TAYLOR'S UNIVERSITY
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BUILDING CONSTRUCTION 2 (ARC 2513)

PROJECT 2: UNDERSTANDING FORCES IN SOLID STRUCTURE & SURFACE STRUCTURE

BUILDING NAME: GUGGENHEIM MUSEUM IN BILBAO, SPAIN

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Introduction

The Guggenheim Museum Bilbao which is located in Bilbao, Basque Country, Spain is a museum of modern and contemporary art. It belongs to the Soloman R. Guggenheim Foundation and was designed by the highly respected Canadian-American architect Frank Gehry.

The museum was inaugurated on the 18th of October 1997 by the late King Juan Carlos I. It was built alongside the Nervion River, which runs through the city of Bilbao to the Cantabrian Sea. This museum features permanent and visiting exhibits of works by Spanish and international artists.

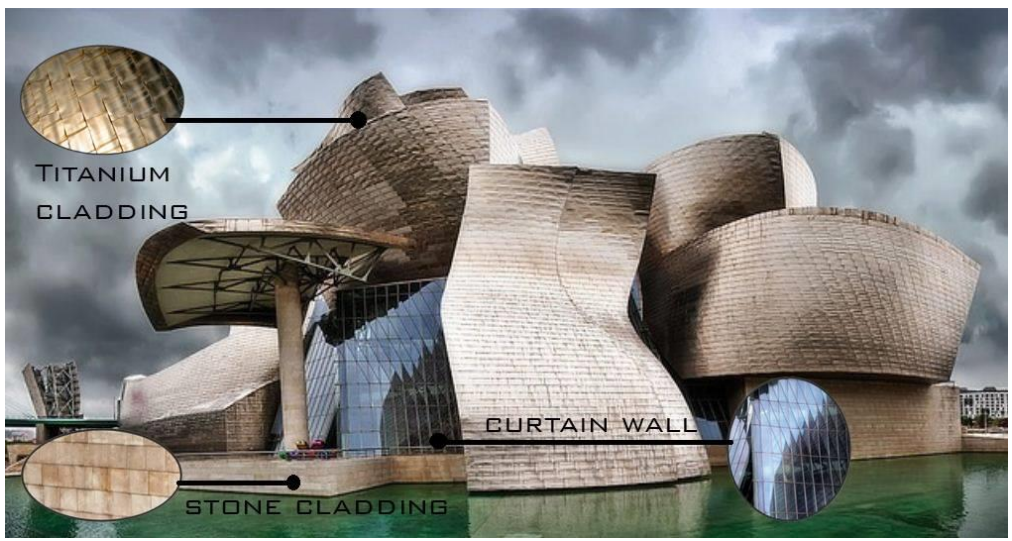
It is one of the most admired works of contemporary architecture as it has been hailed as a “signal moment in the architectural culture” because it represents “One of those rare moments when critics, academics and the general public were all completely united about something”.

Design Intensions

This building is to be of the same quality as its contents, with an importance equal to that of the artworks it would eventually house. Not only was the building design difficult given this criterion but also the site location further challenged the design of the new museum.

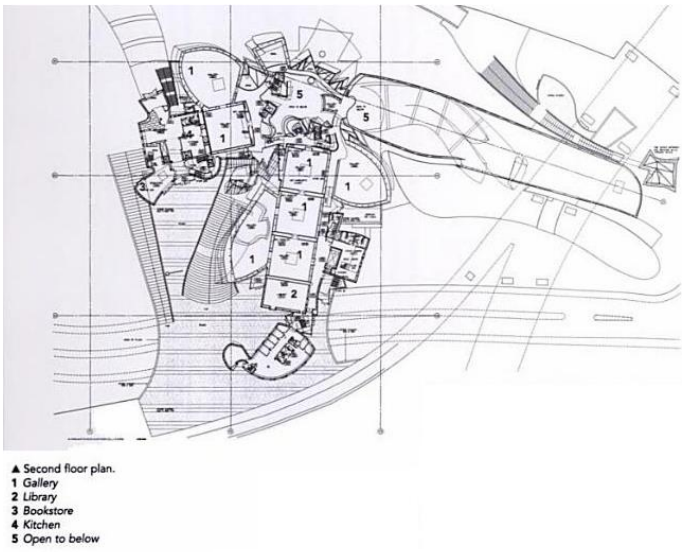
The unique and fluid forms required and exceptional team of engineers, architects and contractors who, as Juan Ignacio Vidarte stated, "brought to fruition a scheme that only sixty months ago seemed utterly impossible. The exterior cladding of the building that provided its signature shape was very difficult to design and construct.Three different elements were used to form the exterior surfaces of the museum which are titanium (25.221 m^2), stone (34.343 m^2) and glass (6.136 m^2). The location of each material is not only defined by the appearance of the exterior, but is also related to the different functions of the interior space: "Titanium cladding for the galleries, limestone for the public facilities (restaurant, library, etc.), and blue render for the administration.

Each material was unique and provided its own set of construction difficulties. However, since the exterior of the building has a very unusual shape, the greatest number of difficulties arose when intersections formed by two or three different materials meeting in peculiar points.

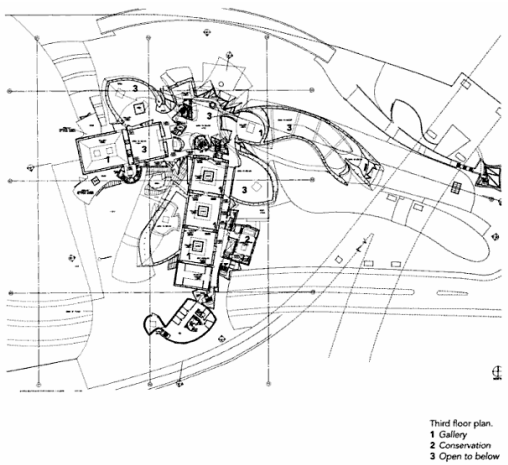


Orthographic Drawings

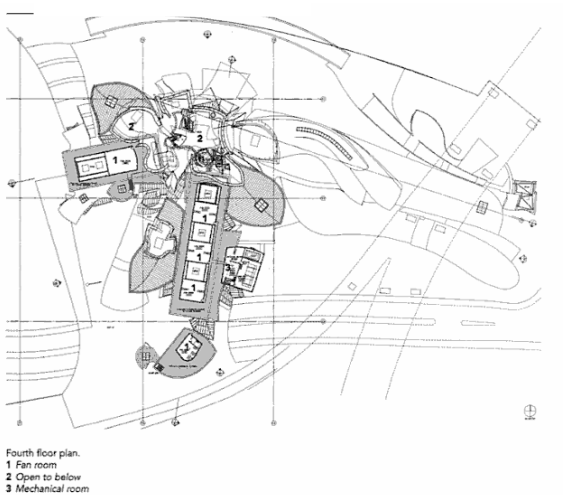
1st Floor Plan



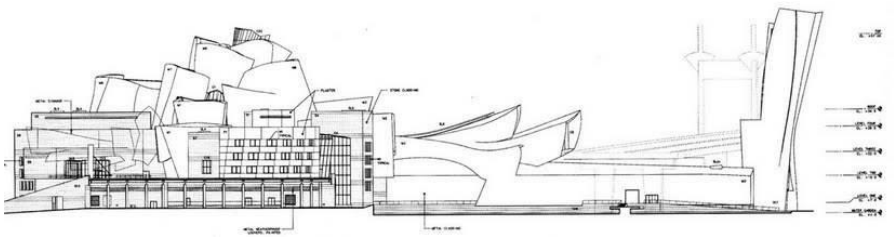
2nd Floor Plan



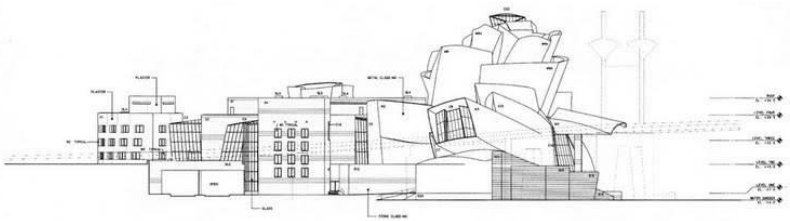
3rd Floor Plan



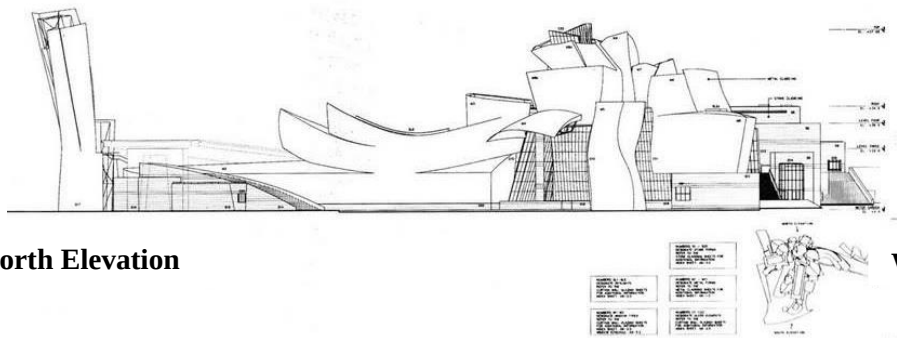
4th Floor Plan



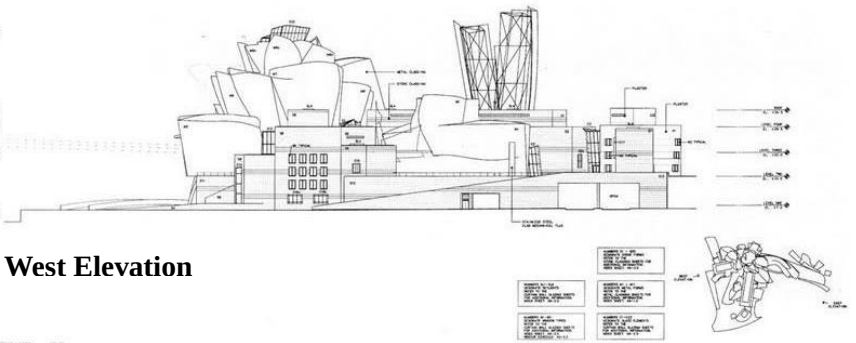
South Elevation



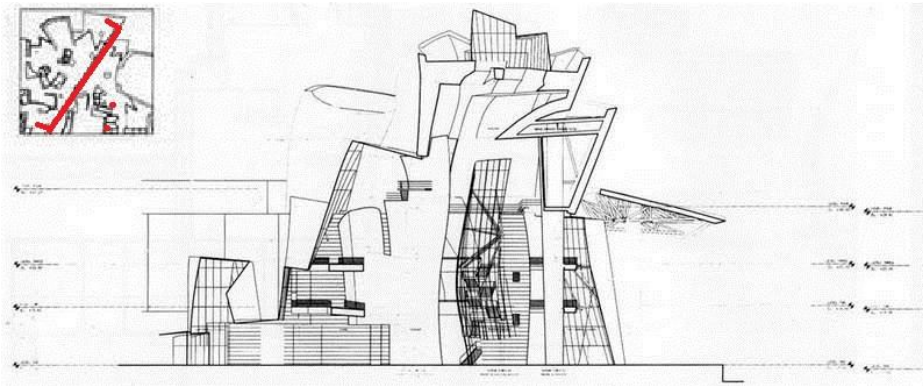
East Elevation



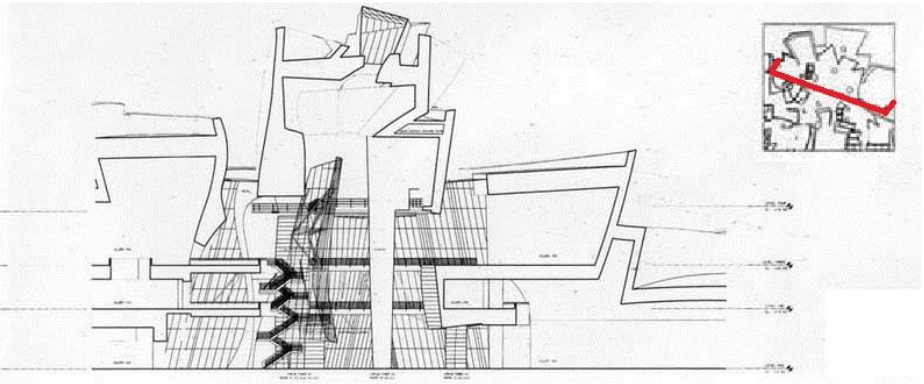
North Elevation



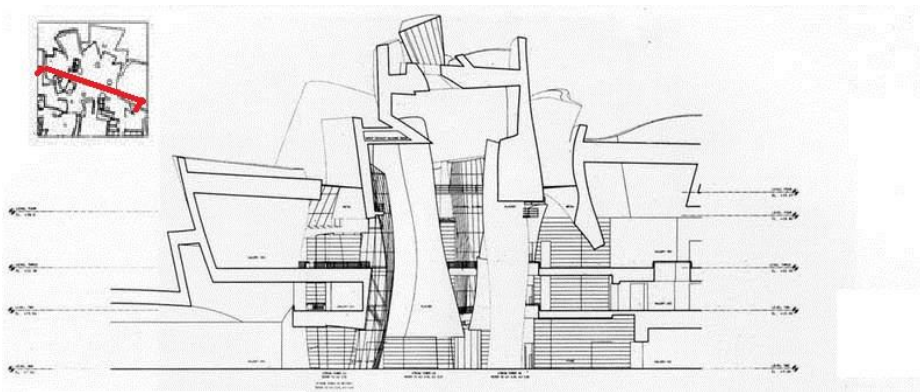
West Elevation



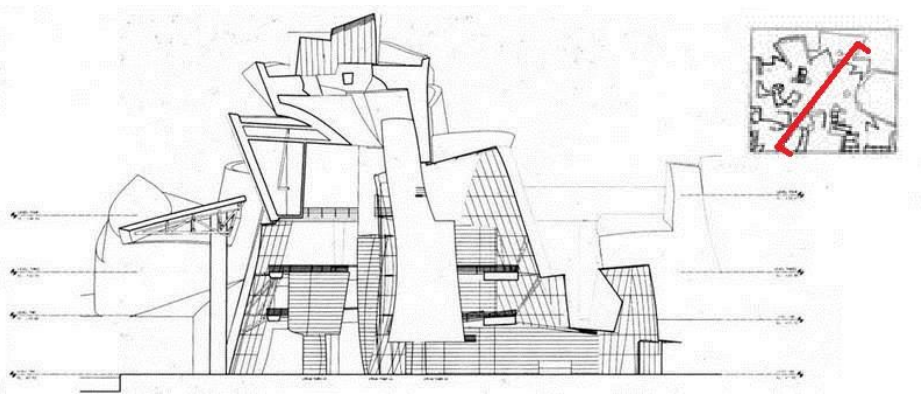
Section A-A



Section B-B



Section C-C



Section D-D

Construction Systems

A. Solid Structure

Function :

1. The solid wall and floor acts as a load bearing structure in which helps in the distribution of the load.
2. This solid structure also converts all the point load which comes from the skeletal steel structure into a distributed load.

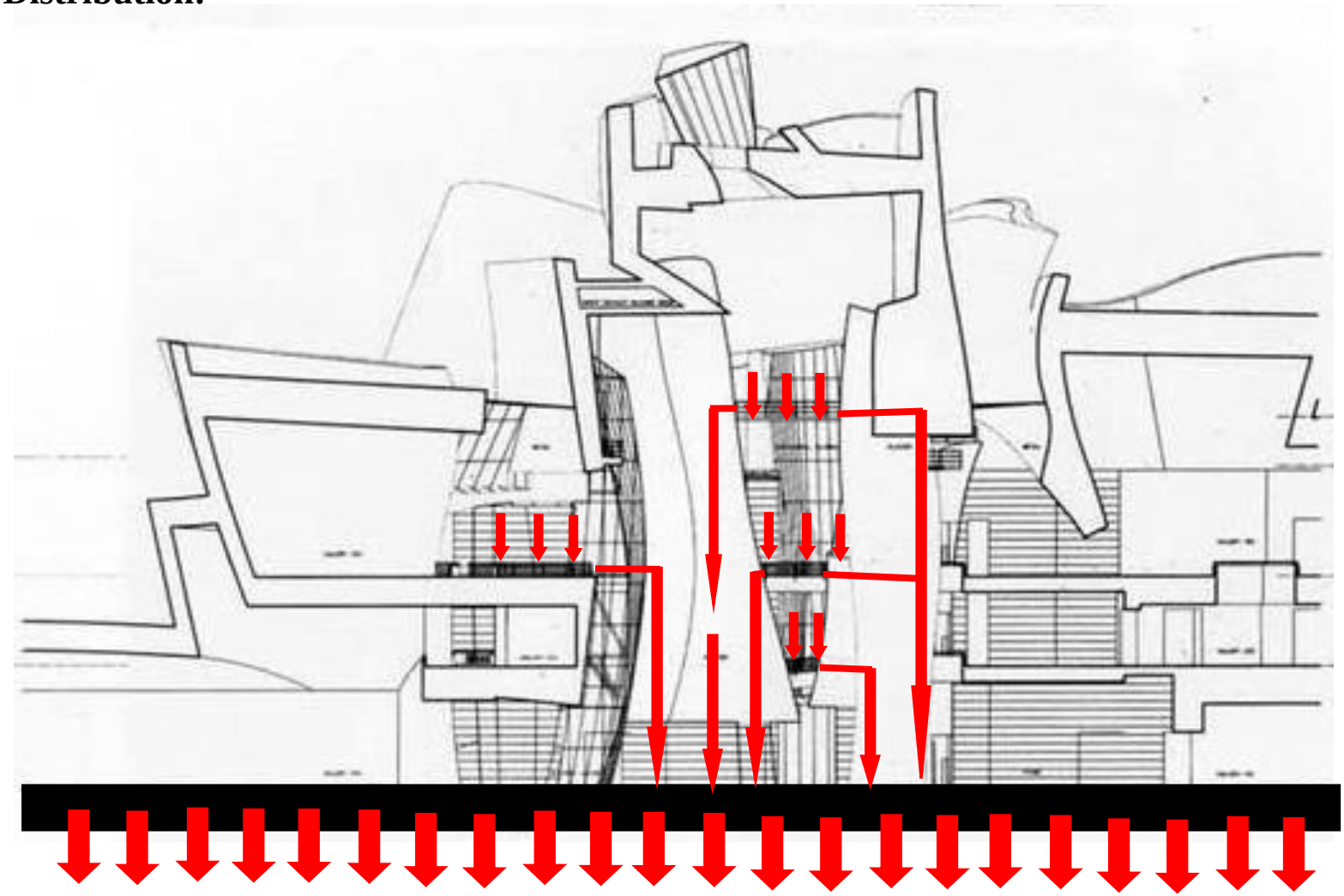
Materials :

- Metal decking
- I-Beam
- Shear connector
- Reinforced mesh
- Reinforcement
- Transfers reinforcement
- P.C Concrete Slab
- In-situ concrete

Joint :

- Reinforcement steel joints.

Load Distribution:



1. The load distribution in this system is a distributed load.
2. This distribution ensures equal load is transferred from the walls and floors throughout the entire building.

B. Skeletal Structure

Function :

1. The entire cladding system uses the skeletal structure as its basic and most primary structure.
2. As a result, this structure is used for its flexibility in its fluidity property for the envelope of the building.
3. The skeletal structure, enables more freedom in terms of its exterior envelope.
4. The use of skeletal structure also allows the load to be distributed through multiple point loads.

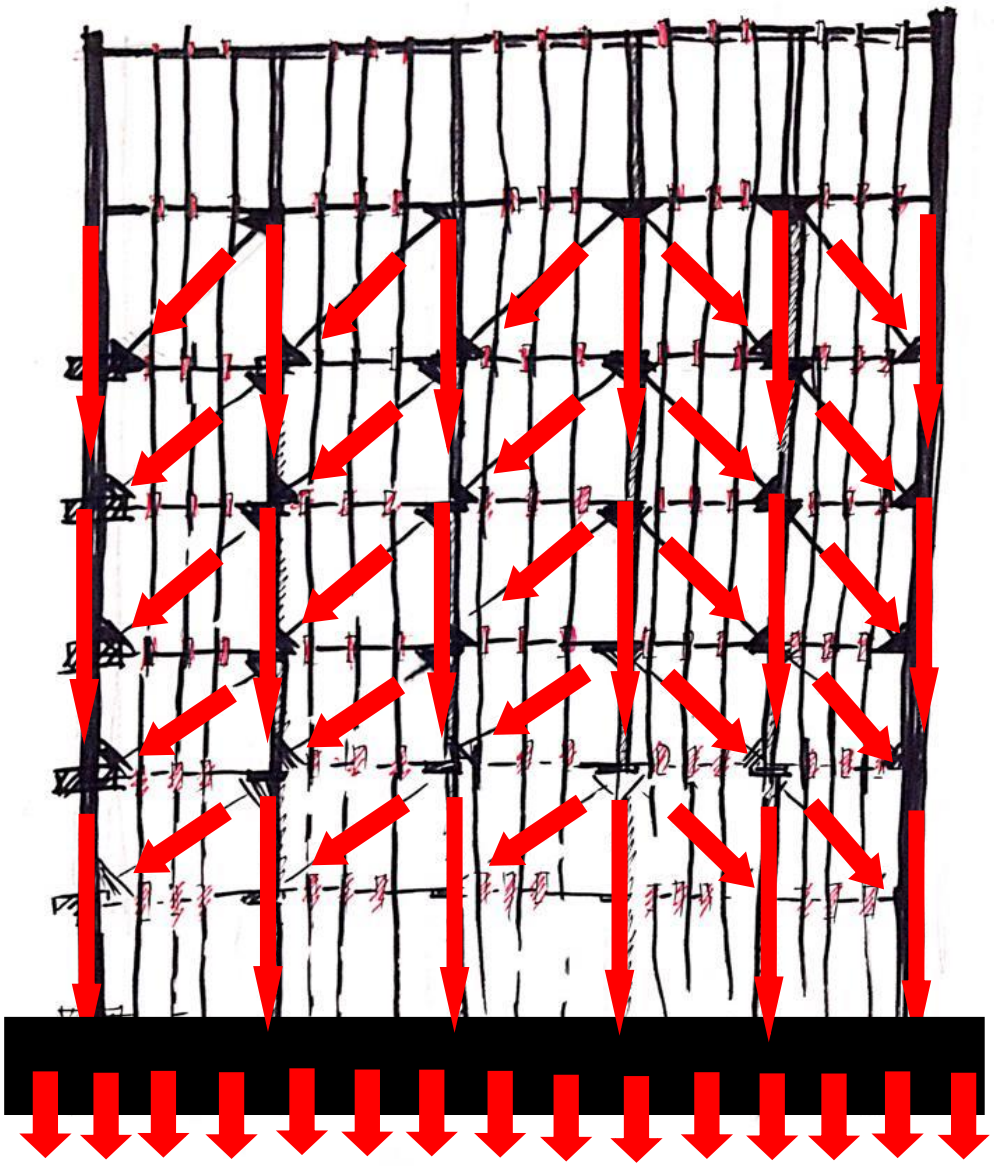
Materials :

- Self-healing waterproofing with slip sheet
- 100mm galvanised steel stud
- Spray-on insulated vapor barrier
- 2mm galvanised sheet
- Stainless steel anchor
- Galvanised steel tube
- Steel tee
- Steel angle
- Steel splice plate
- Rectangular steel beam

Joint :

- Pinned Joint
- Nut and bolt joint

Load Distribution :



1. The use of skeletal structure also allows the load to be distributed through multiple point loads.
2. This distribution is transfered throught the columns and beam which make up the entire skeletal structure.

Construction Methods

A. Titanium Cladding

Materials used :

- Customised pattern 0.38mm thick titanium sheets
- Self-healing waterproofing with slip sheet
- 100mm galvanised steel stud
- Spray-on insulated vapor barrier
- 2mm galvanised sheet

Construction Method :

1. The primary structure of the skeletal system was first built up using galvanized steel.
2. The steel splice plate is then connected onto the primary structure.
3. Upon connecting this,
4. The lower edge of each titanium panel is curved around and behind the hangers overlapped with another panel requiring installation from the bottom to the top.
5. The hangers and the wrapping of the panels allow adjustments to be made during installation as well as
6. thermal expansion and contraction movement.
7. After this, 3 100mm galvanized steel studs with equal gaps were placed in between the 2 vertical steel structures creating a secondary structure. These 2 elements were connected using a pinned connection.
8. A slip sheet with a layer of self-healing waterproofing layer was then placed on the studs. This transparent membrane was incorporated into the structure to further enhance its waterproofing capability.
9. With a thickness of only 1.13mm, it has the ability to “grow” around holes and re-seal around them.
10. Finally, the titanium sheet were then carefully screwed accordingly to the studs, creating a very organized pattern and sequence to the cladding.
11. Weep holes were created at the base of the titanium panel curve to provide and outlet for any water that may condensate or seep behind the panels from the roof runoff .

B. Stone Cladding

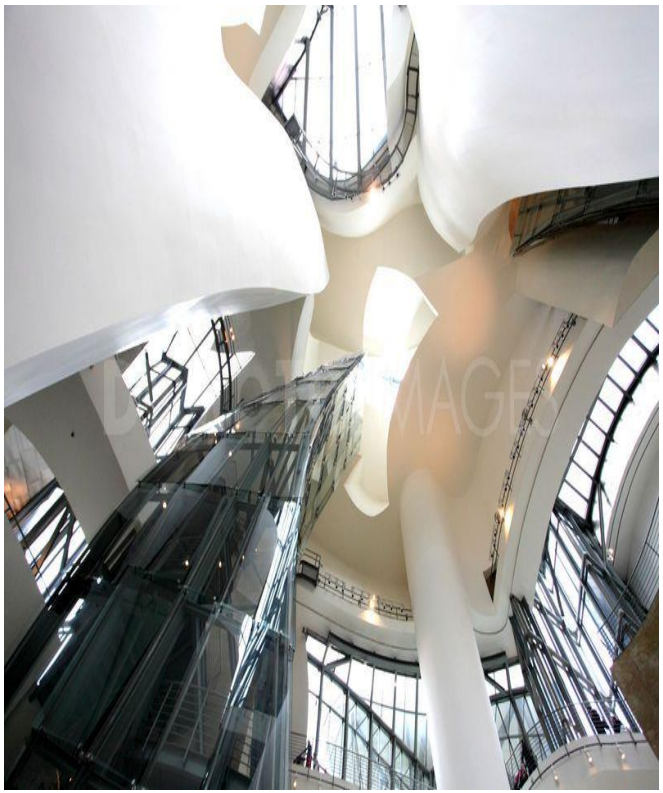
Materials used :

- Stone cladding
- Stainless steel anchor
- Galvanised steel tube
- Steel tee
- Steel angle
- Steel splice plate
- Rectangular steel beam

Construction Method :

1. The primary structure of the skeletal system was first built up using galvanized steel.
2. The 2mm galvanized sheet is then connected to the Primary structure using a pinned connection..
3. Upon connecting this, a rectangular steel beam is then connected to the steel splice plate using a steel angle.
4. Next, a steel tee is placed and secured onto the other edge of the rectangular steel beam.
5. A steel angle is then connected to the exposed surface of the steel tee while the other surface of it is connected to the galvanised steel tube.
6. A steel anchor is placed on the galvanised steel tube and finally the stone cladding is secured through the anchor.

C. Concrete Floor Slab & Wall



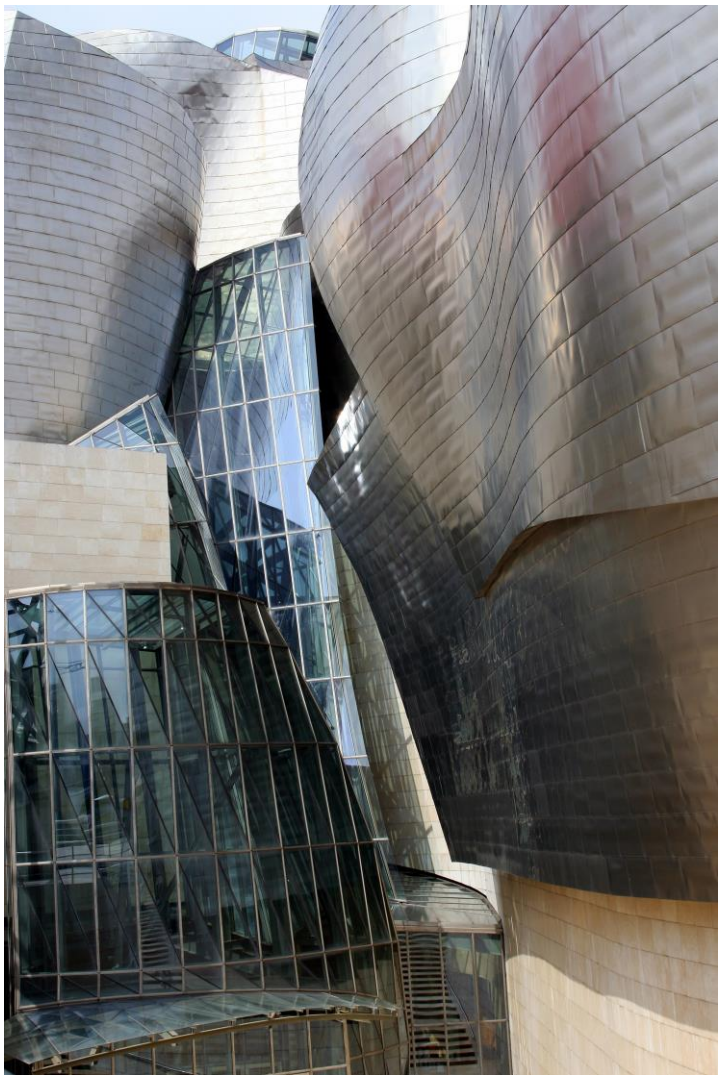
Materials used :

- Metal decking
- I-Beam
- Shear connector
- Reinforced mesh
- Reinforcement
- Transfers reinforcement
- P.C Concrete Slab
- In-situ concrete

Construction Method :

1. The metal decking is tied by a skillful worker and be ready for the setting up as the reinforcement.
2. The reinforced mesh, and the transfers reinforcement is then placed above the metal deck. It is then firmly secured.
3. The I-beams are then connected to the metal deck by screwing them together.
4. A formwork is constructed using timber and supported by temporary scaffolds.
5. A shear connector is then placed to ensure the connection is secured.
6. In-situ concrete is mixed on site and poured into the formwork.
7. After the concrete as fully cured, the formwork is removed.

D. Curtain Walling



Materials used :

- Steel Brackets
- Setting Blocks
- Extruded thermal break
- Stainless Steel Closure Plate with Thermal Insulation
- Aluminum Mullion
- Glass

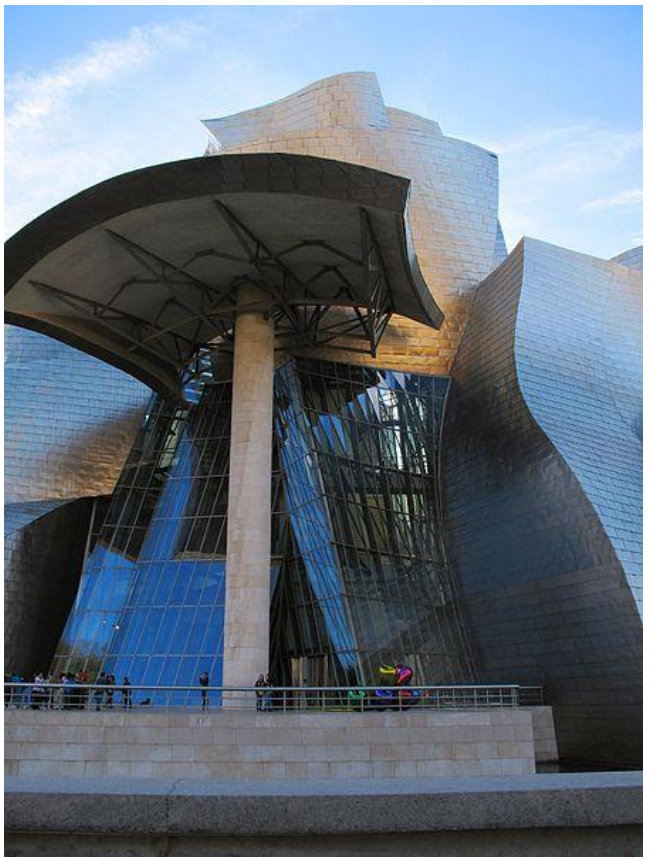
Construction Method :

1. Due to the unique and unusual shapes of curtain wall, a skillful worker is needed.
2. CNC machine is used in this project to cut off all the glass panels as 2000 out of 2200 panels, the glass were uniquely shaped and most of the shapes are very complex.
3. Triangular glass panes were used in the construction to create curved surfaces without the additional expense and complexity of curved glass.
4. A gap was inserted to eliminate the joining of the two different system due to the difficulties of joining the glass curtain wall with other cladding materials.

E. Roof

Materials used :

- Stone cladding
- Titanium cladding
- Galvanized lattice steel truss
- Galvanized steel studs
- Screws



Construction Method :

1. The construction of the roof was done after the constructer of the steel column.
2. This enable the column to be embedded into the roof allowing the roof and the column to be as one unit.
3. Ones this is completed, the galvanized lattice steel trusses were positioned and secured using the pinned connection.
4. After this, galvanized steel studs were placed and secured onto the trusses.
5. Another piece of truss is the secured to the steel studs, allowing extra support to the roof.
6. Upon finishing this part, another set of studs were place on top of the trusses.
7. This enables a surface to be exposed for the titanium cladding to be arranged.

Modeling Processes

Materials used and its representation.

1. Maroon coloured PVC sticks -> Primary structure and structural support
2. Black coloured PVC sticks on mass model -> exposed structural system, roof trusses, & Railings
3. Black colured PVC sticks on structural model -> Galvanised steel panels for cladding
4. Aluminium sheet -> Titanium Cladding
5. Balsa Wood -> Stone Cladding
6. Plastic Transperancy Sheet -> Curtain Walling
7. White coloured PVC sticks -> Mullions
8. Plaster of Paris on structural model -> Light weight concrete
9. Wire mesh -> Steel reinforcements

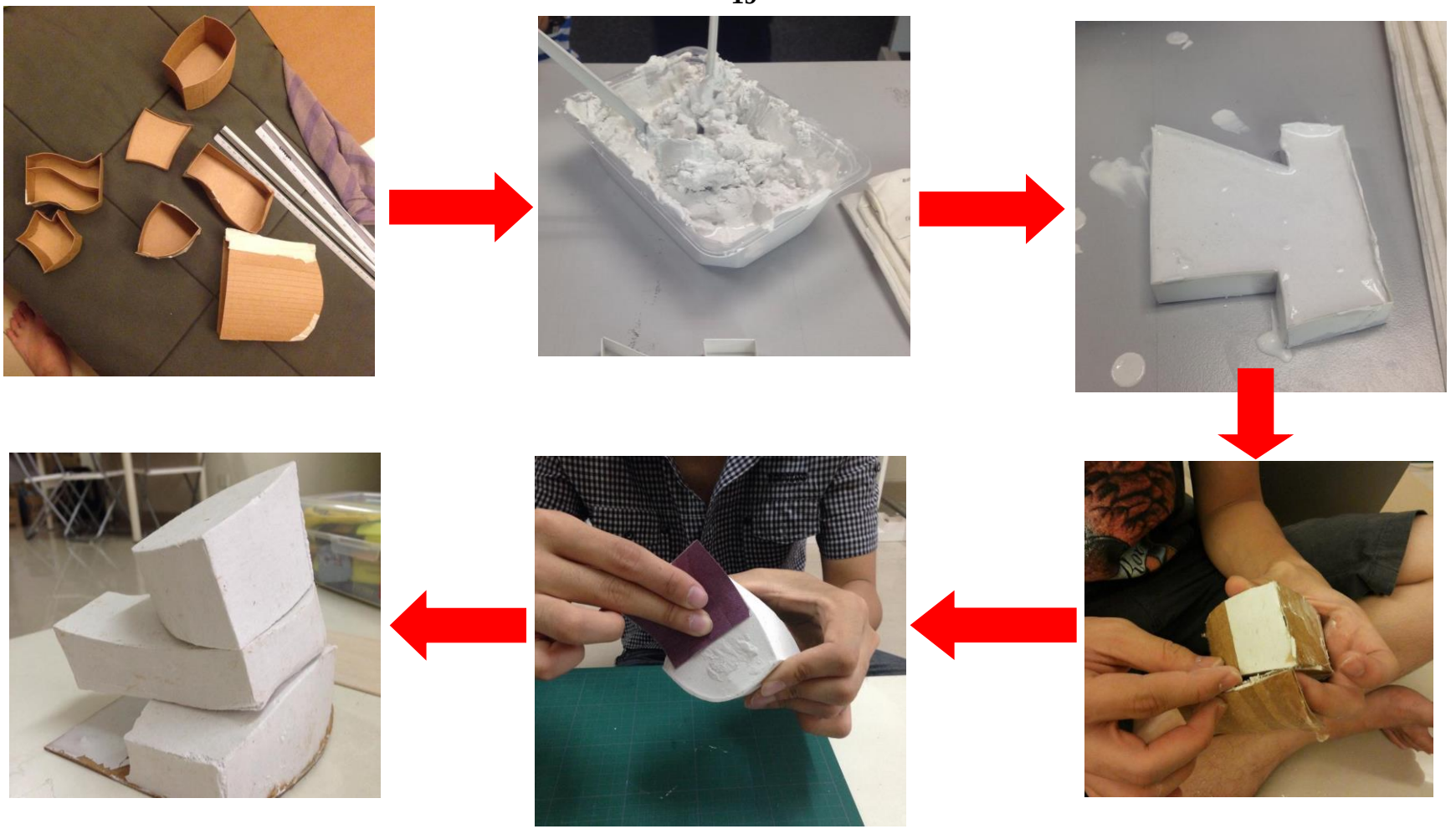
A. Mass Model

Materials & Equipments:

- ➢ Brown and white model board
- ➢ UHU glue
- ➢ Plaster of Paris
- ➢ Water
- ✓ Metal ruler
- ✓ Cutter
- ✓ Cutting mat

Process :

1. The shape of each of the mass model was measured and cut from the brown model board.
2. Upon making the shape, plaster was mixed and poured into the template
3. This model was allowed to sit overnight to harden.
4. The brown model board is slowly peeled off from the mould the next day.
5. The mass model is then smoothened using a sand paper.



Problems faced & Solutions :

1. The proportions used for the plaster was wrong, causing the model to be very fragile and crack.
2. The uneven envelope of the structure made it difficult for us to obtain the proper measurements for the moulding template

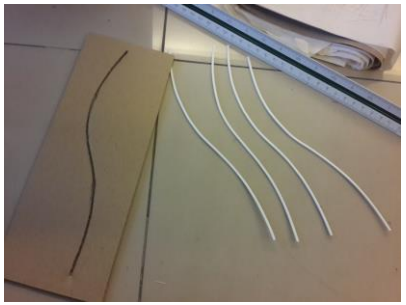
B. Steel Structure

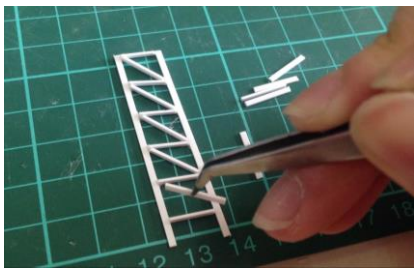
Materials & Equipments:

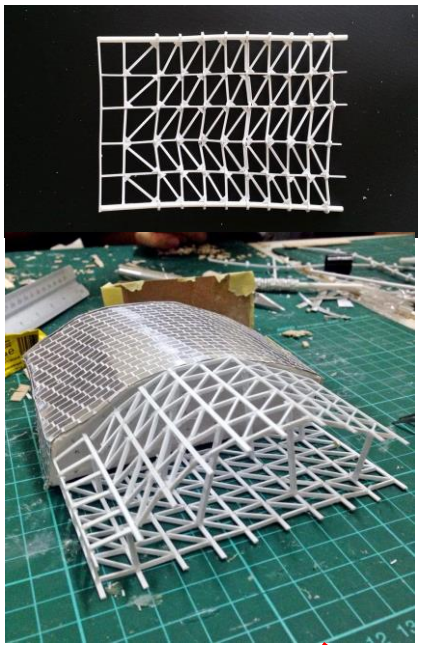
- ➢ PVC Sticks
- ➢ UHU glue
- ➢ Super Glue
- ➢ Maroon spray paint
- ✓ Cutter
- ✓ Cutting mat
- ✓ Tweezer
- ✓ Metal ruler

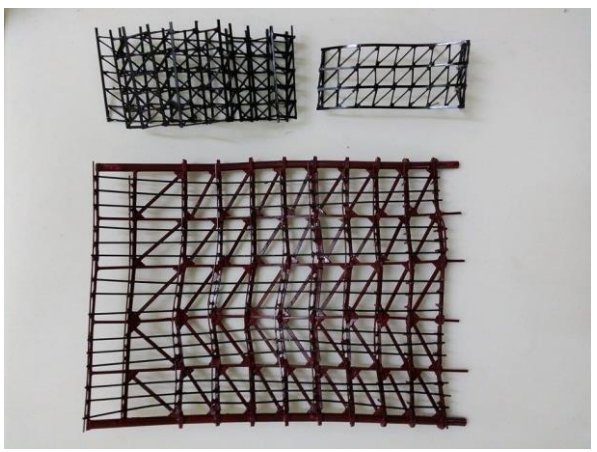
Process :

1. The template for the curved structure of length 32cm was cut and the 2 thick round and 4 thick rectangular PVC strips were inserted into it.
2. Hair dryer was used to heat and shape the PVC which were inserted into the template.
3. Hexagonal bolts of 2 different diameter sizes; 0.5cm and 0.2cm were cut.
4. A 10.97cm thick rectangular PVC strip is cut and the 2 round PVC strips were connected to the 2 ends of the strip, creating the main support for the structure.
5. The 4 thick rectangular strips on the other hand was stuck in equal distance on the same strip creating the intermmediate support.
6. Small intermediate sticks of diff sizes leaving out the 5^{th} space from the bottom for the placing of the I-beam creating horizontal support to complete the primary structure.
7. The I-beams were measured, cut and placed.
8. The triangular diagonal supports are then cut and placed accordingly. The diagonal supports are then cut and placed.
9. 3 studs of length 1cm is cut and placed in between one modular gap. This step is repeated until all the gaps are filled.
10. The long strips of length 32cm were cut and placed on the studs, creating the aluminium panels.
11. The whole structure is then spray painted into a more rustic colour as a resemblance of the actual structure.









Problems faced & Solutions :

1. The PVC strips were too small to be stuck using UHU glue. As a contingency plan we used super glue in which was a success.
2. The PVC strips were too small to handle using hand, thus we used twizer.
3. The surface area of the sticks were too small, causing them to fall off frequently.

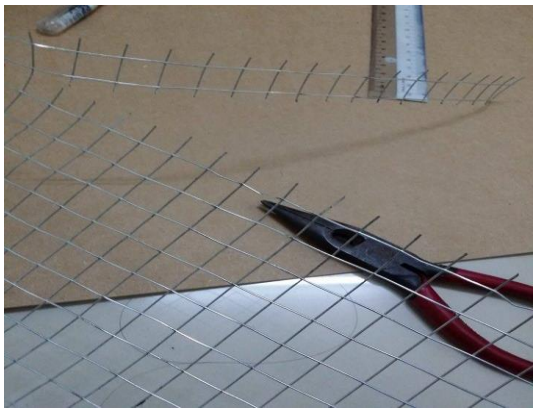
C. Concrete Wall

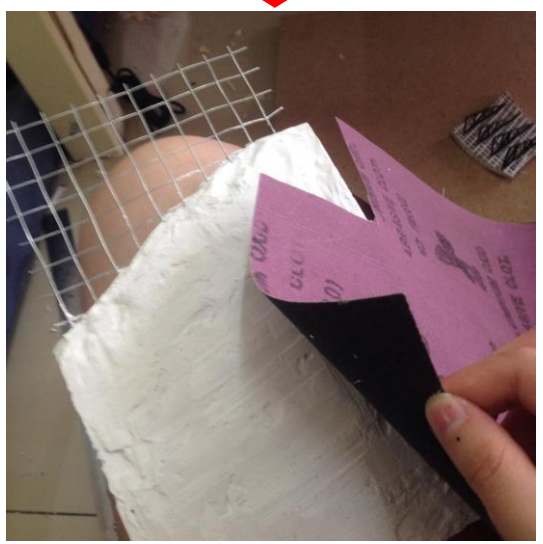
Materials & Equipments :

- Brown model board
- Plaster of Paris
- Water
- Wire mesh
- UHU glue
- ✓ Cutter
- ✓ Pliers
- ✓ Metal Ruler
- ✓ Cutting mat

Process :

1. The shape of each of the mass model was measured and cut from the brown model board.
2. Upon making the shape, the wire mesh was cut to fit the template.
3. The plaster was mixed and poured into the template with the wire mesh. Halfway exposing part of the wire mesh.
4. This model was allowed to sit overnight to harden.
5. The brown model board is slowly peeled off from the mould the next day.
6. The mass model is then smoothened using a sand paper.
7. The wall is then stuck to the steel structure.



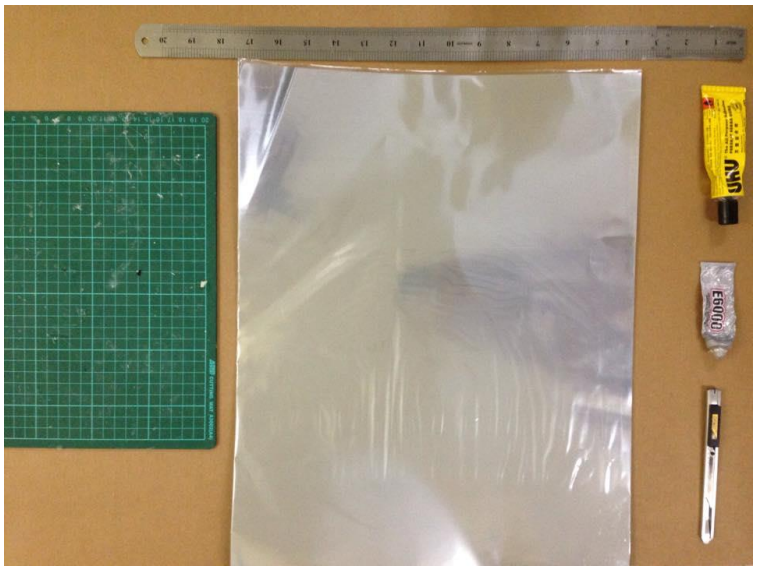


Problems faced & Solutions :

1. The proportions used for the plaster was wrong, causing the model to be very fragile and crack.
2. The uneven envelope of the structure made it difficult for us to obtain the proper measurements for the moulding

template

D. Titanium Cladding

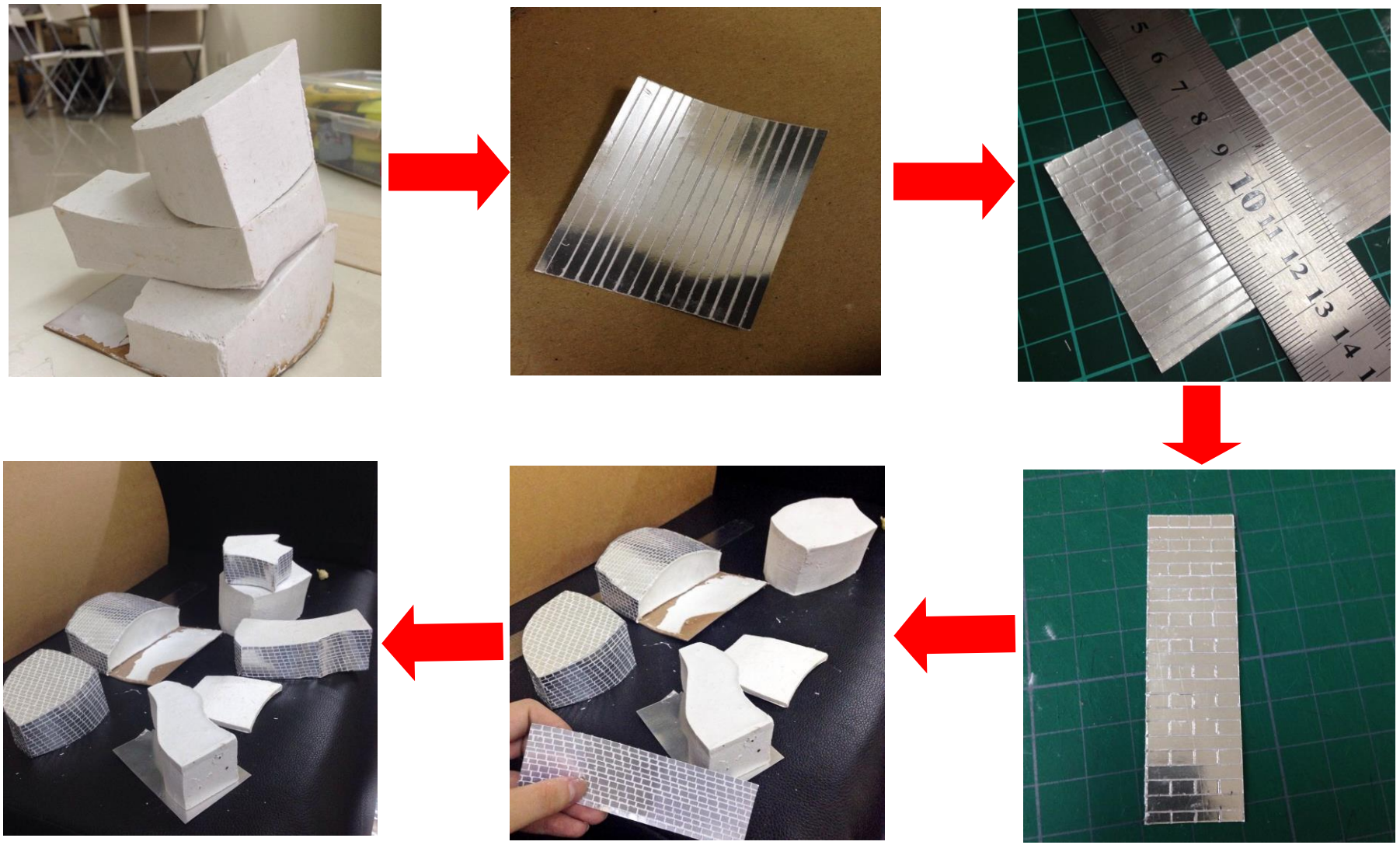


Materials & Equipments:

- Mass model
- 0.05cm aluminium sheet
- UHU glue
- E6000 glue Cutter
- ✓ Metal ruler
- ✓ Cutting mat

Process :

1. The moulded mass models were used as a base of the titanium cladding.
2. The thin aluminium sheets were cut according to the sizes of the surfaces with the titanium cladding.
3. Lines of 0.3cm were drawn horizontally onto the sheets.
4. Vertical line with a gap of 0.5cm were drawn on one of the lines. The next vertical lines were drawn under the first, but displaced slightly to the right. This will give a sense of sequence shown in the actual cladding.
5. The lines are then scared by taking off the first layer of the sheet; shining layer. This will give an impression that the cladding was done individually.
6. After scaring, the sheet is then glued to the moulded mass model.

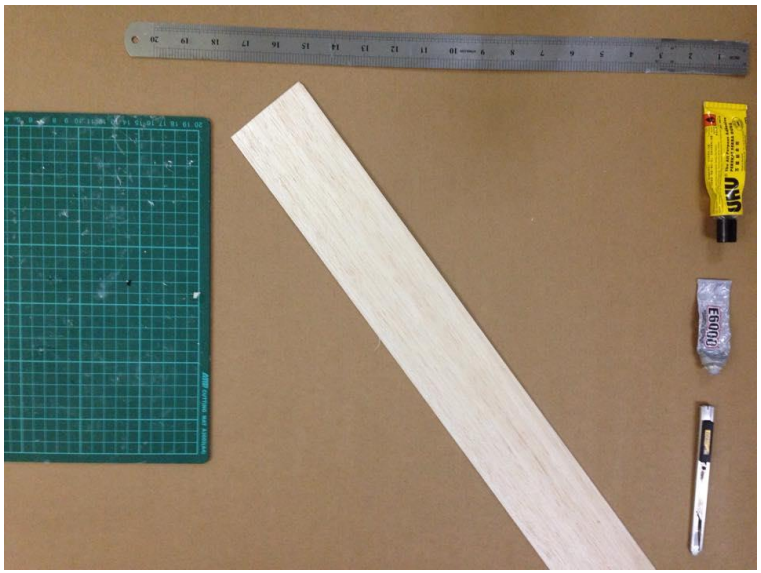


Problems faced & Solutions :

1. The scaring was the part in which too most time and the hardest.

2. The thin lines were hard to be removed for the scaring.

E. Stone Cladding



Materials & Equipments :

- ➢ Mass model
- ➢ 0.05cm aluminium sheet
- ➢ UHU glue
- ➢ E6000 glue
- ✓ Cutter
- ✓ Metal ruler
- ✓ Cutting mat

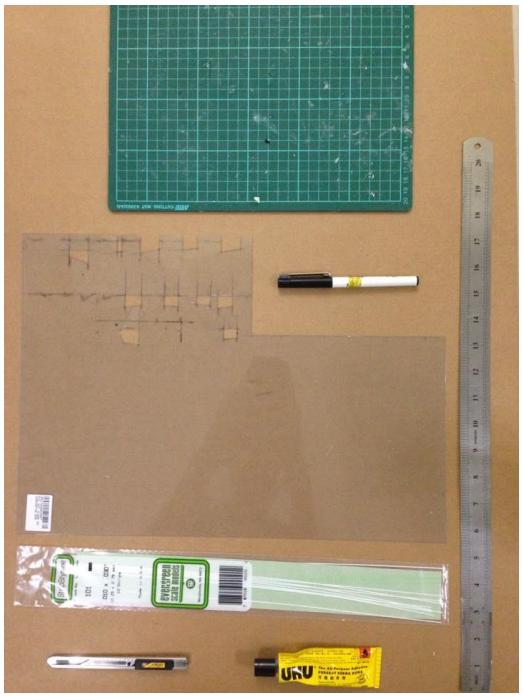
Process :

1. The moulded mass models were used as a base of the stone cladding.
2. The thin balsa wood were cut according to the sizes of the surfaces with the stone cladding.
3. Lines of 0.3cm were drawn horizontally onto the wood.
4. Vertical line with a gap of 0.5cm were drawn on one of the lines. The next vertical lines were drawn under the first, but displaced slightly to the right. This will give a sense of sequence shown in the actual cladding.
5. The lines are then scared by removing the top part of the wood. This will give an impression that the cladding was done individually.
6. After scaring, the wood is then glued to the moulded mass model.

Problems faced & Solutions :

1. The scaring was the part in which too most time and the hardest.
2. The thin lines were hard to be removed for the scaring.
3. Cladding the column was tough as the diameter is too small. It caused the balsa to break easily. As a solution, we cut the balsa into half and soaked into water to ease the bending process.

F. Curtain Walls

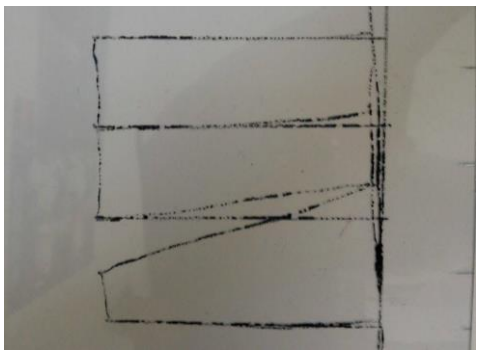


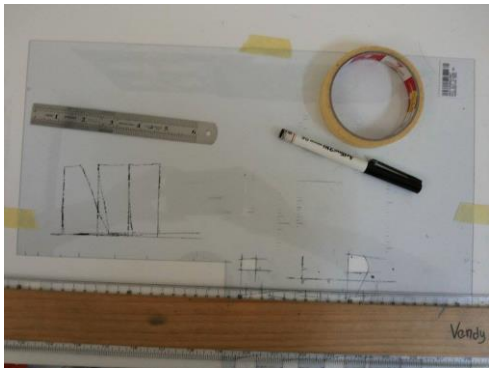
Materials & Equipments :

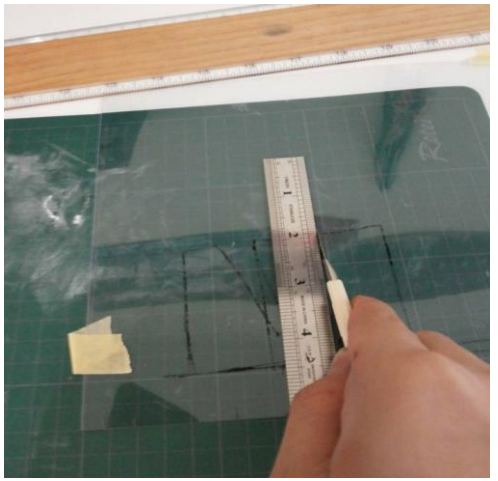
- ➢ PVC sticks
- ➢ Plastic transparency sheet
- ➢ UHU glue
- ✓ Cutter
- ✓ Metal ruler
- ✓ Marker

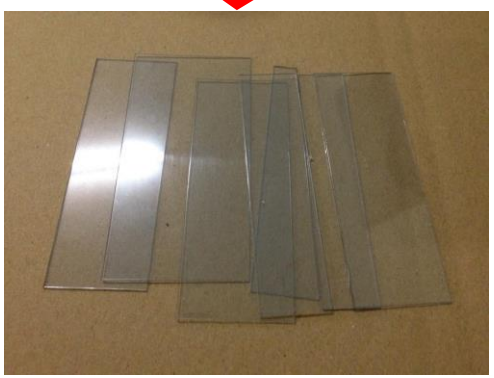
Process :

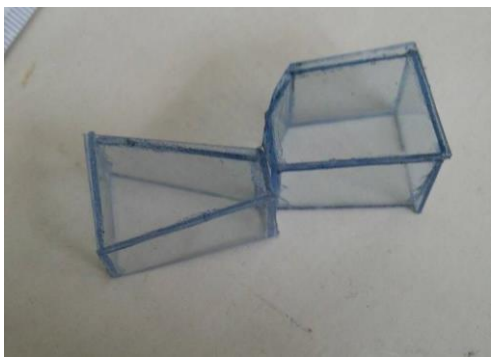
1. The sizes of the curtain walls are measured.
2. These dimensions were then drawn onto the plastic using a removable marker. This method was used to ensure the markings made are able to be erased.
3. Masking tape was placed onto the plastic to ensure a smooth line was cut.
4. The pieces needed are then glued together using UHU glue.




Vendy







Problems faced & Solutions :

1. The plastic was hard to be glued together due to the transperency factor when using super glue. As a solution, the use of UHU glue made it easier to be glued, thus incresing its tidiness.

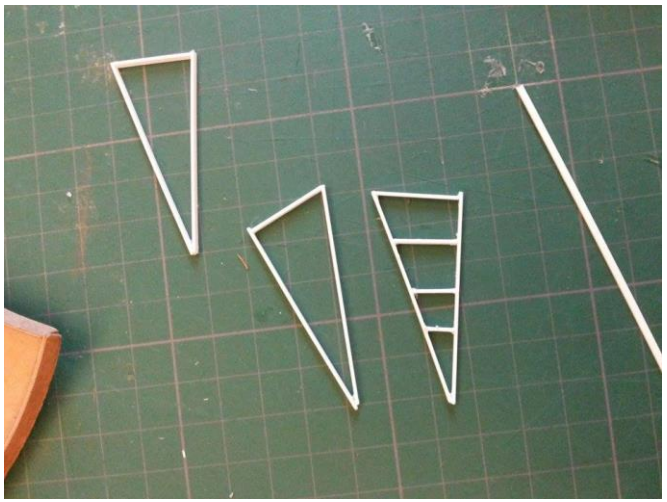
G. Roof Trusses

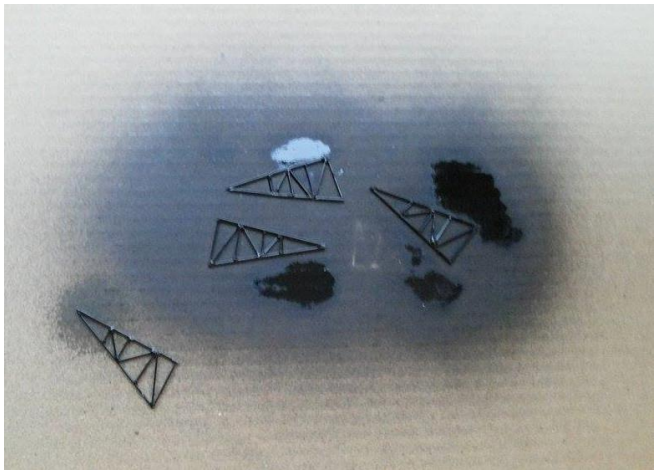
Materials & Equipments:

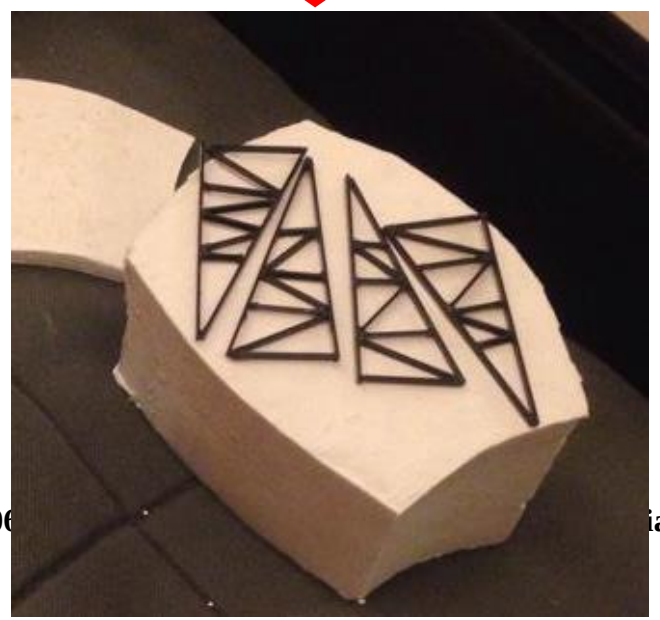
- ➢ PVC sticks
- ➢ UHU glue
- ➢ Black spray paint
- ✓ Metal ruler
- ✓ Cutter
- ✓ Tweezer
- ✓ Cutting mat

Process :

1. PVC sticks of length 4.5cm, 5.2cm and 2.2cm is measured, cut and stuck into a triangular shape.
2. This creates the main structure for the roof truss.
3. Other PVC sticks of various length are cut as intermediate trusses.
4. This structure is then spray painted black.
5. These step were repeated 4 times, creating 4 trusses which are used in supporting the cantilevered roof.







Problems faced & Solutions:

1. The PVC strips were tough to be handled using hand, thus we used tweezer.
2. The surface area of the sticks were too small, causing hem to fall off frequently.

H. Minor Detailing

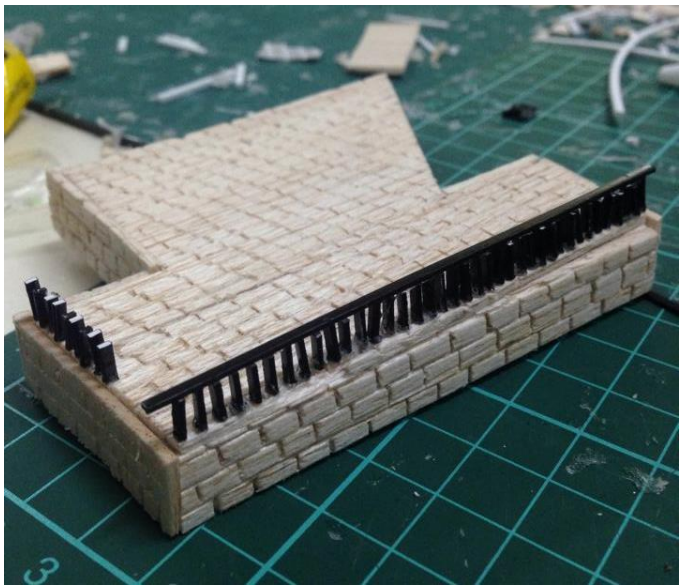
a) Railing

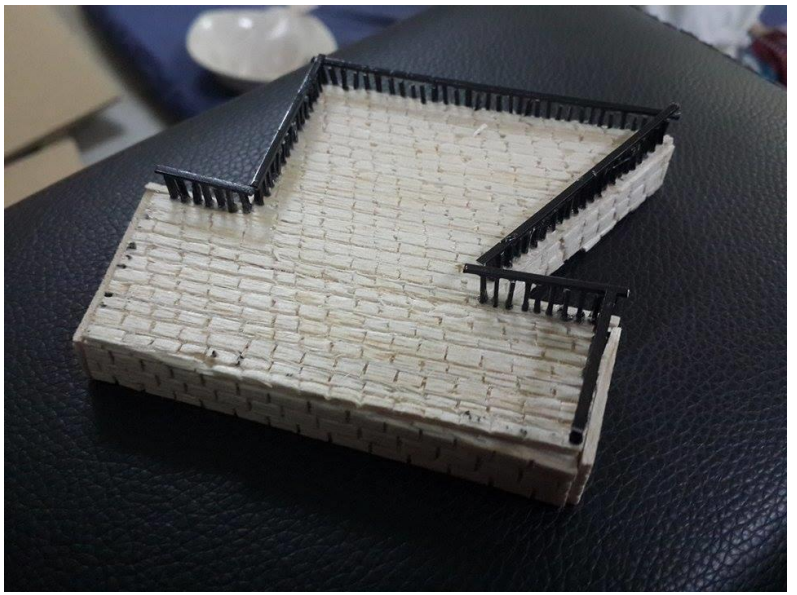
Materials & Equipments:

- ➢ PVC sticks
- ➢ UHU glue
- ➢ Black spray paint
- ✓ Ruler
- ✓ Cutter
- ✓ Tweezer
- ✓ Cutting mat

Process :

1. 98 Sticks of length 0.5cm were cut, creating the separation between the railings.
2. Other sticks of dimensions 2cm, 4.2cm, 7.7cm, 5.7cm, 2.6cm, and 2.5cm were also measured and cut creating the handles for the railings.
3. These tiny sticks were spray painted black.
4. They were then alligned and stuck at the edge of the platform forming the railing leaving 2 of the side vacant as they are used for access purposes.
5. The different longer sticks were then placed on the line of smaller sticks forming the handrail.



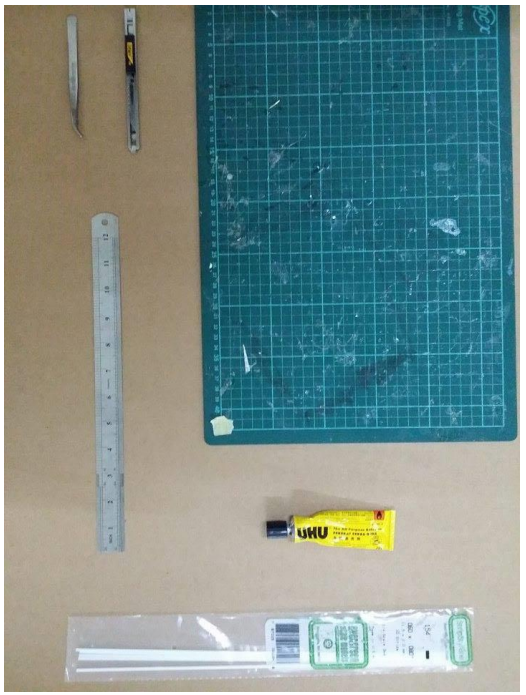


Problems faced & Solutions:

1. The The PVC strips were too small to be stuck using UHU glue and also tough to be handled using hand, thus we used tweezer.

2. The surface area of the sticks were too small, causing them to fall off frequently.

b) Mullions

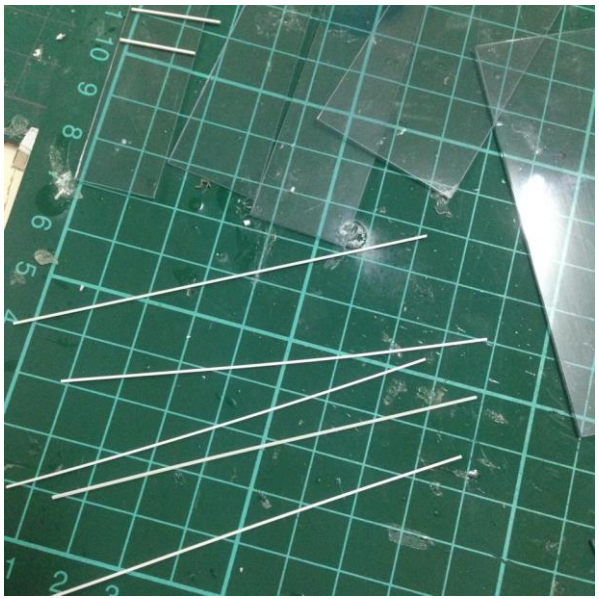


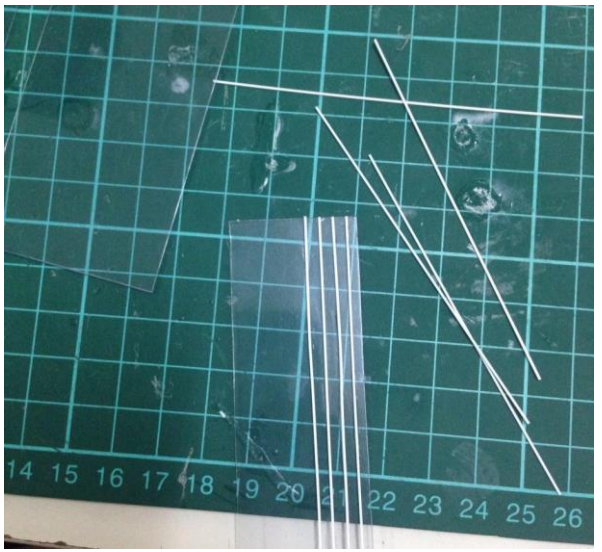
Materials & Equipments:

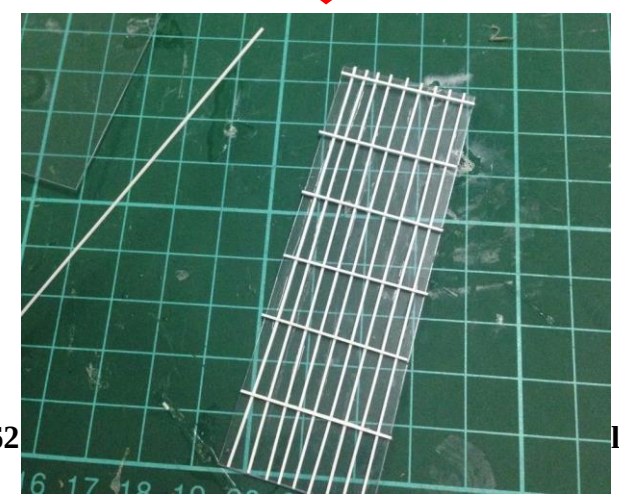
- ➢ PVC sticks
- ➢ UHU glue
- ✓ Ruler
- ✓ Cutter
- ✓ Tweezer
- ✓ Cutting mat

Process :

1. PVC strips of length 8.5cm were cut for the vertical side.
2. Strips of length were then cut for the horizontal side.
3. Upon cutting, the vertical strips were then glued onto the plastic pieces.
4. After drying, the horizontal pieces were equally placed with a constant distance of 1.5cm.







Problems Faced & Solutions :

1. The size of the mullions were too small to be handled with hand, thus a tweezer was used.
2. The problem of sticking the mullions were also encountered due to its very small surface area., thus UHU glue was used.

I. Skeletal Structure Joint
(Pin Joint + Nut & Bolt Joint)

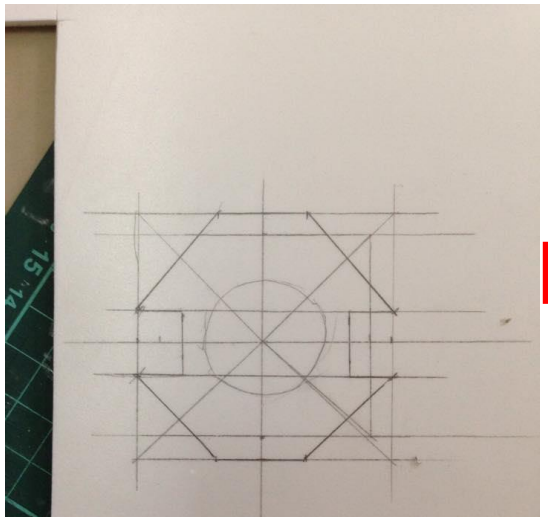
Materials & Equipments :

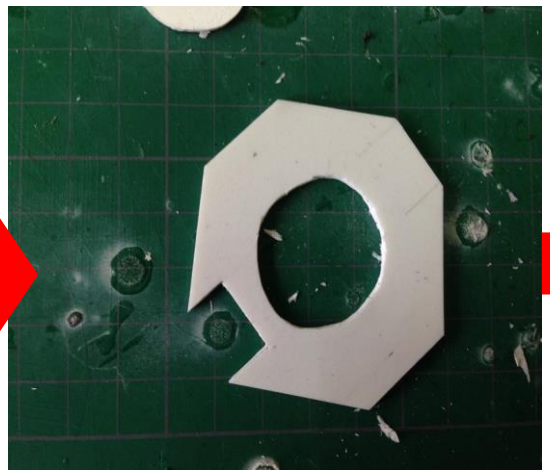
- PVC foam board
- White model board
- UHU glue
- ✓ Ruler
- ✓ Cutter
- ✓ Tweezer
- ✓ Cutting mat

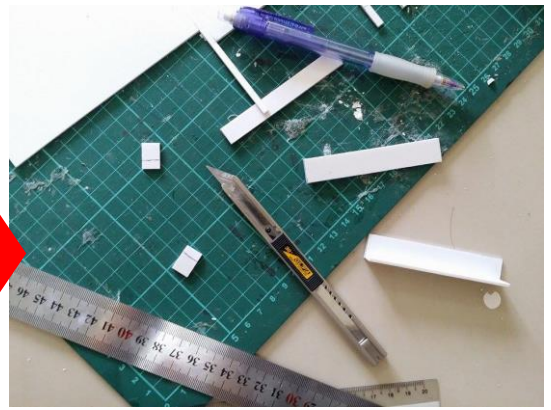
Process :

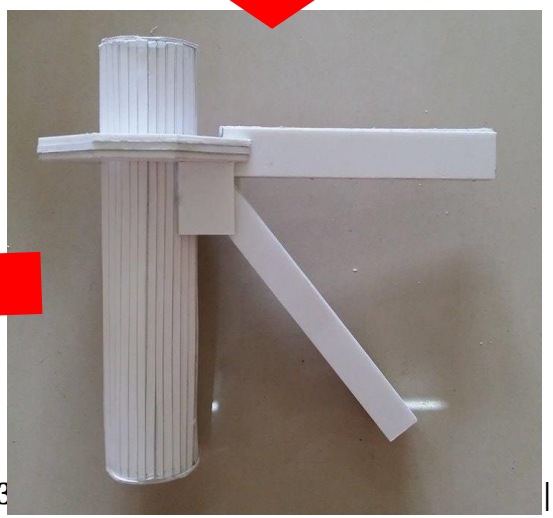
1. The white model board is cut into dimensions of 12cm x 8cm.
2. This board is further cut halfway with a gap of 0.25cm. This is to ensure, when bent, a smoother cylinder is produced.
3. Both the edges of the cylinder was capped.
4. 3 regular octagons were cut from the PVC foam board. This step was taken to ensure the thickness is achieved.
5. A circle of diameter 2.6cm was cut out from the octagonal shape.
6. The shape was then inserted into the cylinder.
7. A small slit of dimension 1cm x 1.5cm was cut out from the octagonal plate.
8. 1 Cuboid of dimensions 1.5cm x 1.5cm x 8cm was cut.

9. Another couboid of dimensions 1.5cm x 1cm x 8cm was cut
10. 2 pieces of rectangluar shapes with dimensions of 1.5cm x 2cm were cut as the diagonal support.
11. All the pieces were then assembled and secured into place.
12. Small pieces of card was also cut as a representation of the nuts.
13. The structure is then spray painted maroon to fit its original state.









Problems Faced & Solutions :

1. Difficulty in cutting the circular shape inside.

Final Product