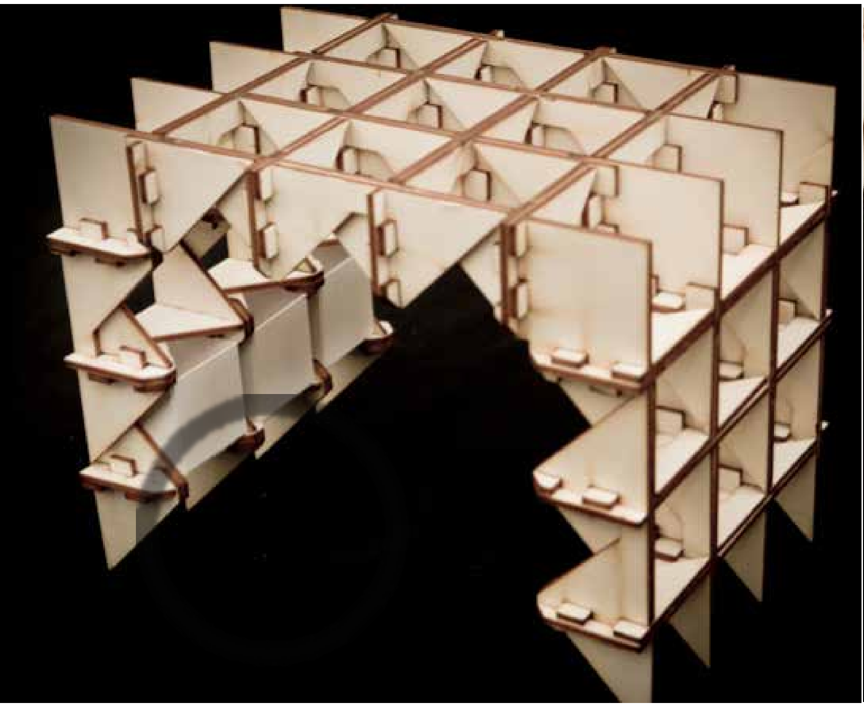
On Form



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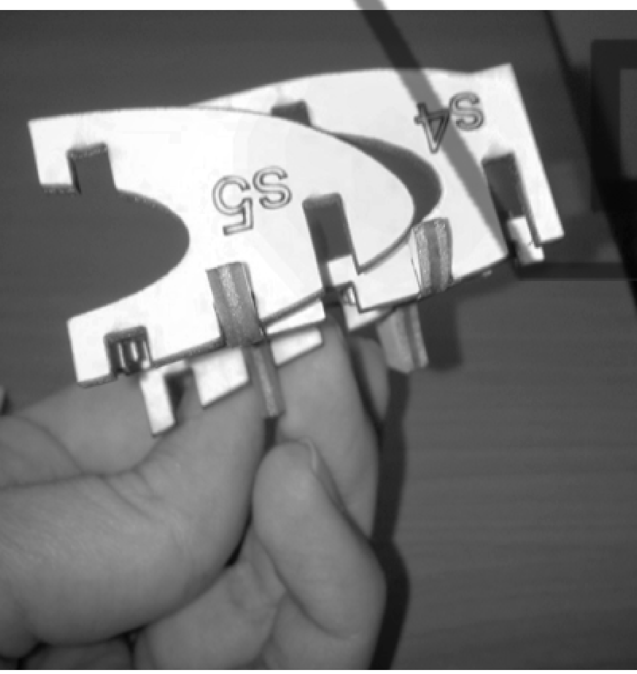

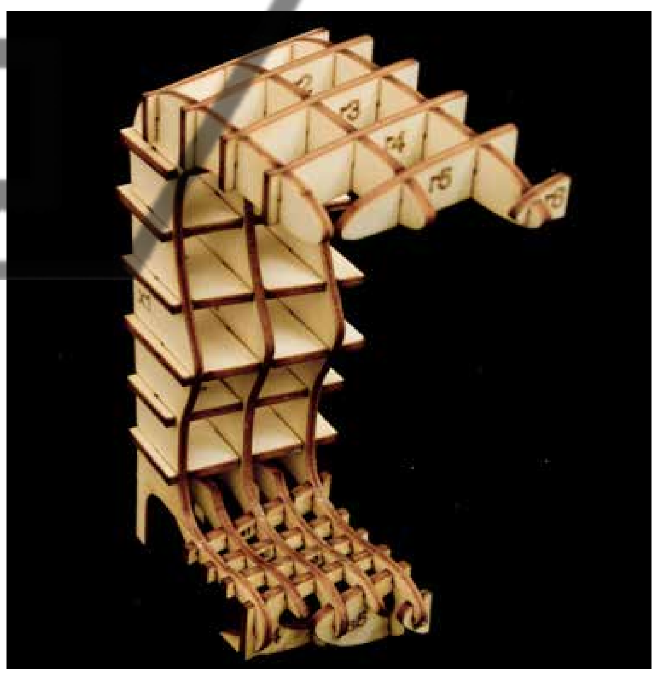

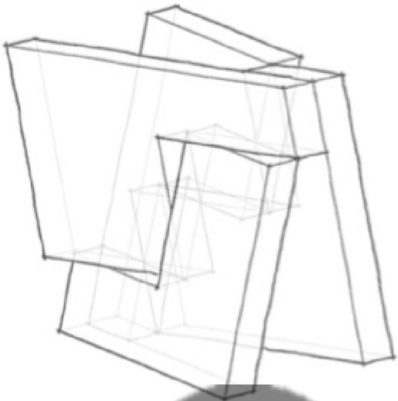

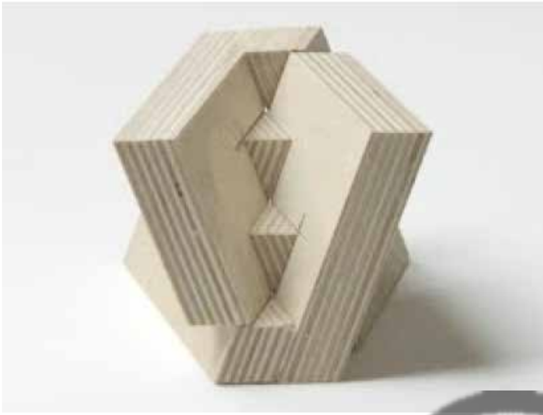

Dror, QuaDror: A structural support system, 2006

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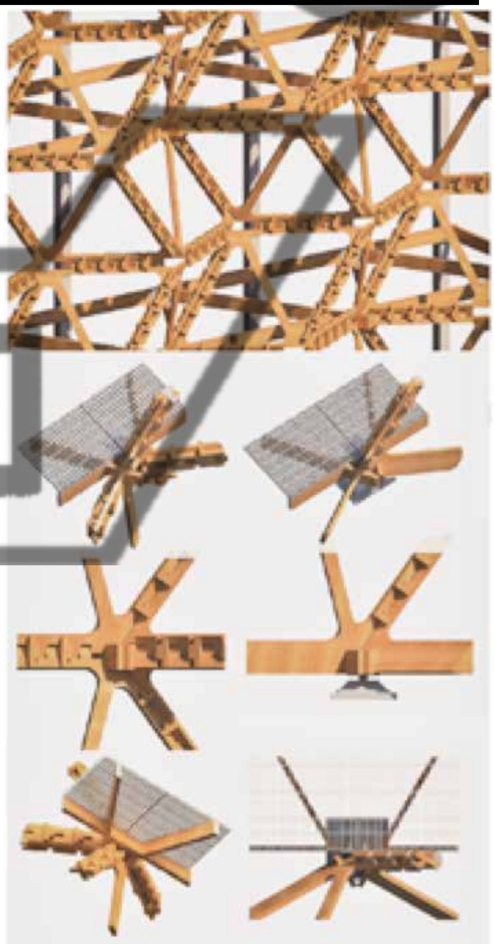

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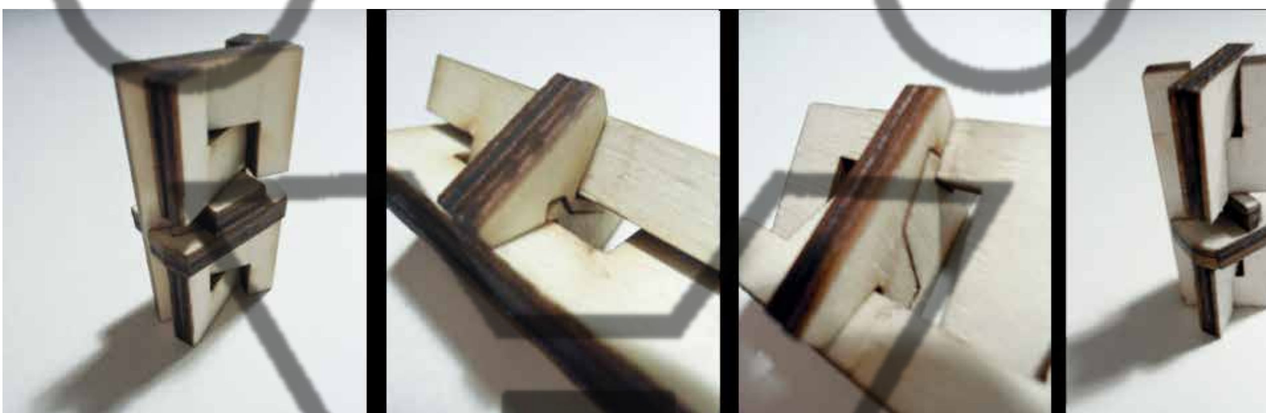
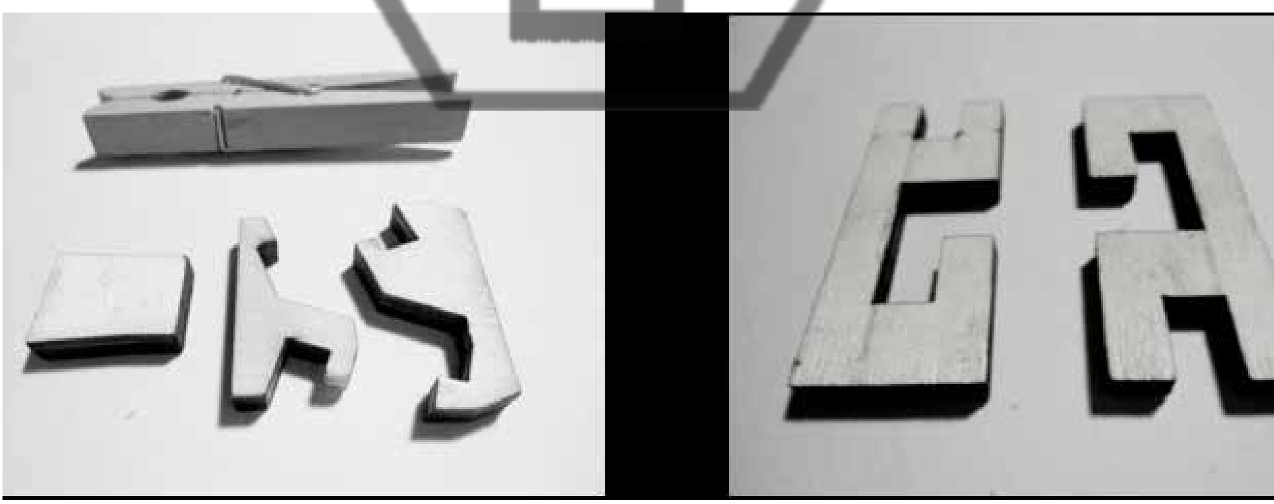
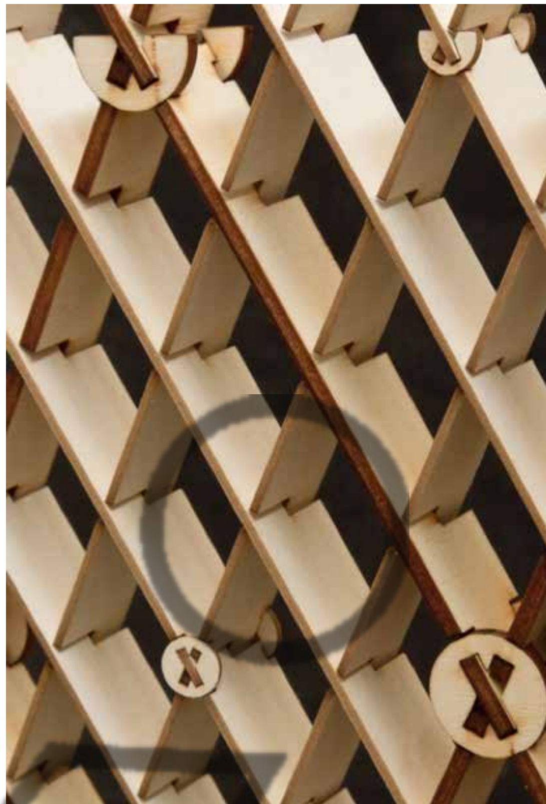
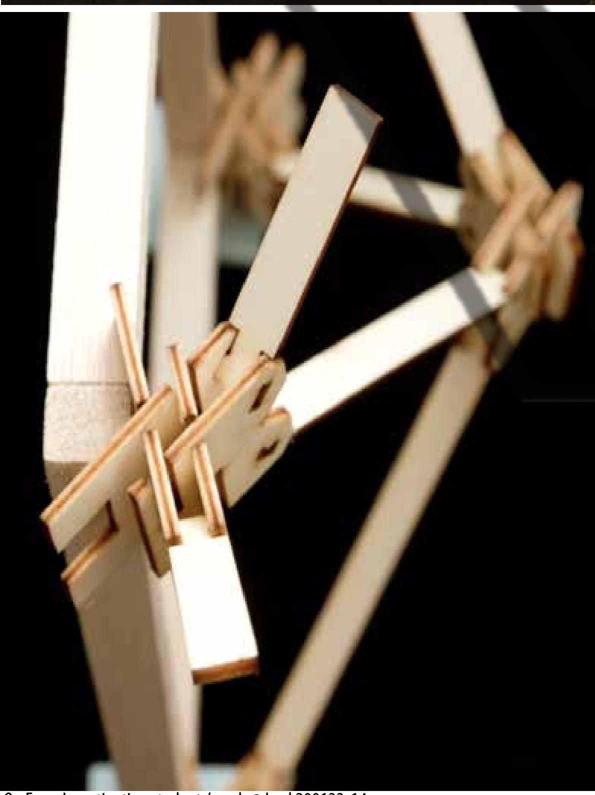
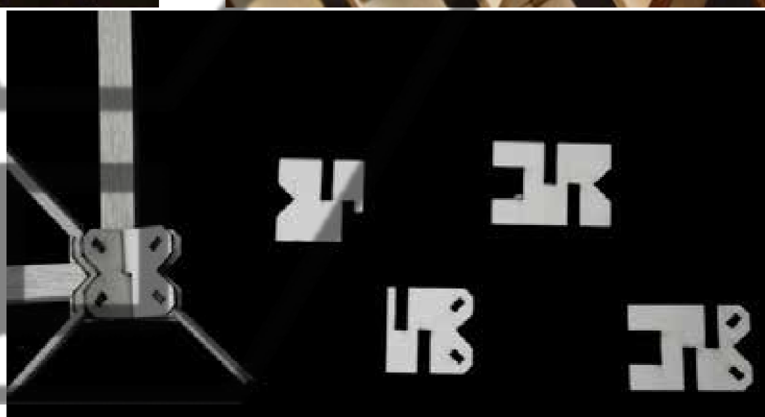
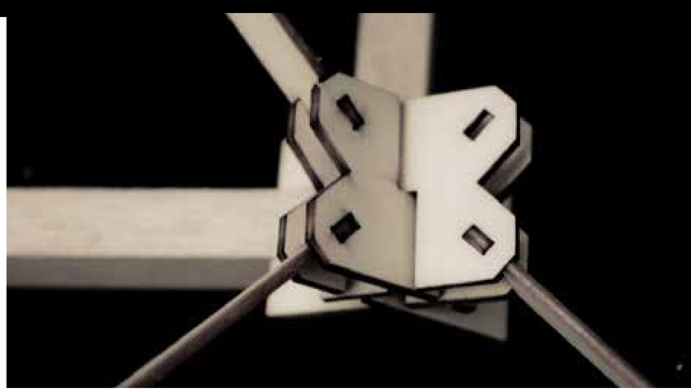










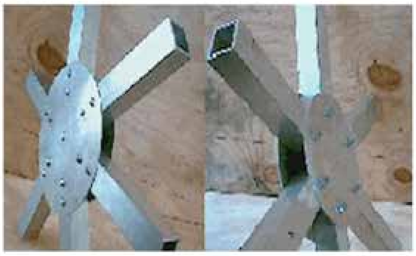


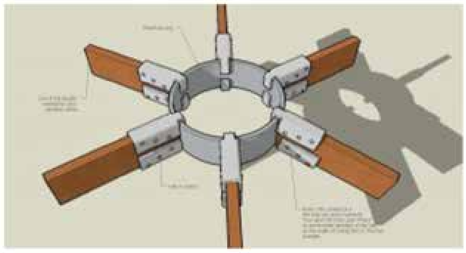
On Form Investigation students' work @ Icad 200133-14

WOOD HUB CONNECTORE

Matt Lowry from Domemade offers a hub system which he proudly describes as great timesaver. Comprising of a series of laser cut stainless steel bra-ckets, the Domemade hub system can be used to construct a geodesic dome of any size. There`s no maths to perform you just alter the lengths of your wood accordingly. The hub system is then connected to the wooden struts using four types of nuts and bolts. There is no need for complex maths calculating angles and ratios with this hub. The bracket simply forms the correct shape as you build the dome. The hub system is ideal for shipping as it packs away in to a small box and has a lower cost than most other systems of this type.

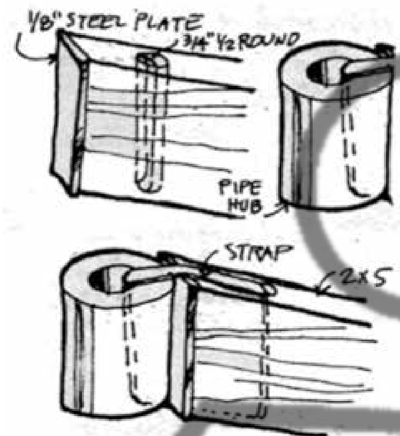
SOME OTHER PART OF HUB





WOOD HUB CONNECTORE

One of the simplest and best wooden dome hub system, the pipe-section hubs and stainless steel strap tightened with a banding device. This was developed by Fletcher Pence the Virgin Island in the early 60s and was strong and elegant. Used by architect Jeffery Lindsay in L.A and Pacific High School for 10 wood-framed domes in the early 70s.



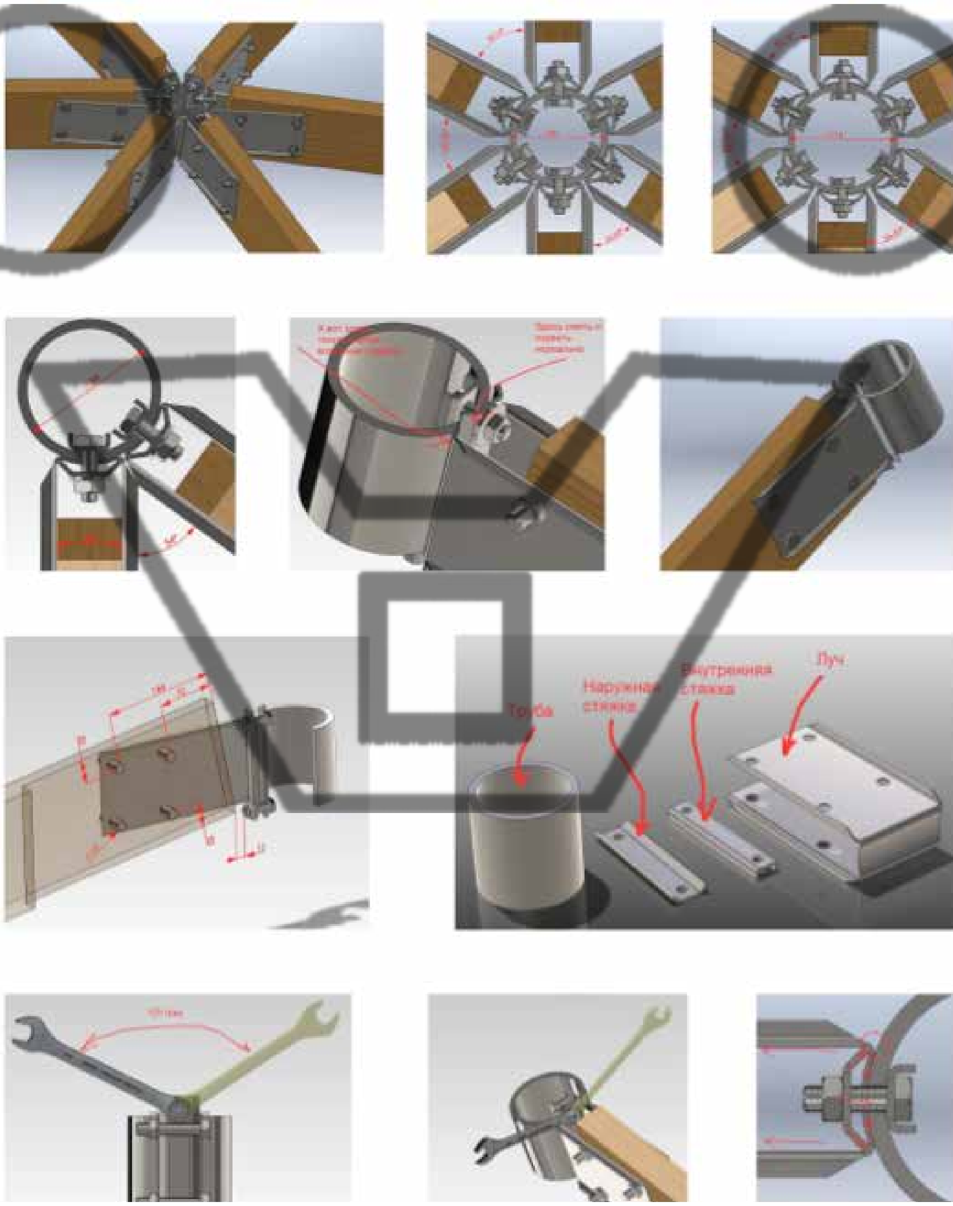
T-blocking hub method. This is an improvement of the strap method by connecting all struts together. As you can see from the image, this solution is elegant and simple, in addition to requiring only basic skills to reinforce hubs.

This hub design being produced in Russia is going through some serious tests in the summer of 2012. Its designer is Pavel Brayvo is the designer of the domesworld.ru forum. The results of these tests will be available to the public on the domesworld.ru forum.
As many pointed out, it is really extraordinary what people on that forum are achieving, like this design, an idea born on the forum that ends up in production.It is a good example for every geodesic community in the world.

WOOD HUB CONNECTORE

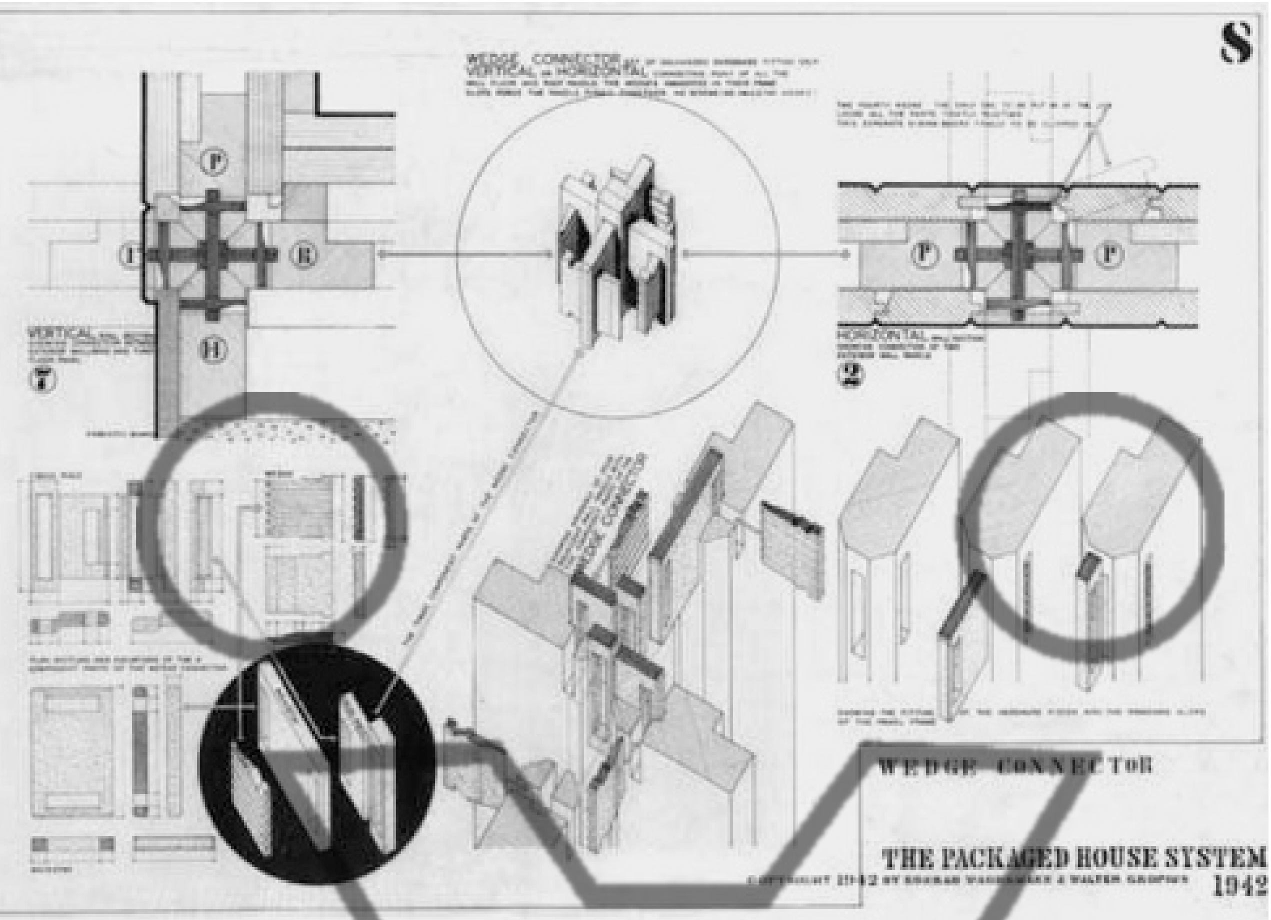
Andrei Saveliev hub system

It is the hub design by Andrei Saveliev. He is a design engineer from Moscow and an major participant on the domesworld.ru forums.

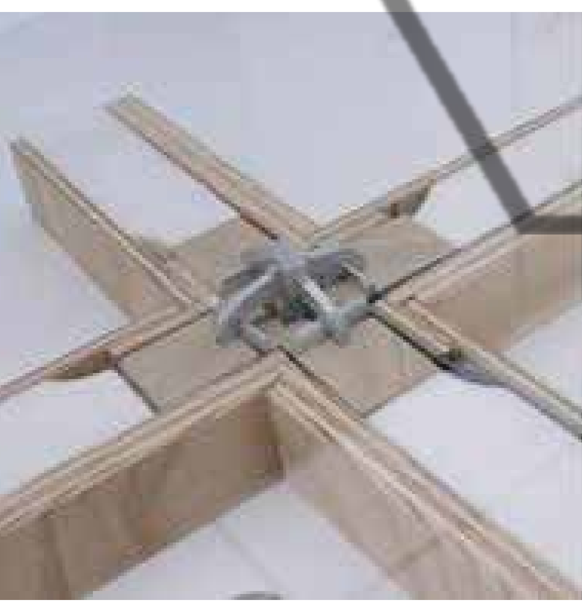


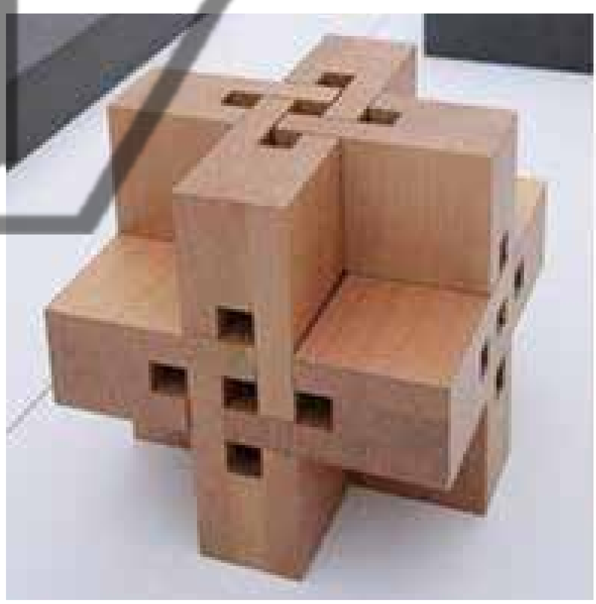
JAPANESE GEODESIC HUB SYSTEM FOR WOOD STRUTS

THIS IS A TRULY ORIGINAL GEODESIC HUB DESIGN WITH A NICE EMPHASIS ON PRESENTATION.



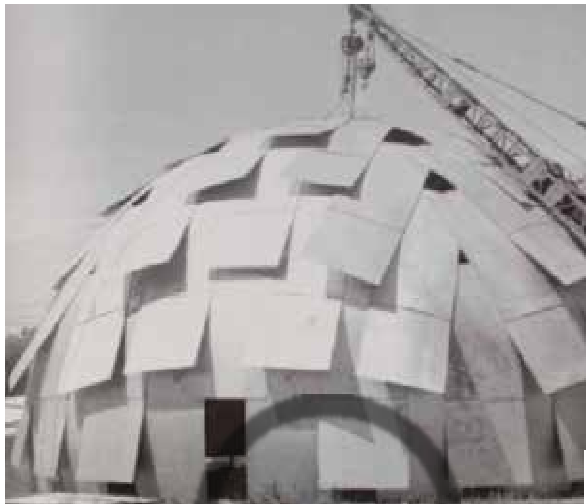
W. Gropius , K. Wachsmann, The Packaged House System - General Panel Corporation, New York, 1941-42



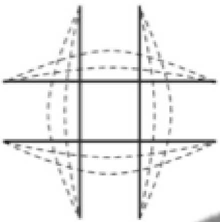


Stressing planar elements

As written above, two-dimensional elements can reach an high structural performance inducing a internal condition of stress through *bending* or *twisting*.
An interesting example where bending and twisting are used to realize a light structure is shown in the following pages.



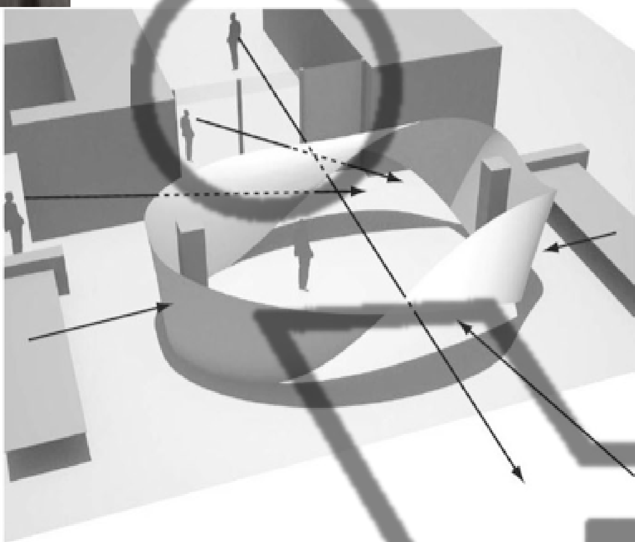
BENDED & TWISTED

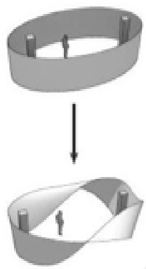


1
Bending using material properties

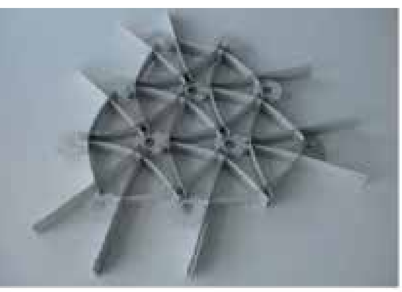
2
Twisted cylinder for view through

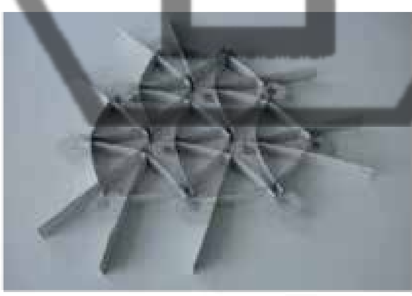
3
Network of forces,
at least 3 intersections to other bent plates

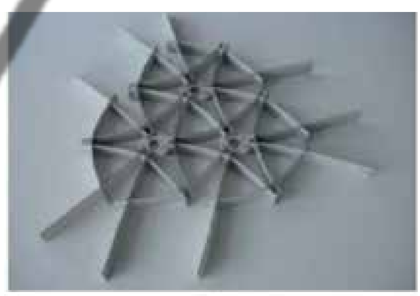


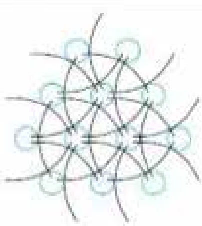


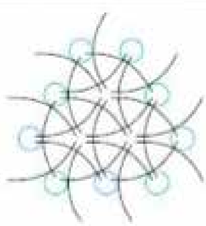
Jesper Theger Christensen

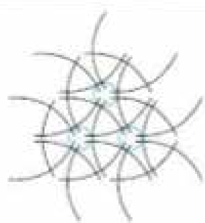


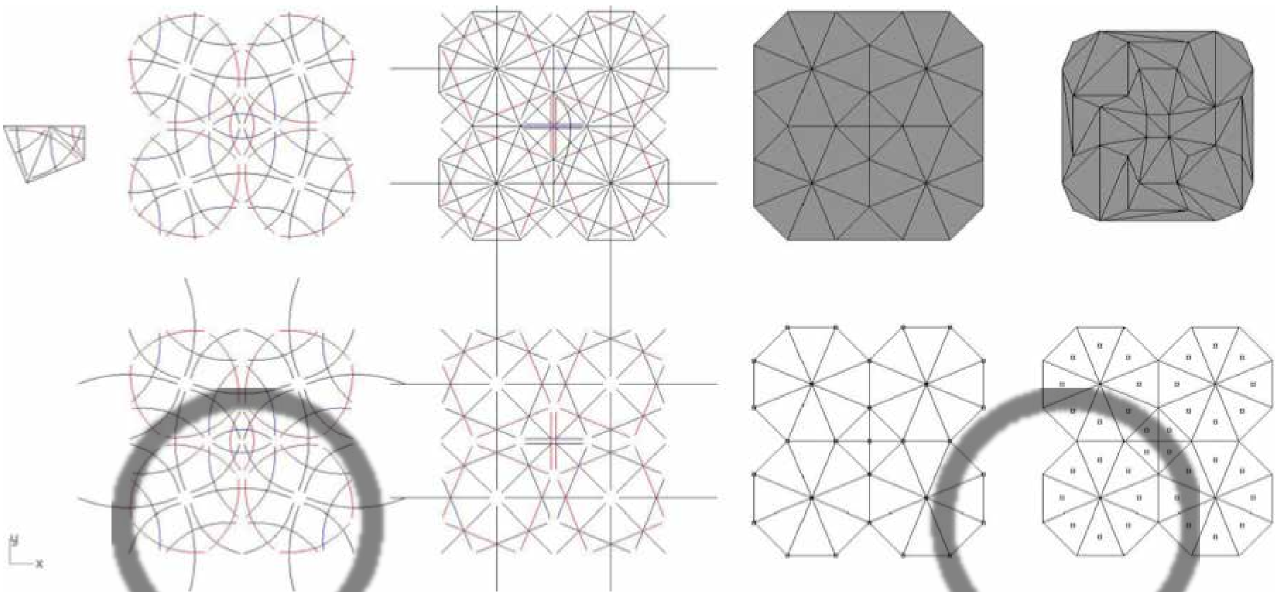




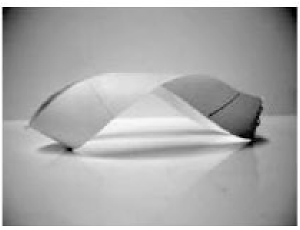


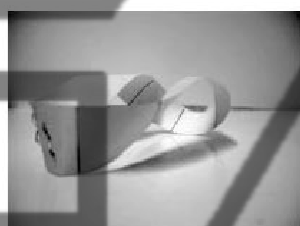


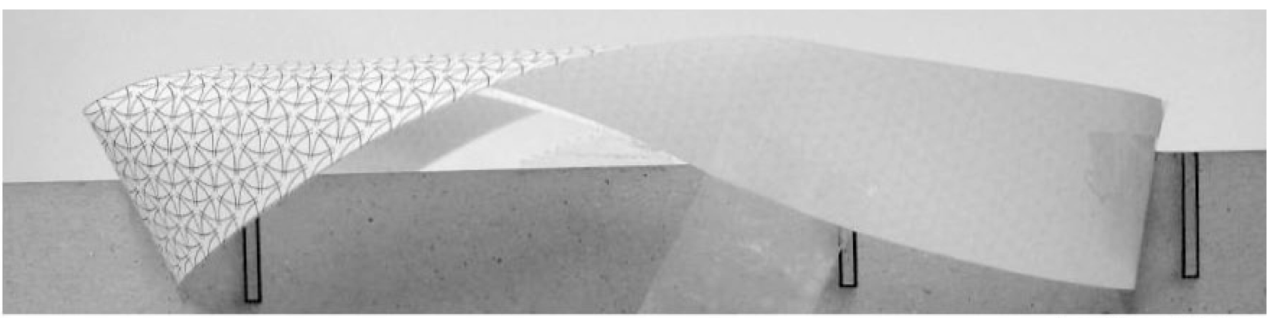




PAPERSTRIP MODELS

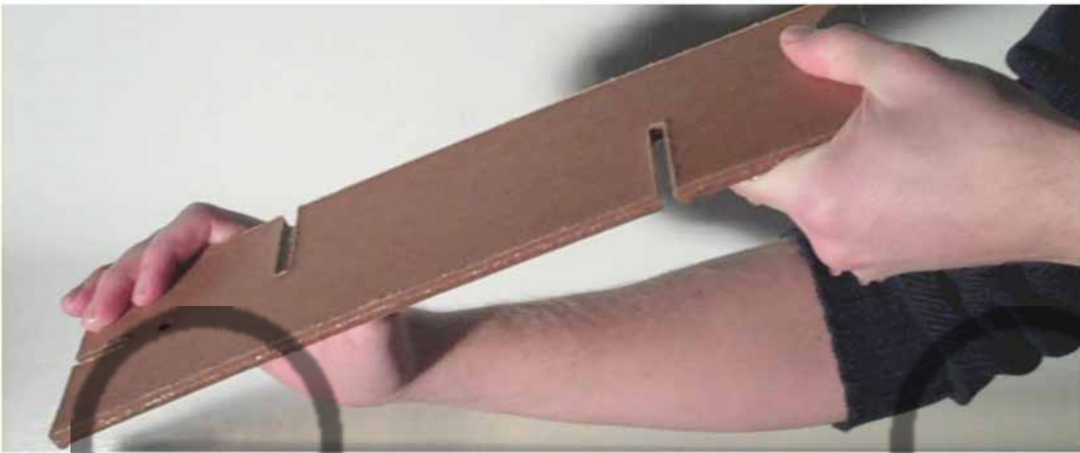


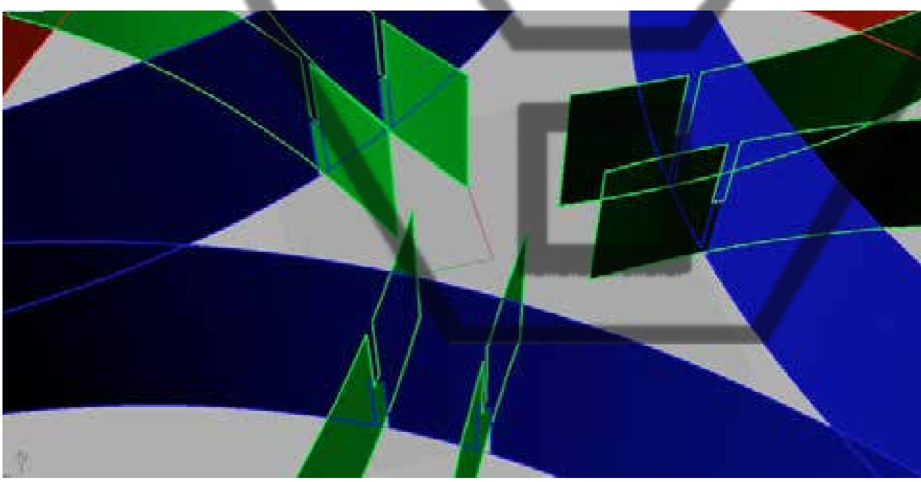


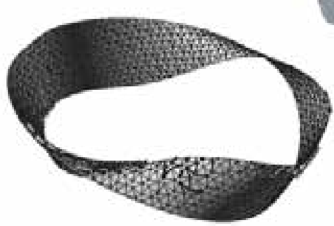


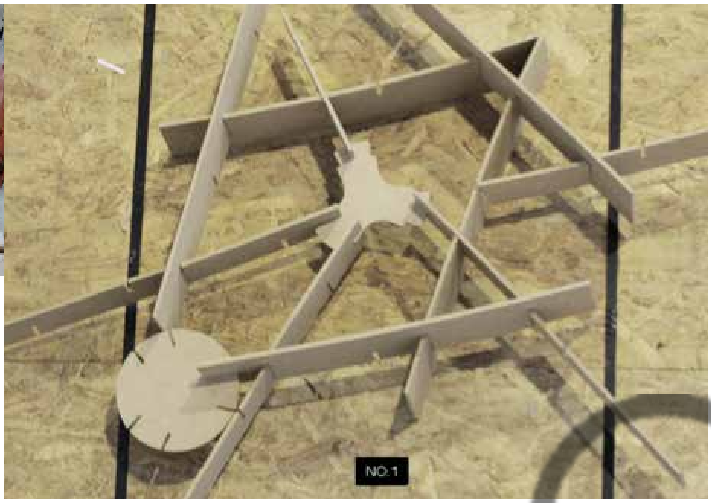
Jesper Thøger Christenser

MATERIAL TEST

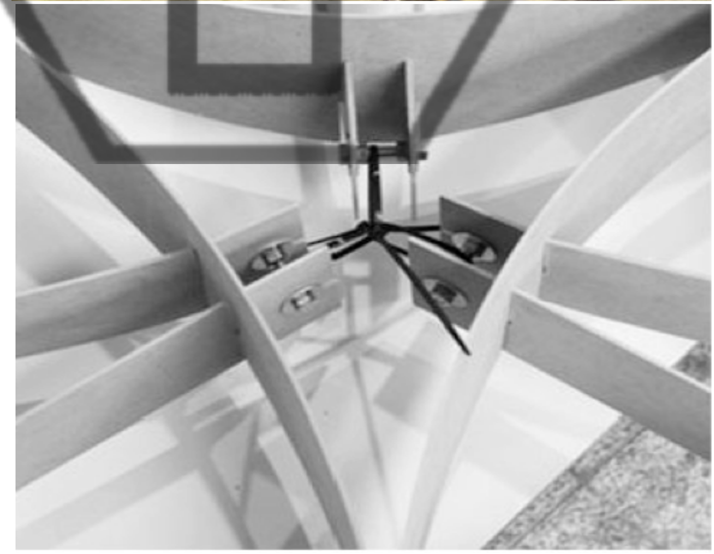


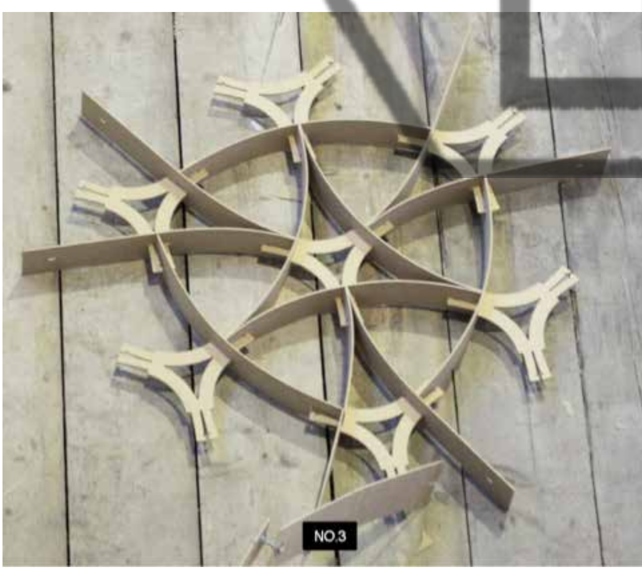





NO.1


NO.2

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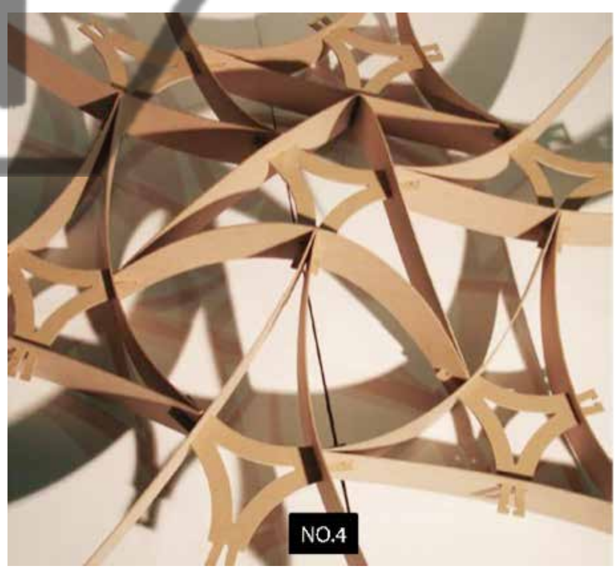
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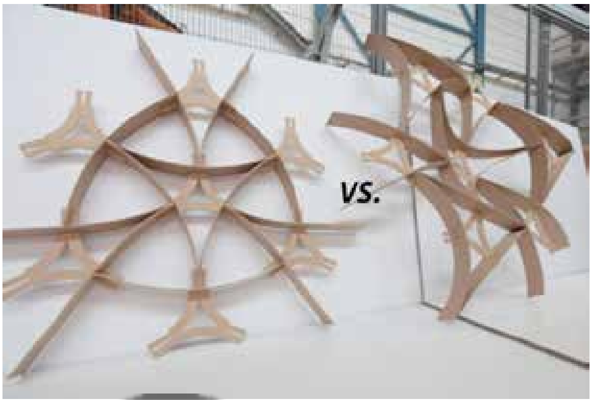
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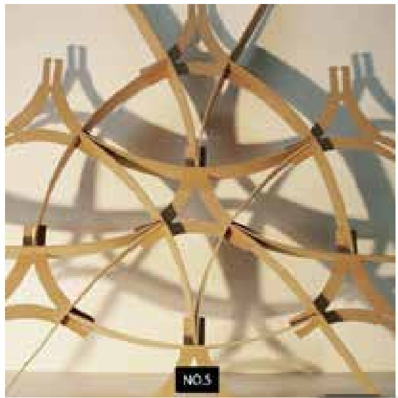
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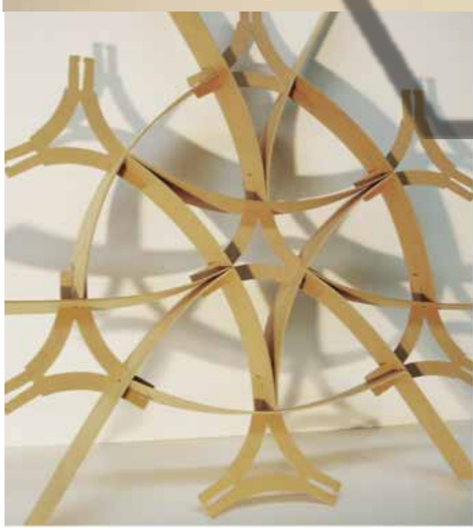

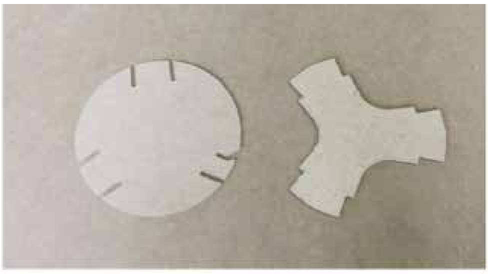

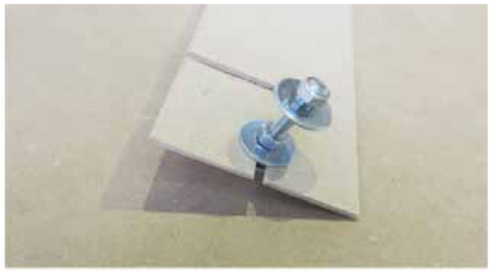

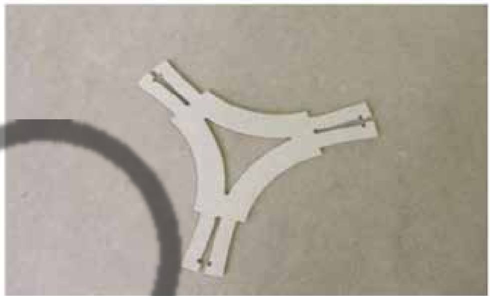


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