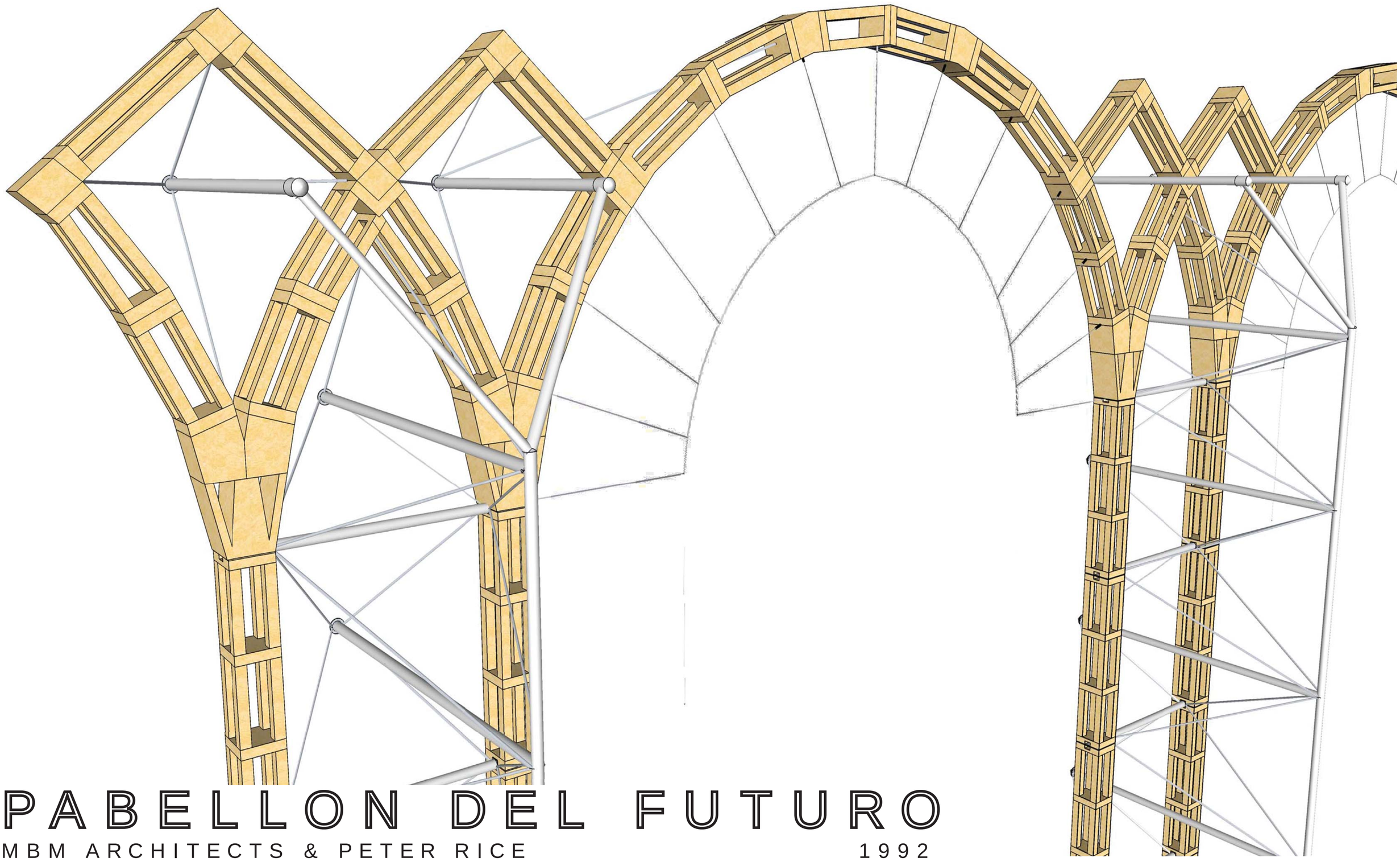
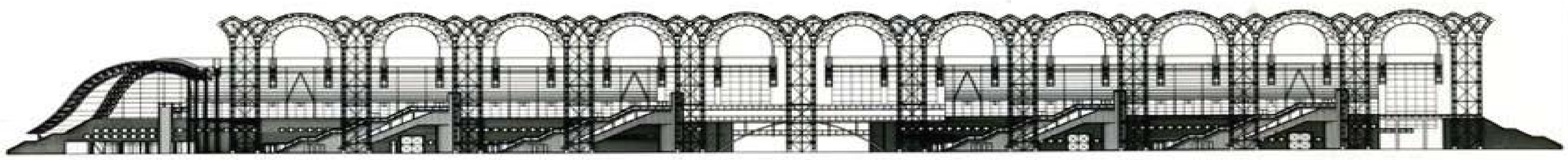
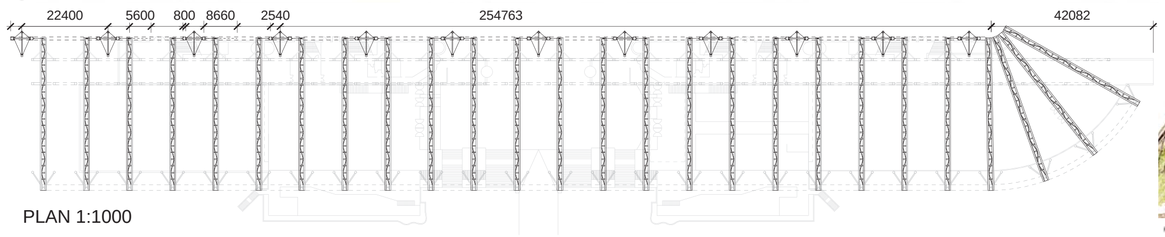


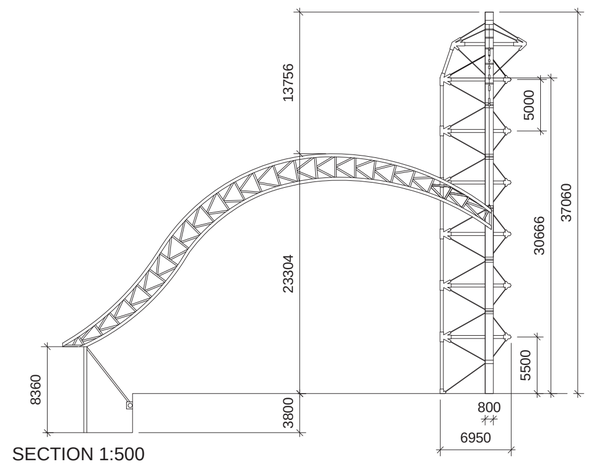
PABELLON DEL FUTURO

MBM ARCHITECTS & PETER RICE 1992

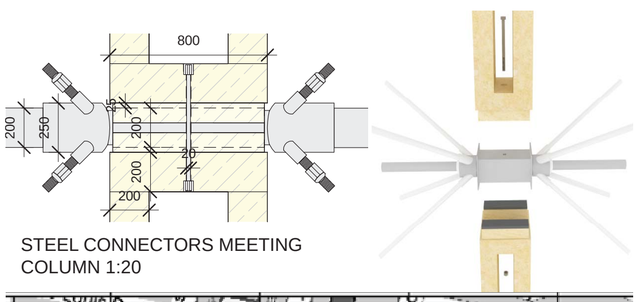




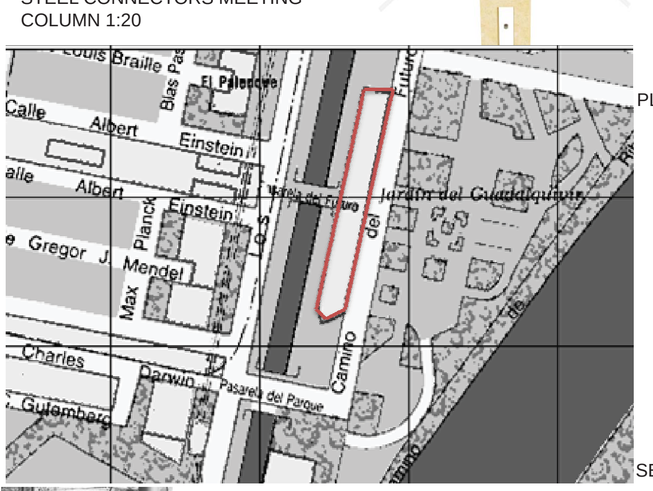
PLAN 1:1000

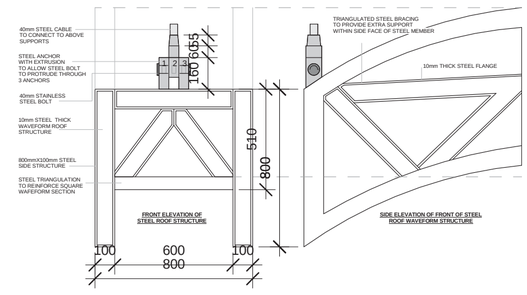


SECTION 1:500

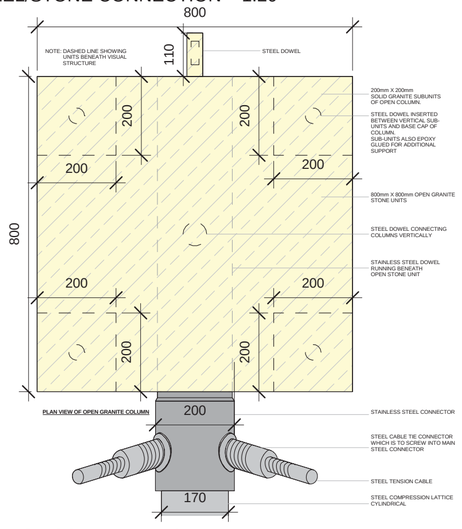


STEEL CONNECTORS MEETING COLUMN 1:20

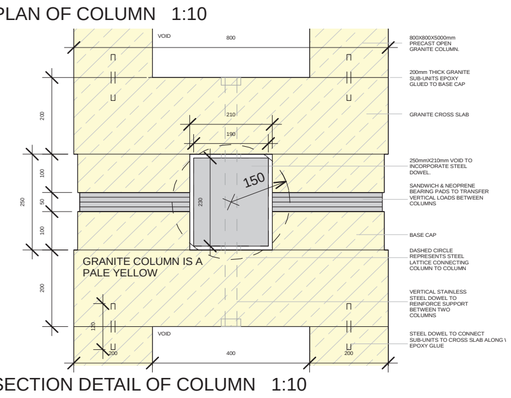




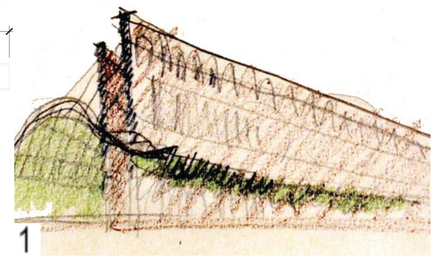
STEEL/STONE CONNECTION 1:20



PLAN OF COLUMN 1:10

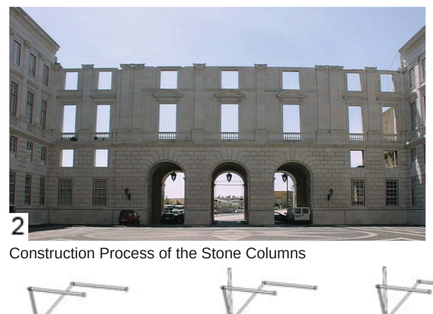


SECTION DETAIL OF COLUMN 1:10

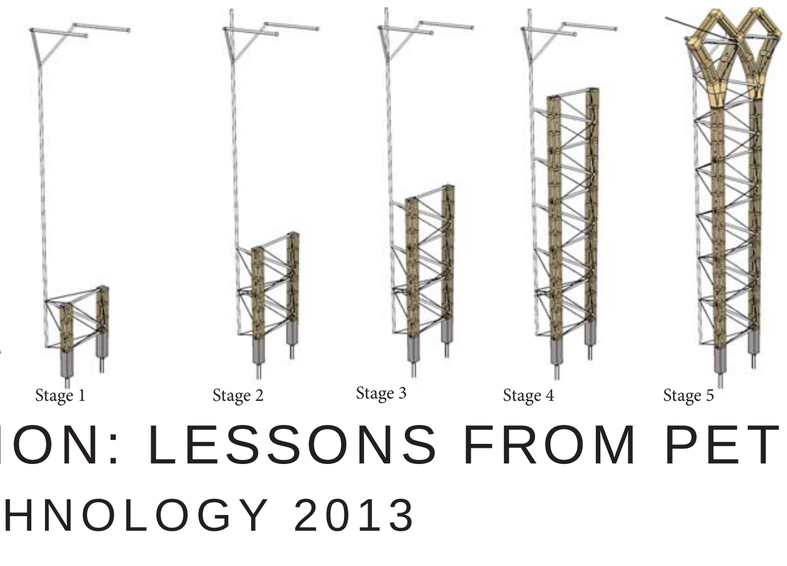


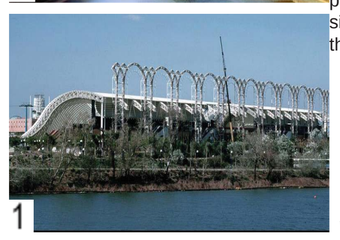
Martorell Bohigas and Mackay (MBM) asked Peter Rice in 1988 to participate in the design for the Pavilion of the Future. This was to be a spectacular building for the 92" World expo. The Universal Exhibition was held in Seville and was to be the largest of its kind. The event coincided with the 500th anniversary of Christopher Columbus's discovery of America and therefore Expo 92 was given the theme 'The age of discovery'.

Rice had previously been amazed by the Ajuda Palace in Lisbon(see pic below). This building was built around a quadrangle but one side had been left unfinished. The construction stopped when Napoleon attacked and the construction never resumed.Rice was fascinated by the fact that the building even stood and this inspired him to construct a building which resembled the fragment of an aqueduct.

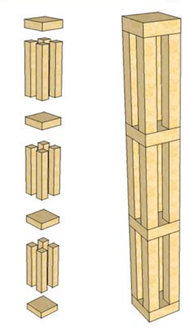


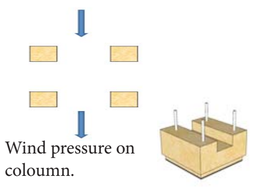
Construction Process of the Stone Columns



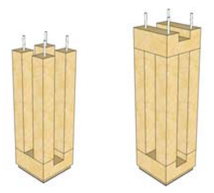


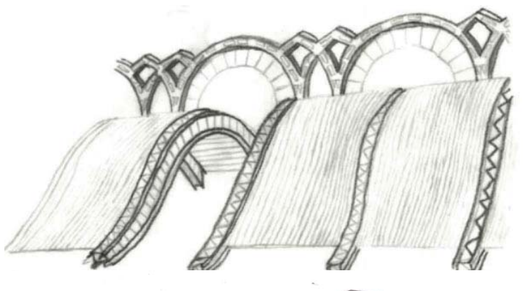
The fully assembled section of the granite column stands at five meters in height. Each column is then fixed together with a steel box section that is sandwiched between the two columns. There is a predrilled hole in the center on both columns and the steel box section, a steel bolt is then slotted in and tighted to specification. There is also an epoxy layer as well which gives the connection added strength. On either side of the plate is a connection from the steel tension cable. These are needed to transfer the structural loads down to ground level.





Wind pressure on coloumn.





CONNECTION & COLLABORATION: LESSONS FROM PETER RICE

3rd & 4th YEAR ARCHITECTURAL TECHNOLOGY 2013

Students: Milo Bashford, Gerard Bennett, Ross Boyce, Patrick Brady, Robert A Burns, Robert G Burns, Sean Casey, Andrew Cleary, Carl Corcoran, Anna Cullen, Chris Daly, Adam Darby, Bernard Deay, Mark Denneny, Vincent Doherty, Mark Doyle, Dean Farrell, Ciaran Ford, Shane Hall, Ross Harrell, Ben Harrison, Colin Hemon, Adam Henderson, Fatma Hinawy, Darren Hoey, David Holland, Brian Kennedy, Akvile Klapatauskaite, Davitt Lamon, Brian Lee, Peter Lemasney, Ciaran Lennon, Brendan Linnane, Sarah MacLoughlin, James Maguire, Peter Mahon, Brian Malone, Michael Malone, Jason McElroy, Kevin McFeely, Karl McGarry, Pauric McGill, Marcus McGuire, Joe McNally, Kevin McNulty, Bryan Menton, Darragh Moore, Stephen Morris, Niall Murphy, Owen O'Flaherty, Ruairi O'Neill, John O'Sullivan, Daryl Phelan, Martin Philip, Ian Plunkett, Robert Quinn, Stephen Ralph, David Reilly, Jonathan Rogers, Anita Salako, Andrei Triffo, Aiga Veltensone, David Veltom, John Wolfe-Flanagan, Dominika Zubiak. **Staff:** Cormac Allen, Eric Bates, Noel Brady, Máirtín D'Alton, Pierce Fahy, Rory Greenan, Orna Hanly, John Lauder, Tim O'Leary, Jim Roche, Sima Rouholamin, David Wright. **Collaborators:** Gerard Crowley, Peter Flynn, Declan McGonagle, Sean Ó Laoire.

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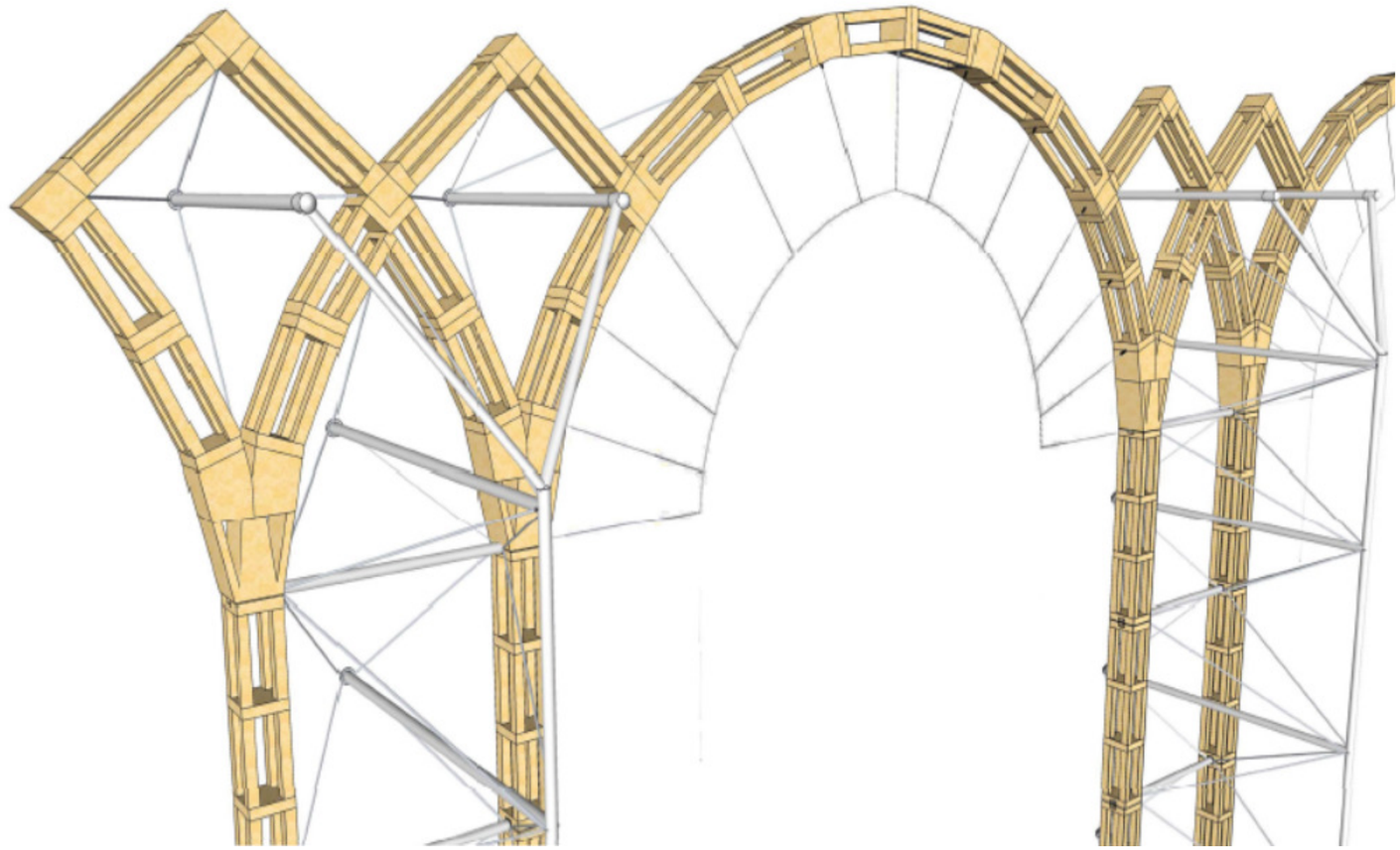
1-http://www.mbmarquitectes.cat/
2-http://cidadanialx.blogspot.ie/2011/06/palacio-nacional-da-ajuda-xix-governo.html

PABELLÓ DEL FUTURO

MBM **1988-1992**



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DIT

DS Dublin School of Architecture

Table of Content

"Rice was, perhaps, the James Joyce *of structural engineering. His poetic invention, his ability to turn accepted ideas on their head and his rigorous mathematical and philosophical logic made him one of the most sought-after engineers of our times." Quote by* Jonathan Glancey

History of Peter Rice

Irelands most prestigious structural engineer Peter Rice (1935–1992) was born in number 52 Castle road, Dundalk, County Louth. He studied in Queen's University in Belfast where he originally studied Aeronautical Engineering but switched to Civil Engineering in which he received his degree. He then spent a further year in The Imperial College. When finishing his studies he was taken on by Ove Arup & Partners where he was appointed to work on his first project which was the roof of the Sydney Opera House in Sydney Australia.

52 Castle road, Dundalk

Queen's University in Belfast

Project History

- Sydney Opera House, Sydney, Australia; 1957
- Crucible Theatre, Sheffield; 1967
- Amberly Road Children's Home, London; 1969
- National Sports Centre, Crystal Palace, London; 1970
- Arts Centre, University of Warwick, Coventry; 1970
- Perspex spiral staircase, jeweller's shop, Jermyn Street, London; 1970
- London Stansted Airport
- Super Grimentz Ski Village, Valais, Switzerland; 1970
- Conference Centre, Mecca, Saudi Arabia; 1971
- Special structures advice to Frei Otto and others on pneumatic and cable structures including "The City in the Arctic"; 1971
- Centre Pompidou (Beaubourg), Paris, France; 1971
- Jumbo jet hangar, Johannesburg, South Africa; 1976
- TGV Station Lille; 1994
- Mobiles Zelt in London London; 1992
- TGV Station Roissy; 1991–94
- Elektronikfabrik Thomson Saint-Quentin-en-Yvelines; 1990
- Umbau des Louvre Paris-1er; 1988–93
- Cité des Sciences et de l'Industrie Paris-19e; 1986
- De Menil Collection Houston; 1981–86
- IBM Pavillon 1980–84
- Quartierslaboratorium' für Stadterneuerung Otranto; 1979
- Residential Complex Corciano*; 1978–82*
- '*Pabellón del Futuro; Seville, Spain; 1992*

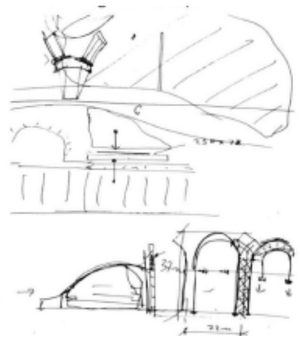
[1]https://maps.google.ie/maps?um=1&hl=en&q=castle%20road%20dundalk&bav=on.2,or.r_qf.&bvm=bv.52434380,d.ZGU,pv.xjs.s.en_US.RJfod4swqLE.O&biw=1440&bih=717&dpr=1&wrapid=tlif138001277859011&ie=UTF-8&sa=N&tab=il

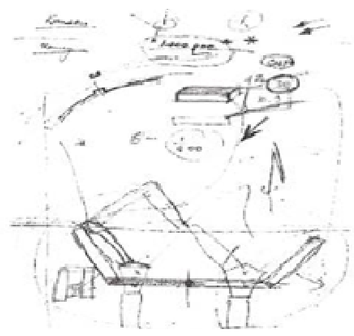
[2] http://uniadmission.com/news-events/queens-university-belfast/

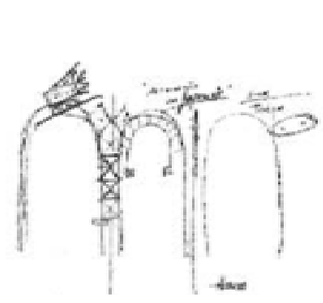
History of Pabellón del Futuro

1988, Peter Rice was invited by architect David Mackay (b.1933) of Martorell Bohigas Mackay (MBM) to join the design team for the Pabellón del Futuro (Pavilion of the Future, engineer: Ove Arup & Partners), one of six themed exhibition halls proposed for Expo '92 in Seville. The client for the Expo '92 project, Pabellón del Futuro, wanted a spectacular building. The architects decided on tall structure that would impress visitors, running along the face of the exhibition hall and supporting its waveform roof and canopy.

The Universal Exhibition was held in Seville during 1992 was claimed by its organiser Expo '92 to be the largest of its kind. The event coincided with the 500th anniversary of Christopher Columbus's discovery of America and hence Expo 92 was given the theme 'The age of discovery'. The Pavilion of the Future (in Spanish: El Pabellón del Futuro) was one of several permanent dramatic pavilions commissioned by the Expo '92 SA, which were destined to house exhibitions based on this broad theme. The pavilion held a prominent location in the Expo '92 site, and its architects, Martorell, Bohigas & Mackay (MBM), saw the eastern facade as the key component of the building's design. They wanted it to be a visually impressive structure which would support the roof over the pavilion halls and act as a decorative screen to the ornamental gardens in front of the pavilion.







'On a visit to Lisbon in 1989 I saw the unsupported wall of the Palacio do Ajuda . I thought that if that wall had stood for 200 years it should be possible to design something like it. When the architects Martorell, Bohigas Mackay required a spectacular structure and the site were linear I thought of the facade of this Palace and felt now was the time to try. In development it became the stone arches. The use of stone stemmed from realising that stone and glass have similar physical characteristics, and that the techniques developed for the glass could also be developed to enable stone to be used structurally. We were also at a point in time when computer software could enable us to examine the true behaviour of stone construction, as explained by Heymann in his book on traditional stone bridges. The development of a flip-flap system of analysis was part of this. Finally stone cutting is now very accurate, because of the demands of facade architecture, and Spain is its home. The rest was inevitable'.[3]

Site Location

ING MATERIALS The work of Peter Rice, Royal Gold Medallist 1992, Royal Institute of British
6 Portland Place London W l N 4AD,June 30th - August 25th 1992.

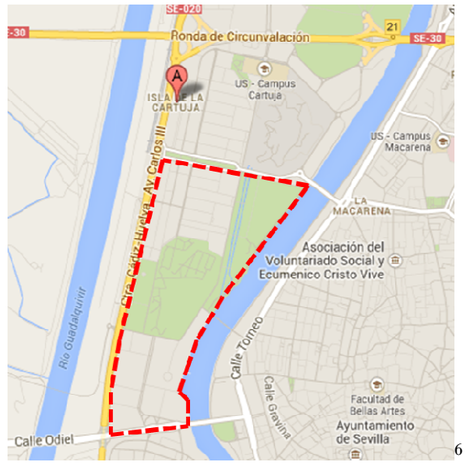
[4]

Location of Seville in Spain

[5]

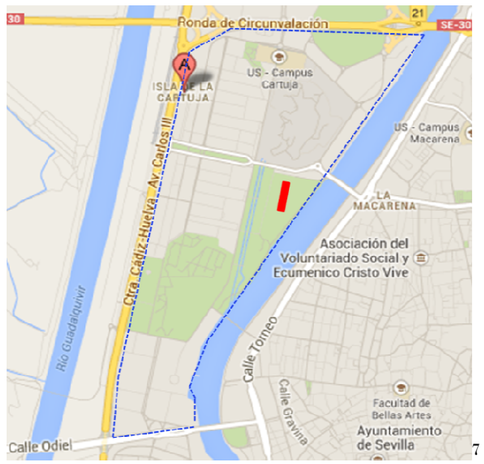
Location of the Site in the city of Seville

The Site is located in Seville which is in the southern region of Spain. On the outskirts of the main city the site is located in the North West area of the city.



[6]

Site Boundary

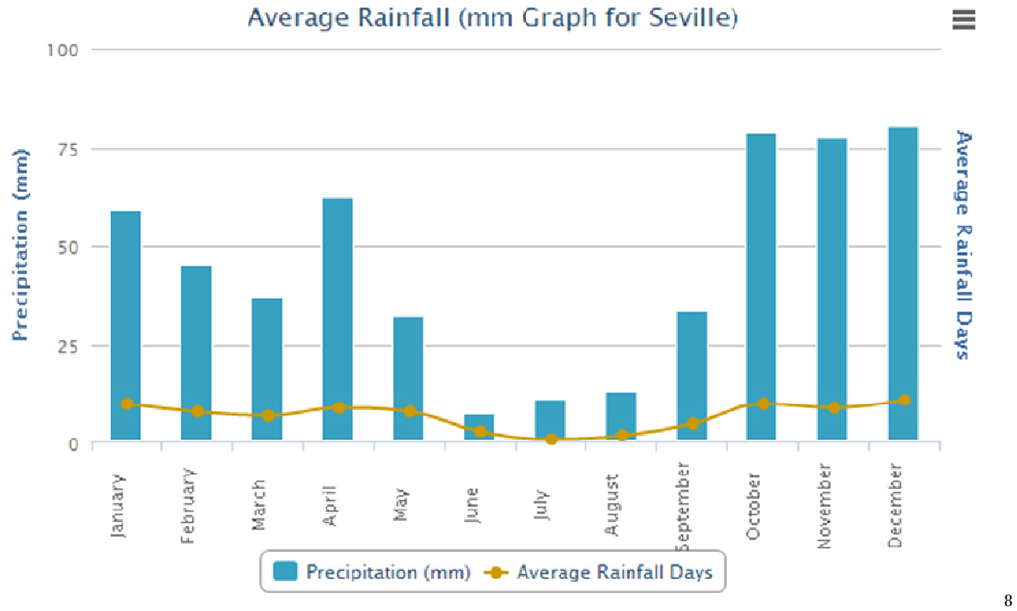


[7]

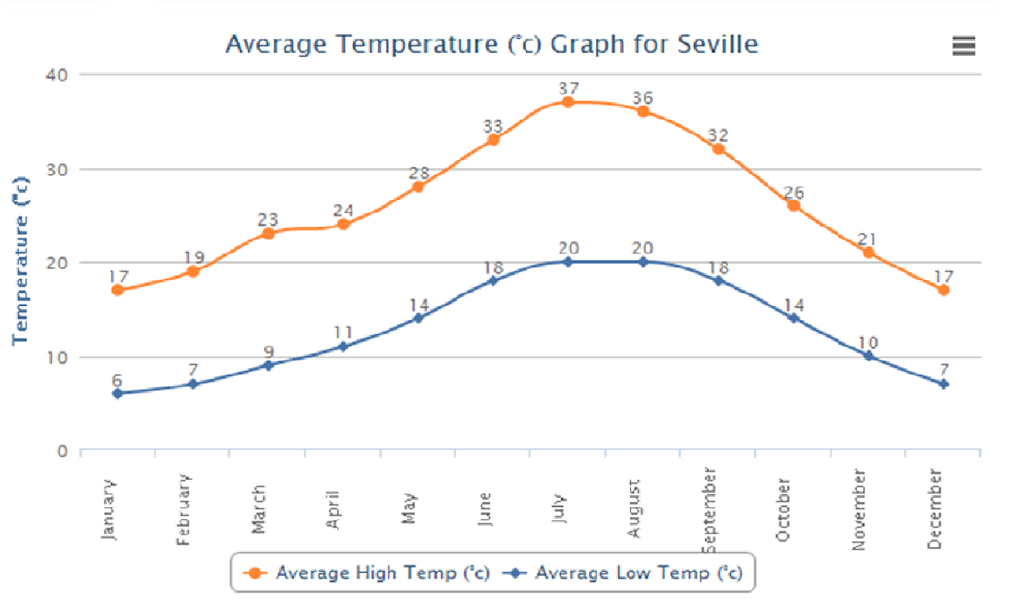
Building Location on Within Site Boundary

The site on the map is in the region of 215 hectares and is sandwiched between the Rio Guadalquivir and the Canal de Alfonso XIII. The building is directly orientated north south which overlooks the formal gardens and the Canal de Alfonso XIII. The Pabellón Del Futuro is acceded by the Camino de lo Descubrimientos.

Site Enviroment



[8]



[9]

[4] http://www.europe-internship.com/tag/practical-training/
[5] https://maps.google.ie/maps?hl=en&tab=wl&authuser=0
[6] https://maps.google.ie/maps?hl=en&tab=wl&authuser=0
[7] https://maps.google.ie/maps?hl=en&tab=wl&authuser=0
[8] http://www.worldweatheronline.com/Seville-weather-averages/Andalucia/ES.aspx
[9] http://www.worldweatheronline.com/Seville-weather-averages/Andalucia/ES.aspx

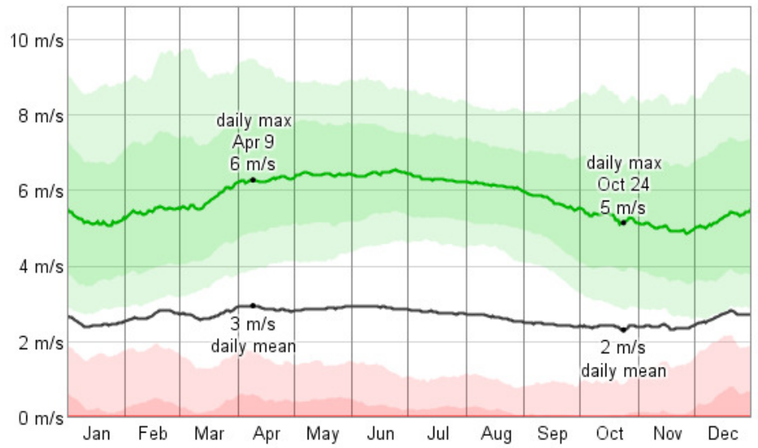
Wind

Over the course of the year typical wind speeds vary from 0 m/s to 7 m/s (calm to moderate breeze), rarely exceeding 10 m/s (fresh breeze).

The *highest* average wind speed of 3 m/s (light breeze) occurs around April 9, at which time the average daily maximum wind speed is 6 m/s (moderate breeze).

The *lowest* average wind speed of 2 m/s (light breeze) occurs around October 24, at which time the average daily maximum wind speed is 5 m/s (gentle breeze).

Wind Speed

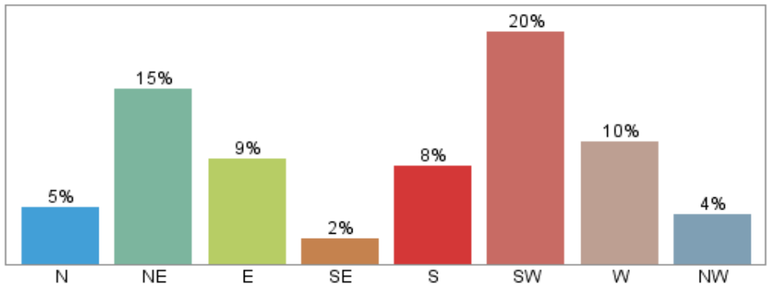


The average daily minimum (red), maximum (green), and average (black) wind speed with percentile bands (inner band from 25th to 75th percentile, outer band from 10th to 90th percentile).

The wind is most often out of the *south west* (20% of the time), *north east* (15% of the time), and *west* (10% of the time). The wind is least often out of the south east (2% of the time), north west (4% of the time), and north (5% of the time).

[10]

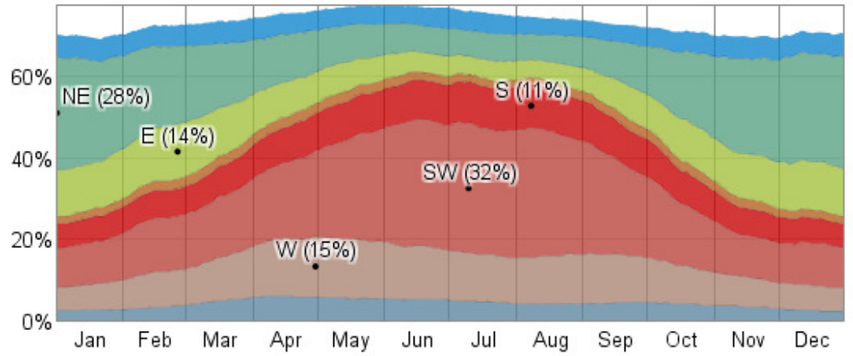
Wind Directions Over the Entire Year



The fraction of time spent with the wind blowing from the various directions over the entire year. Values do not sum to 100% because the wind direction is undefined when the wind speed is zero.

[11]

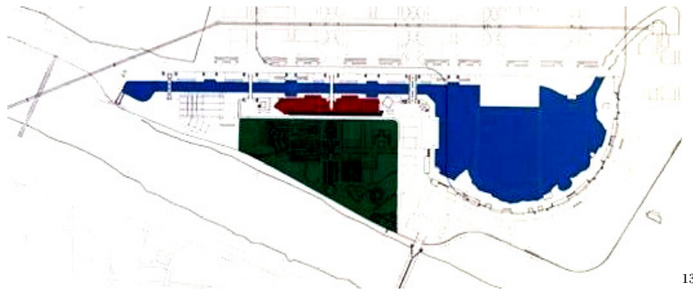
Fraction of Time Spent with Various Wind Directions



The fraction of time spent with the wind blowing from the various directions on a daily basis. Stacked values do not always sum to 100% because the wind direction is undefined when the wind speed is zero.

[12]

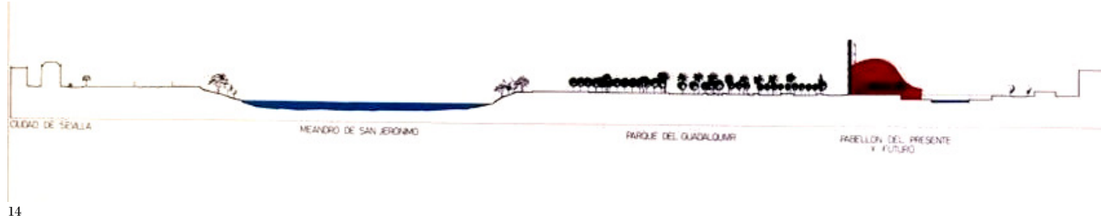
Site Topography



[13]

Site Plan

To the east side of the pavilion is a formal garden which is planted with trees and foliage. On the boundary of the gardens is the Canal de Alfonso XIII. On the west elevation a storm drain runs parallel to the building which is connect to the Rio Guadalquivir.



[14]

Site Section

[10] http://weatherspark.com/averages/32062/Sevilla-Andalucia-Spain
[11] http://weatherspark.com/averages/32062/Sevilla-Andalucia-Spain
[12] http://weatherspark.com/averages/32062/Sevilla-Andalucia-Spain
[13] http://www.mbmarquitectes.cat/proyectos_detalle.php?id_proyecto=28&id_sub_categoria=5
[14] http://www.mbmarquitectes.cat/proyectos_detalle.php?id_proyecto=28&id_sub_categoria=5

Design Intent

The main focal point for the design of the Pabellón del Futuro was the stone facade on the east elevation of the pavilion. This was the main influences of Peter Rice's design on the building. He was inspired by a business trip he took to Lisbon where he saw the Palácio Nacional da Ajuda.

The Ajuda National Palace was built on the site of a temporary wooden building in 1755 to house the royal family at the time as the provisions building had been damaged after a earthquake and tsunami. The Building was begun by architect Manuel Caetano de Sousa, who intended a late Baroque-Rococo building. Later, it was entrusted to José da Costa e Silva and Francisco Xavier Fabri, who planned a magnificent building in the modern neoclassical style. Over time the project has undergone several periods when the construction was stopped or slowed due to financial constraints or political conflicts. When the Royal Family had to flee to Brazil (in 1807), following the invasion of Portugal by French troops, and the work proceeded very slowly with Fabri taking charge of the project, later followed by António Francisco Rosa. Lack of financial resources would also a result in the reduction of the projects scale. The construction of the Ajuda Palace, which began in 1796 and lasted until the 19th century, was a project plagued by various/diverse political, economic and artistic/architectonic problems.[1] It was invaded by Napoleon's troops in 1807, and discontinued by Liberal forces who imposed a constitutional monarchy that reduced the power of the monarchy.[1] Artistically, it was a convergence of the Baroque styles from Mafra, very connected to regal authority, with the birth of the Neoclassic style from Italy.[15]

16

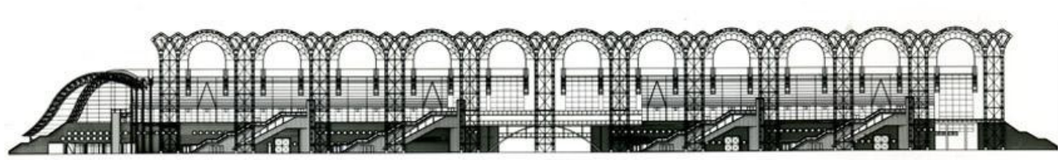
Peter Rice *'I mused at the time that it was surprising that it stood up, but it was there, proof positive that it worked. It was not unlike the medieval ruins of churches, visible through Europe. Obviously such structures must be stable. I was very interested and thought one day I would build a structure like that'.*[17]

[15] http://en.wikipedia.org/wiki/Ajuda_National_Palace
[16] http://commons.wikimedia.org/wiki/File:Pal%C3%A1cio_Nacional_da_Ajuda_-_P%C3%A1tio.jpg
[17] Kevin Barry, Traces of Peter Rice: The Lilliput Press Ltd, 2012

18

Aqueduct of Segovia

Peter Rice *'the search was then on for a form for the facade. From the beginning we had postulated that to justify the facade it should be used to support the roof of the pavilion behind. At a philosophical level we theorized that the facade or screen should be like a modern ruin, like a fragment of a viaduct or the aqueduct that we had found in Southern Spain and it was this notion that gave us the idea for the form. A series of arches seemed a reasonable and logical form for the screen to take'.* [19]



20

Elevation of Stone Facade

In this picture we can see the design intent from Peter Rice as he described in the extract above. Their is eleven roman style arches which are connect by intermittent gothic style arches to form the stone facade. The steel tension cables weave its way between the stone and the roof emphasizes the form of the facade.

[18] http://tripplan.com/aqueduct-of-segovia
[19] Kevin Barry, Traces of Peter Rice: The Lilliput Press Ltd, 2012
[20] http://www.mbmarquitectes.cat/proyectos_detalle.php?id_proyecto=28&id_sub_categoria=5

Design Approach

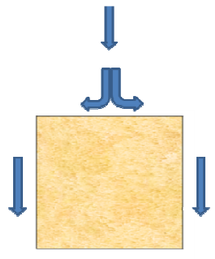
The design approach from the start was the facade to be constructed with stone. Granite is a light-coloured igneous rock with grains large enough to be visible with the unaided eye. It forms from the slow crystallization of magma below Earth's surface. Granite is composed mainly of quartz and feldspar with minor amounts of mica, amphiboles and other minerals. This mineral composition usually gives granite a red, pink, gray or white colour with dark mineral grains visible throughout the rock.[21] Granite is a structural and ornamental stone, and due to its high strength and durability, it is used for massive structural work. Fine-grained granite is used for ornamental, monumental and inscription purposes. It is the hardest of structural stones and that is why it is an ideal choice for flooring, counter tops, vanities and exterior applications.[22] These were the main reasons why the design team decided on granite as the core material to construct the facade.

[23]

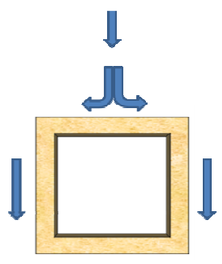
[24]

North-western Spanish Granite

The next decision Peter Rice was the profile of the columns themselves was going to take shape. Normally a stone column would be square, but in a tall facade this has its downfalls. Firstly the extra weight that has to be supported and secondly additional bracing would have to be incorporated into the structural design to deal with the wind loads on the facade. The hollow core does reduce the overall weight of the column but it still has the problem with wind loads on the surface and manufacturing methods would be timely and costly.

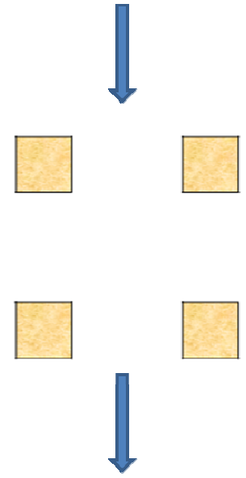


Window load on solid column

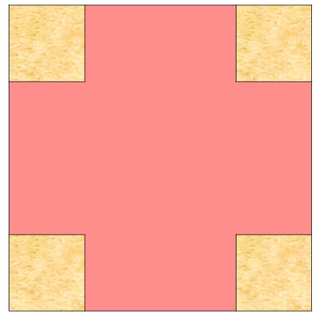


Hollow column

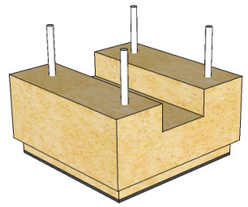
The third option was to maintain the structural strength of the column but reduce the surface area which will reduce the amount of wind pressure on the face of the column, by cutting down on the material used there was a reduction in the cost the manufacturing the stone column. The column's overall dimension is 800X800mm in width and depth which is 0.64M2. Each column is 200x200mm in width and dept(0.04M2) which adds up to 0.16M2 as there are four columns. This reduced the over material of 0.48M2, which is a 31% reduction in granite used.



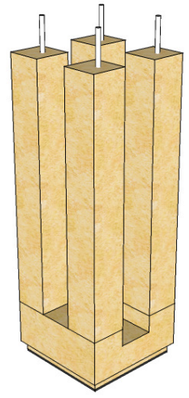
Wind pressure on column



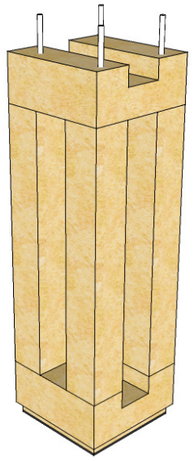
Red area indicated materials reduced.



Step one in the column process is the base stone which has steel pins connected

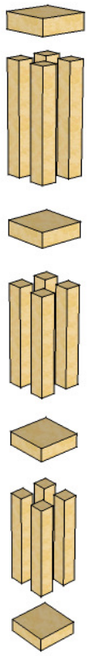


Step two is when the four supports are connecting to the base stone by the steel pins and epoxy resin.

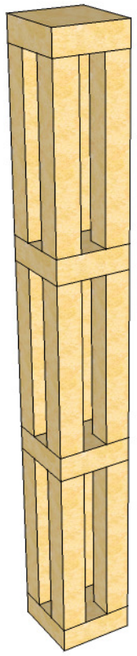


Step three the four granite supports are cap and the process is repeated twice more to complete a full column.

[21] http://geology.com/rocks/granite.shtml
[22] http://www.fgco.biz/granite_stone_information.aspx
[23] The granite was quarried in blocks of 200X200X1400mm and transported for assembly.
24 http://www.bfrandassociates.com/naturalstone101.html

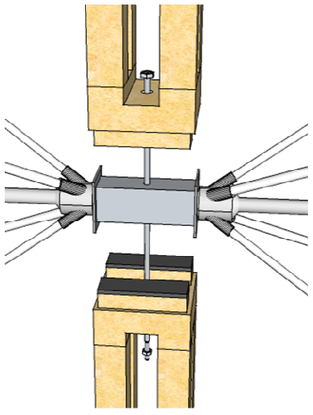


Exploded view of one granite column

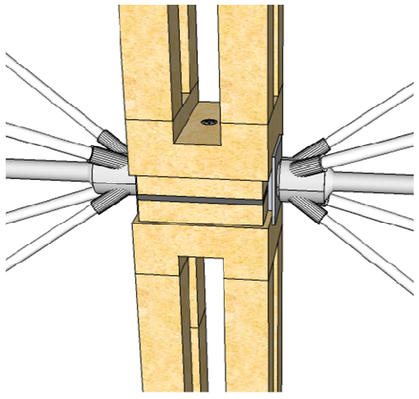


A fully complete column

The fully assembled section of the granite column stands at five meters in height. Each column is then fixed together with a steel box section that is sandwished between the two columns. There is a predrilled hole in the center on both columns and the steel box section, a steel bolt is then sloted in and tighted to specification. There is also an epoxy layer as well which gives the connection added strenght. On either side of the plate is a connection from the steel tension cable. These are need to transfer the structural loads down to ground level.

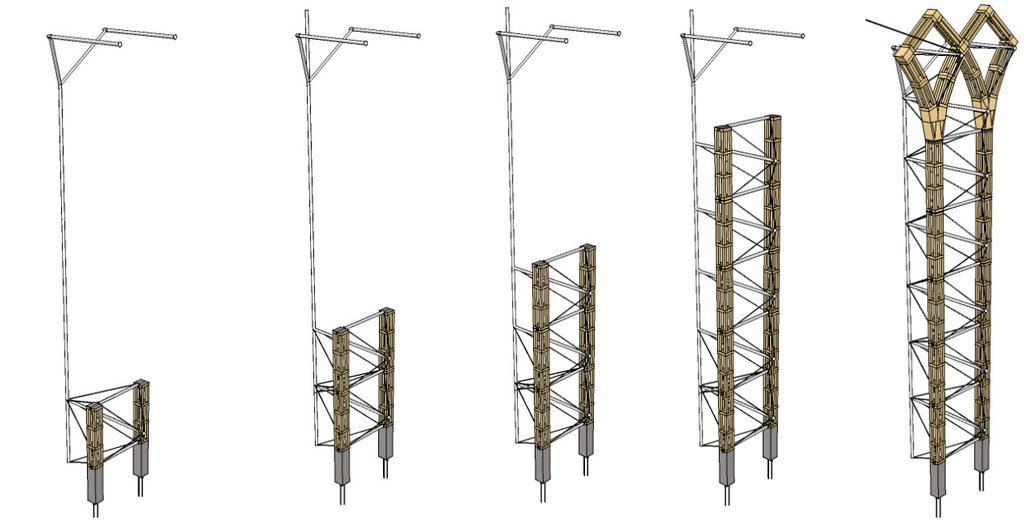


Explodded view of connection between columns



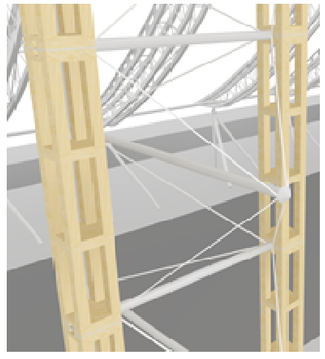
View of connection assembled.

Construction process of the Stone Columns



Stage 1 Stage 2 Stage 3 Stage 4 Stage 5

The precast stone columns were constructed off site including the steel braceing. When the system arrived on site the first unit was cranned onto concrete columns and the fixed into place. The sequence continued up five levels. The top gothic archs were asseble off site also so when it came to instalation on site it was relativley straight forward.



View of one section of stone column

Peter Rice inspecting the stone [25]

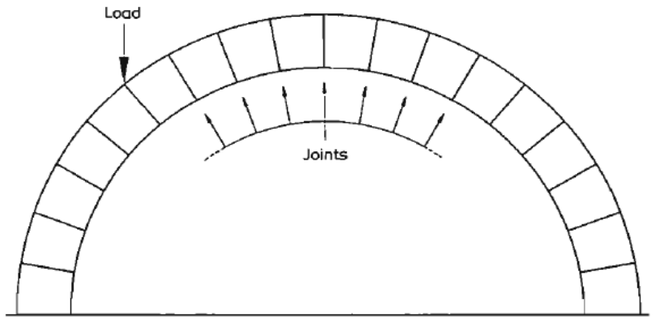
Granite being parpered to hoist [26]

[25] http://www.engineering-timelines.com/who/Rice_P/ricePeter9.asp
[26] http://www.engineering-timelines.com/who/Rice_P/ricePeter9.asp

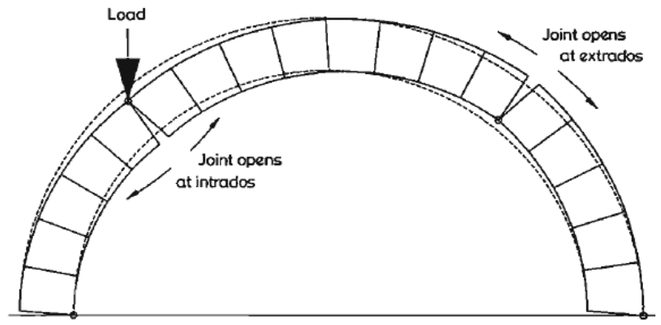
Construction process of the Stone Arch

For the arches, advantage was taken off that the load capacity of a stone arch is primarily dependent on its geometric proportions. Compressive stresses within stone arches are normally well below the crushing strength of the stone, it is possible to reduce the cross-sectional area of an arch without significantly reducing its strength, so long as the overall geometric depth of the arch profiles maintained. By hollowing out the stone units from which the arch is compromised, it was possible to reduce the amount of stone used, while maintaining its overall geometric stability. The same opening-out principle was applied to the stone column elements of the facade. Here again, while removing most of the overall column section, compressive stresses in the stone could be maintained well below its crushing strength. By maintaining stone in the outside corners of the section, the column retained adequate stability under axial load. Significant shear loads in the columns were avoided by ensuring that all horizontal (wind) loads on the facade were transmitted to ground by a complementary steel bracing system within the towers.[27]

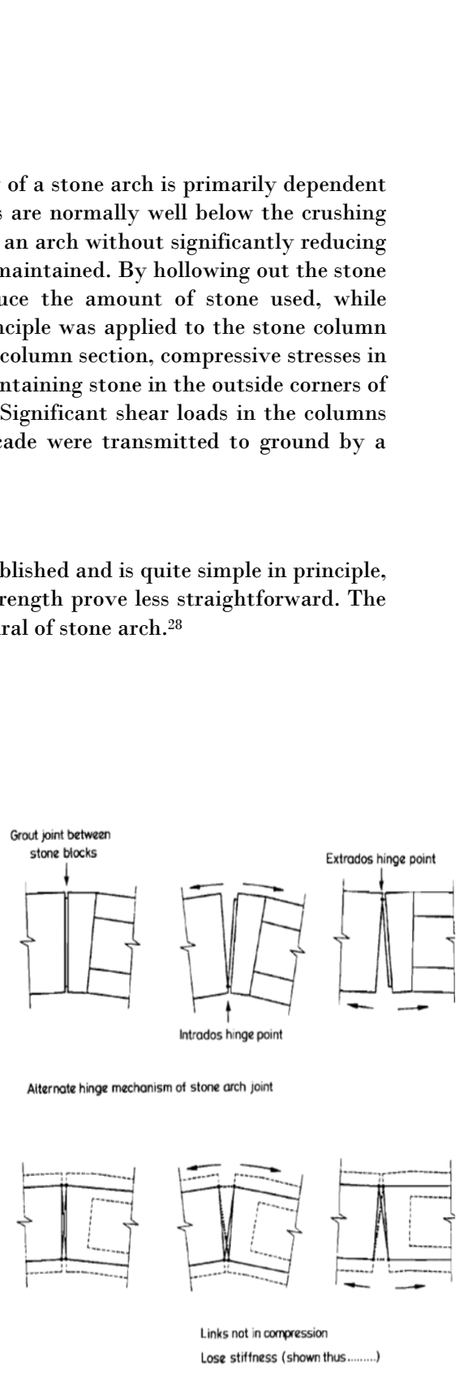
Although the basic theory of a stone arch's stability is well established and is quite simple in principle, the practical methods of analysis required to demonstrate an arch's strength prove less straightforward. The difficulty arises primarily because of the non-linear structural behavioural of stone arch.[28]



Arch before onset of mechanism



Onset of collapse

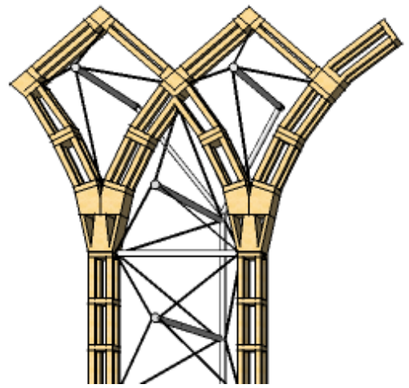


Alternate hinge mechanism of stone arch joint

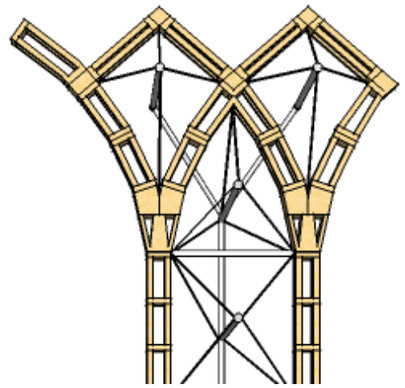
Links not in compression
Lose stiffness (shown thus.....)

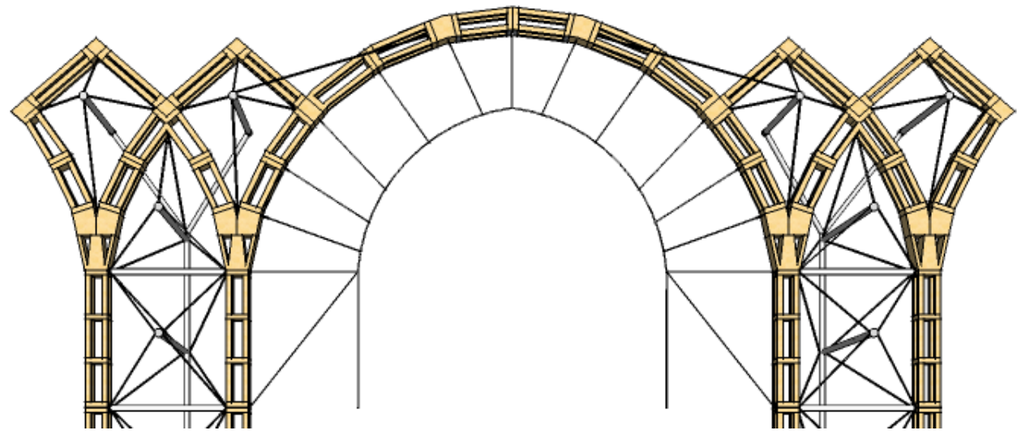
29

The construction method of the arch is the same method as the Romans used while construction the aqueducts across Europe and Southern Spain. The Romans gained much of their engineering skill from the Etruscans. From them, the Romans learned the use of the keystone arch, which enabled them to build extremely strong and durable bridges. The Romans solved this problem by using a type of construction called voussoir arch with keystone. [30] Voussoir means a wedge-shaped brick used in the building of an arch.



Construction stage 1



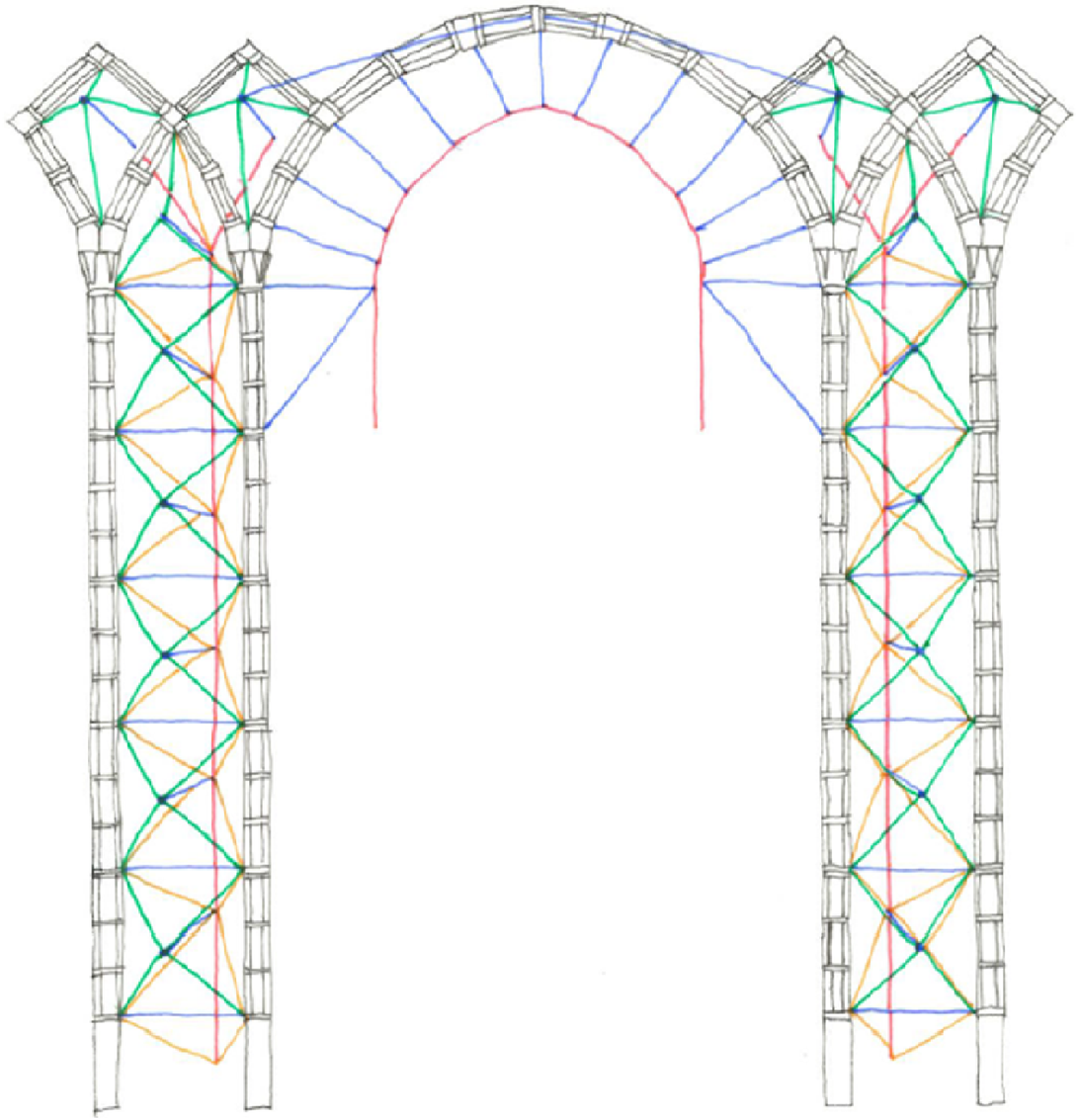


Construction stage 2

[27] The Structural EngineedVolume 72/No 11/7 June 1994
[28] The Structural EngineedVolume 72/No 11/7 June 1994

[29] The Structural EngineedVolume 72/No 11/7 June 1994
[30] http://jaysromanhistory.com/romeweb/engineer/art2.htm

Structural investigation into stone arch



The diagram above describes how the structural forces are transferred throughout the structure from the top of the thirty seven meter stone arch all the way to the foundations. This stone facade plays tricks with your natural senses as most people wonder how this stone façade is standing up. It does and it has stood for over twenty years. Not alone did Peter Rice design a two hundred and fifty meter long facade at thirty seven meters in height up by itself but he then decides that he wants the stone facade to structural support the roof of the main pavilion. Instead of fixing the tension cables to the ground to transfer the forces to the foundation, Peter Rice cunningly uses the self weight of the roof structure to keep the arch itself in compression. This gives the structure a very elegant and a delicate look.

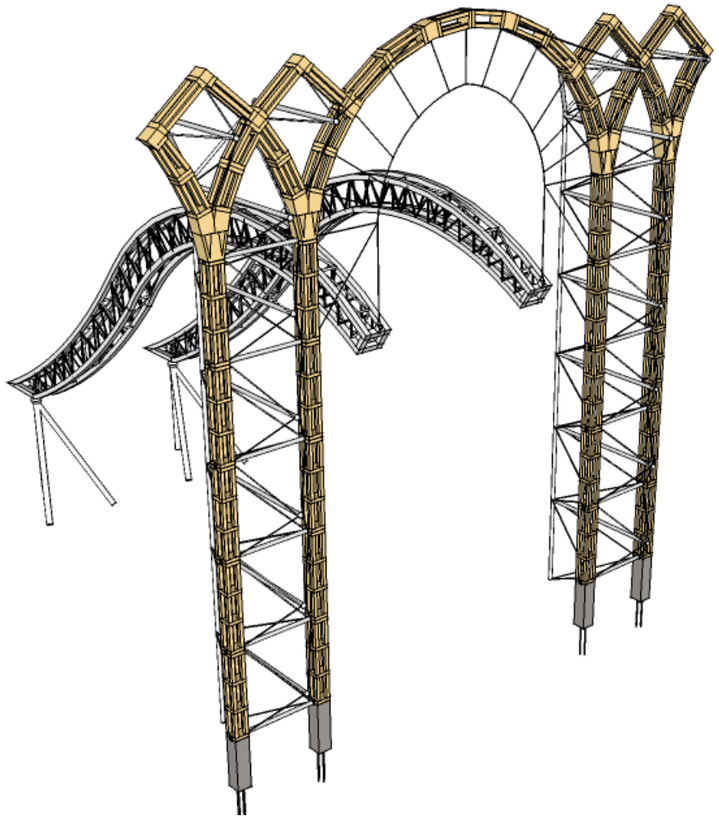
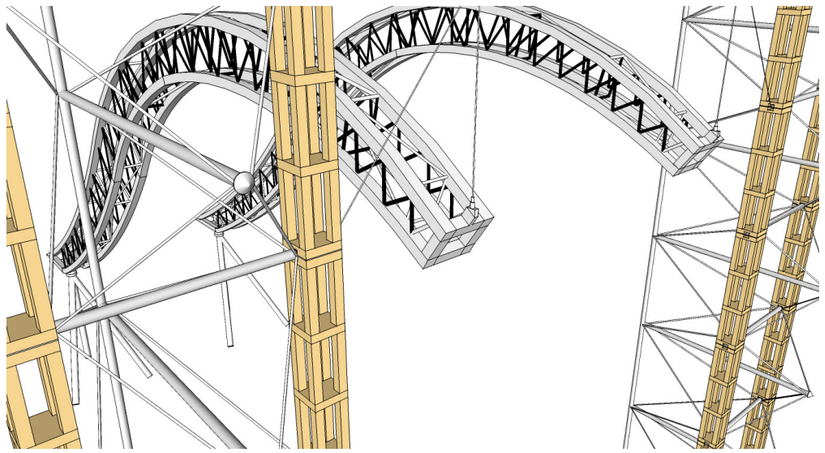
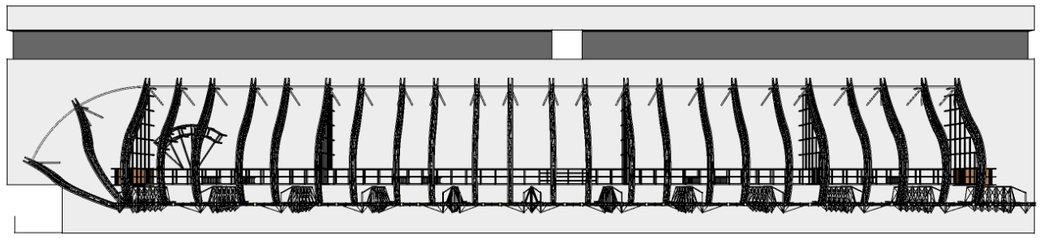


Diagram showing how the steel trusses are being supported from the steel tension cables that are fixed to the stone arch.

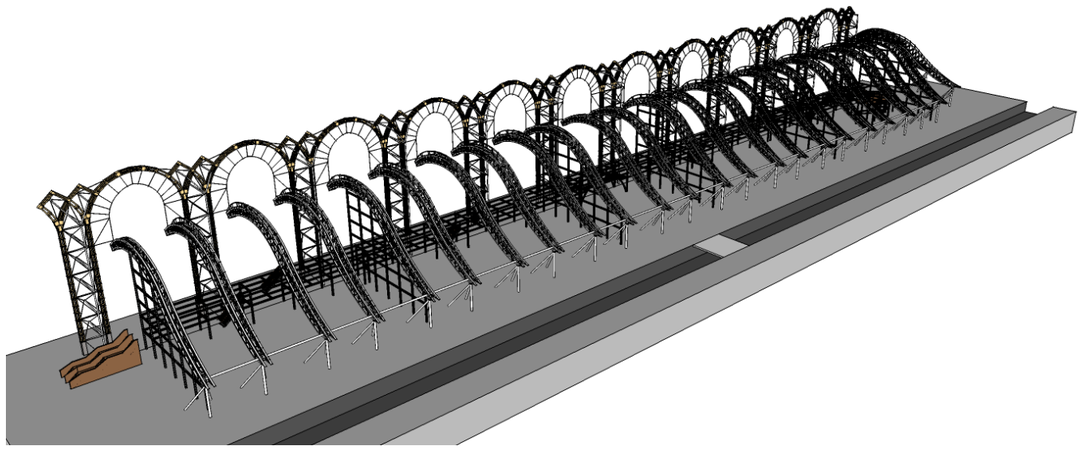


Close up view of the fixings of the tension cables to steel beams.

Overview of Steel Structure



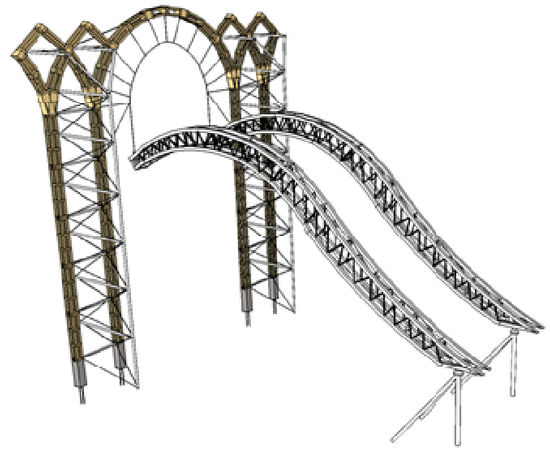
Plan the Pabellón del Futuro showing the structural grid



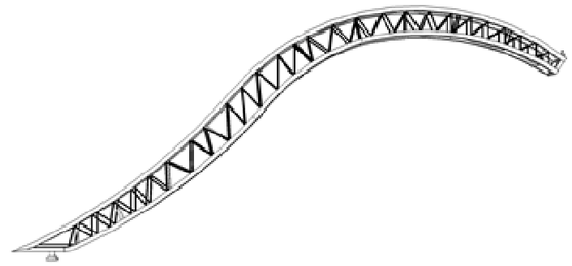
Three dimensional model showing the structural profile of the Pabellón del Futuro

[31]

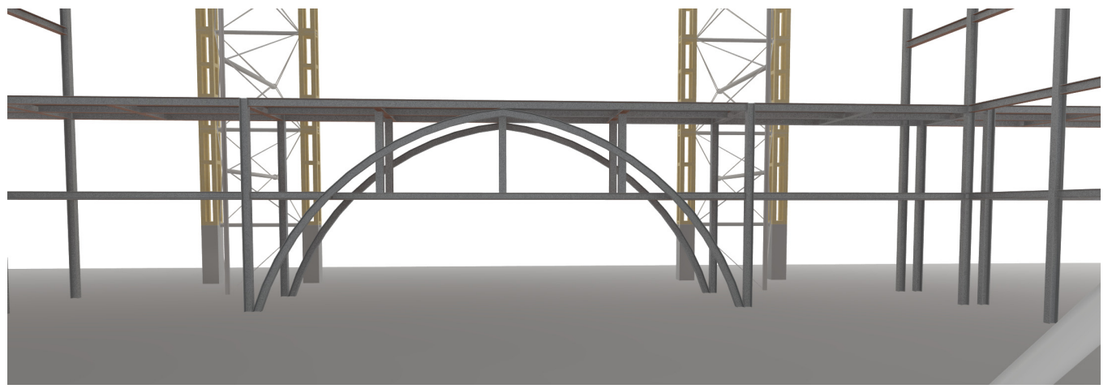
[32]



The steel beam is supported at two points. As indicated on the pervious page one end of the steel beam is hung from the tension cables which are fixed from the granite stone arch. The other side of the steel beam is fixed to a steel post which splays into three legs which disperses the loads to the foundation.



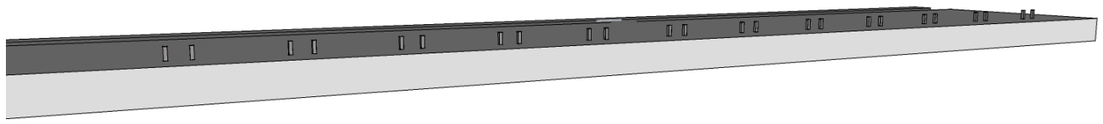
The main structural beam system for the roof is steel curved castellated beam. The beam is constructed from steel box section with internal struts that transfers the load very delicately to the two main supports.



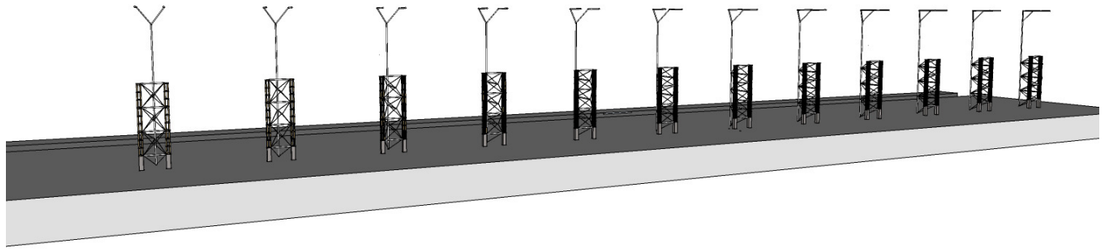
The Steel frame at main entrance is a focal point for the grand entrance. This supports two walk ways above and has the mark of Peter Rice as it has style and function rolls all into one.

[31] http://www.engineering-timelines.com/scripts/engineeringItem.asp?id=1294
[32] http://juliperezcatala.com/proyectos/equipamientos-ocio-cultura-pabellon-expo-92.php

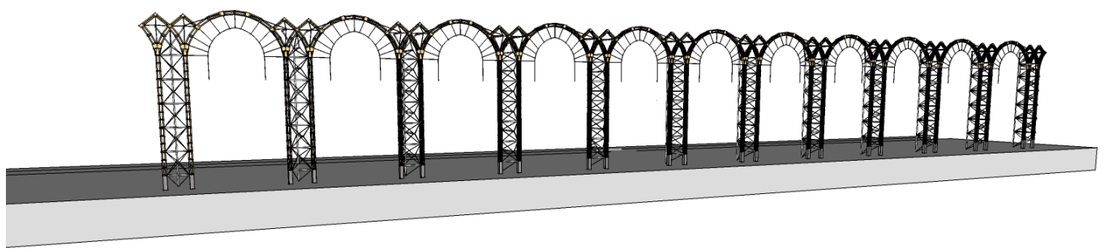
Sequence of Construction



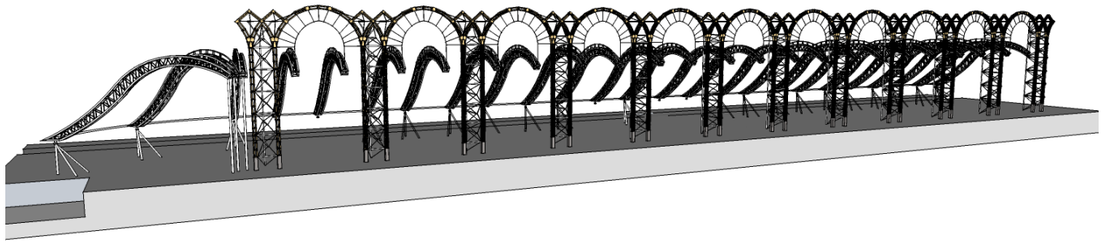
Stage 1; Foundations and concrete up-stands poured into place.



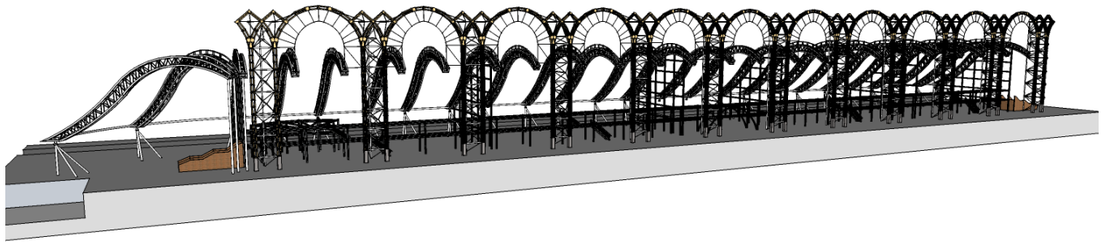
Stage 2: Preassembled stone and steel cross bracing craned and bolted into place.



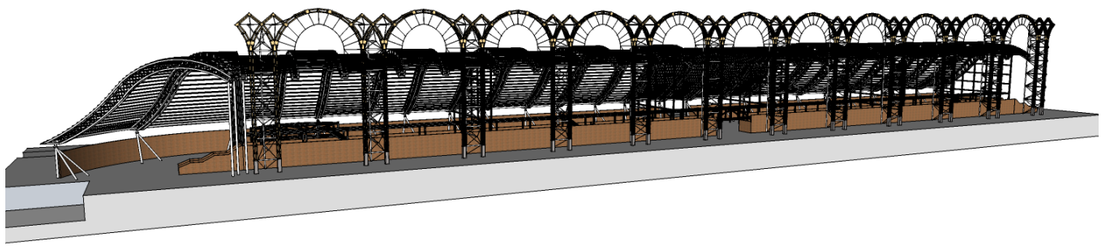
Stage 3; Stone façade completed with gothic and roman arches in place. Tension cables fixed and ready for steel roof system to be fixed.



Stage 4; Steel roof trusses are craned into place and fixed to tension cables on stone facade and steel supports.



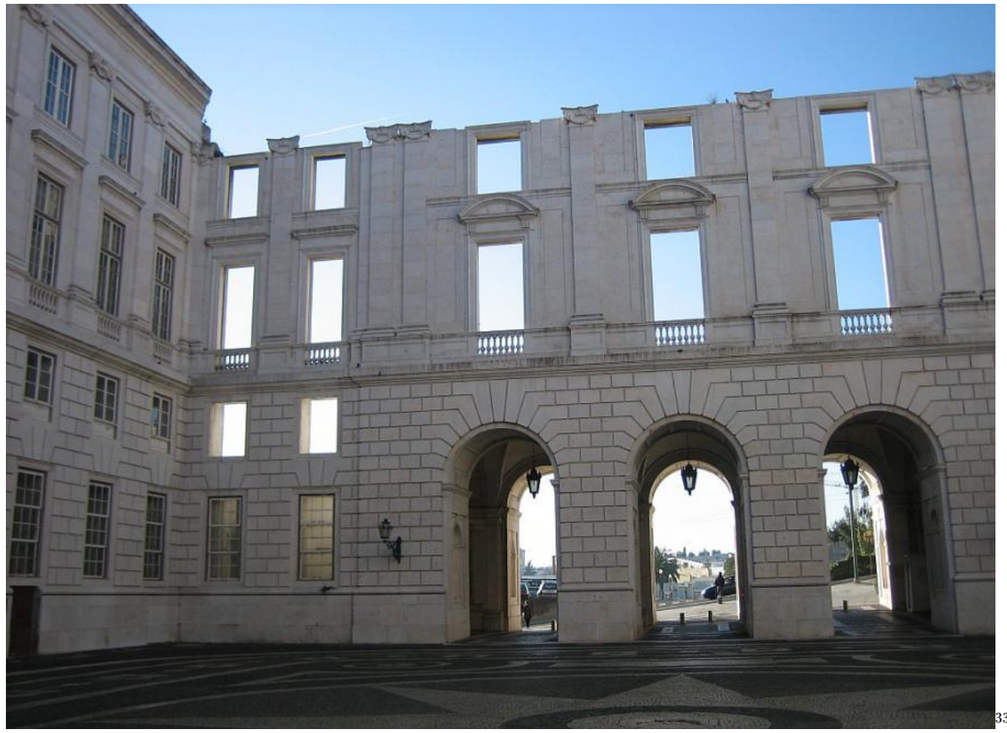
Stage 5; Secondary steel fame, stairs and end supports are fixed to the main.



Stage 6; Steel C channels are fixed to the top of the steel roof truss.

Precedents

In the project Pabellón del Futuro there were a couple of areas that influenced the design. The objective for Peter Rice and the architects was to create a modern day ruin and the building that inspired Peter Rice to this concept was The Ajuda National Palace.



33

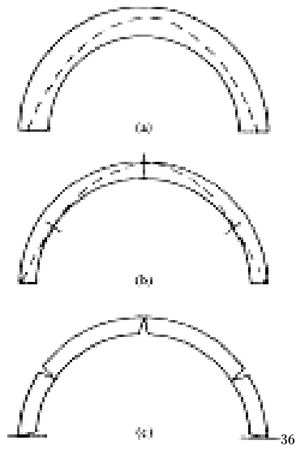
The Ajuda National Palace unfinished facade.

34

Ruins of a Church, Sicily, Italy, Europe

35

Lisbon - Ruins of the Carmo Church



36

37

Investigation into how stone arch bridges worked and notably following the methods developed by Professor Jacques Heyman in his developed model of the stone arch voussoirs.

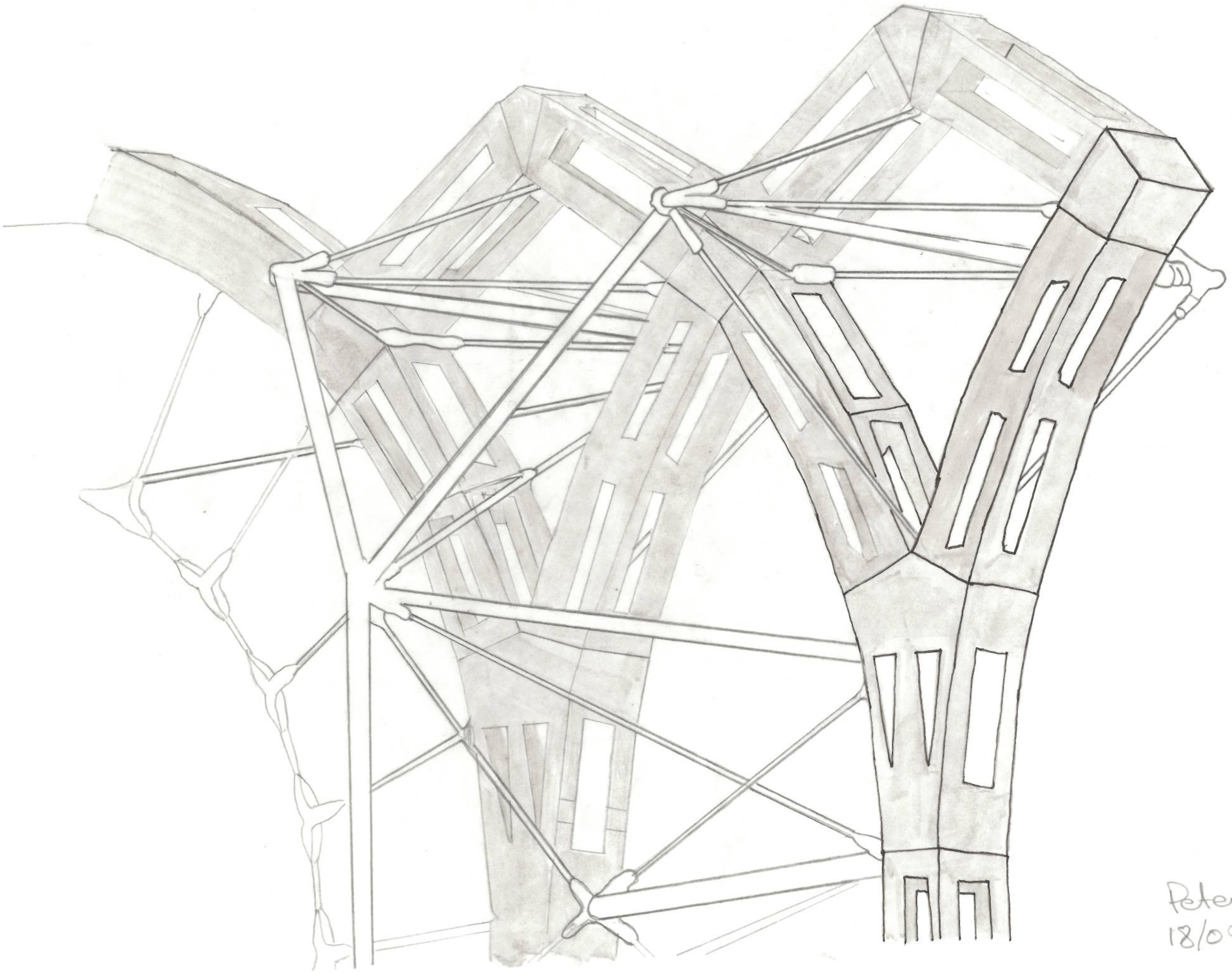
38

The aqueducts of southern Spain were also precedents for The Pabellón del Futuro. Spanish stone has been used in construction since pre roman times and Peter Rice wanted to show how far the stone technology has evolved and want could be done.

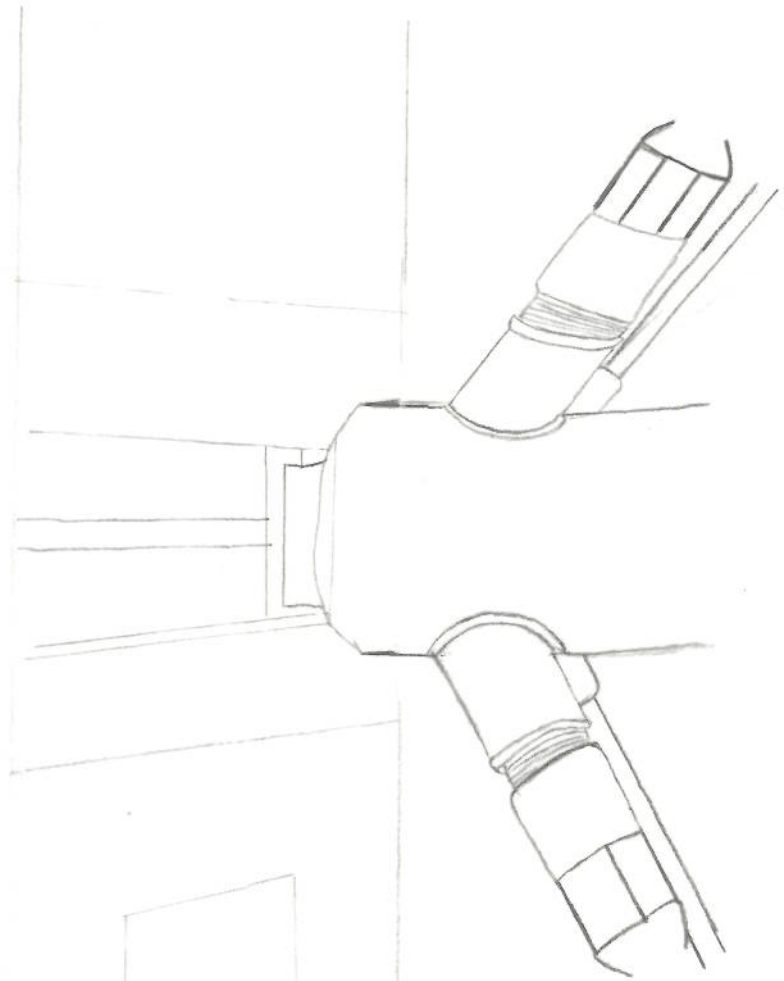
33 http://www.historvius.com/ajuda-national-palace-1238/
34 http://eu.art.com/products/p611066259-sa-i4038233/posters.htm
35 http://goeurope.about.com/library/phot/bl_lisbon_carmo_1.htm

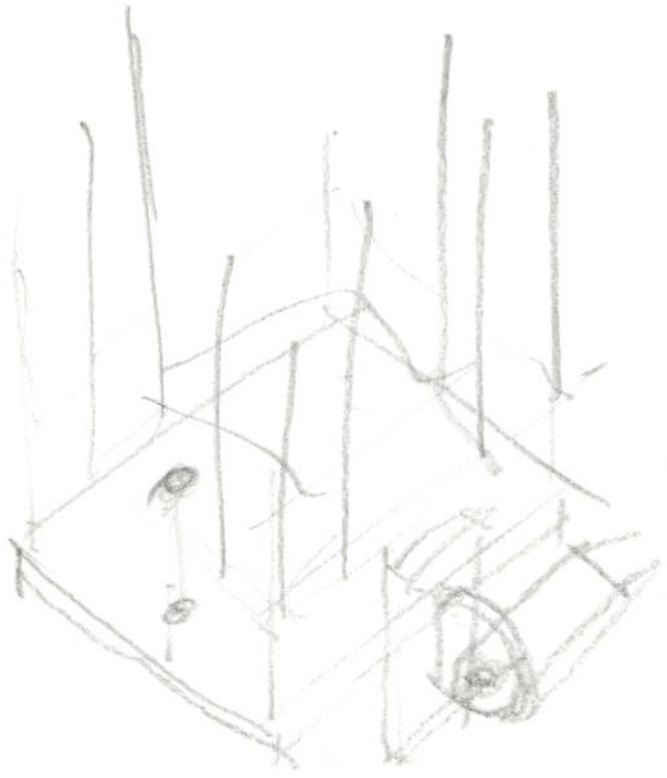
36 JACQUES HEYMAN FREng EMERITUS PROFESSOR OF ENGINEERING, UNIVERSITY OF CAMBRIDGE, Why ancient cathedrals stand up, The structural design of masonry
37 http://commons.wikimedia.org/wiki/File:Ancient_Roman_triumphal_arch_of_Medinaceli-Spain.jpg
38 http://www.theworldisabook.com/2906/segovia-day-trip-with-kids/

Rough Work

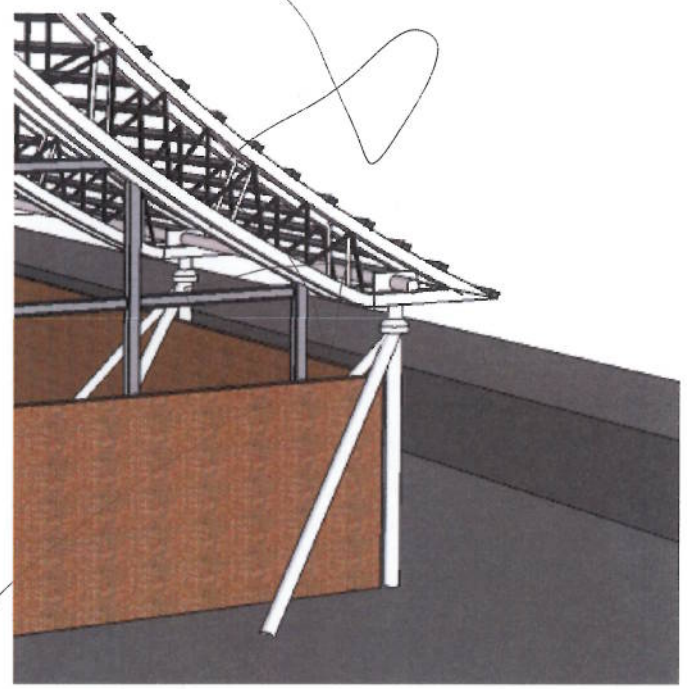


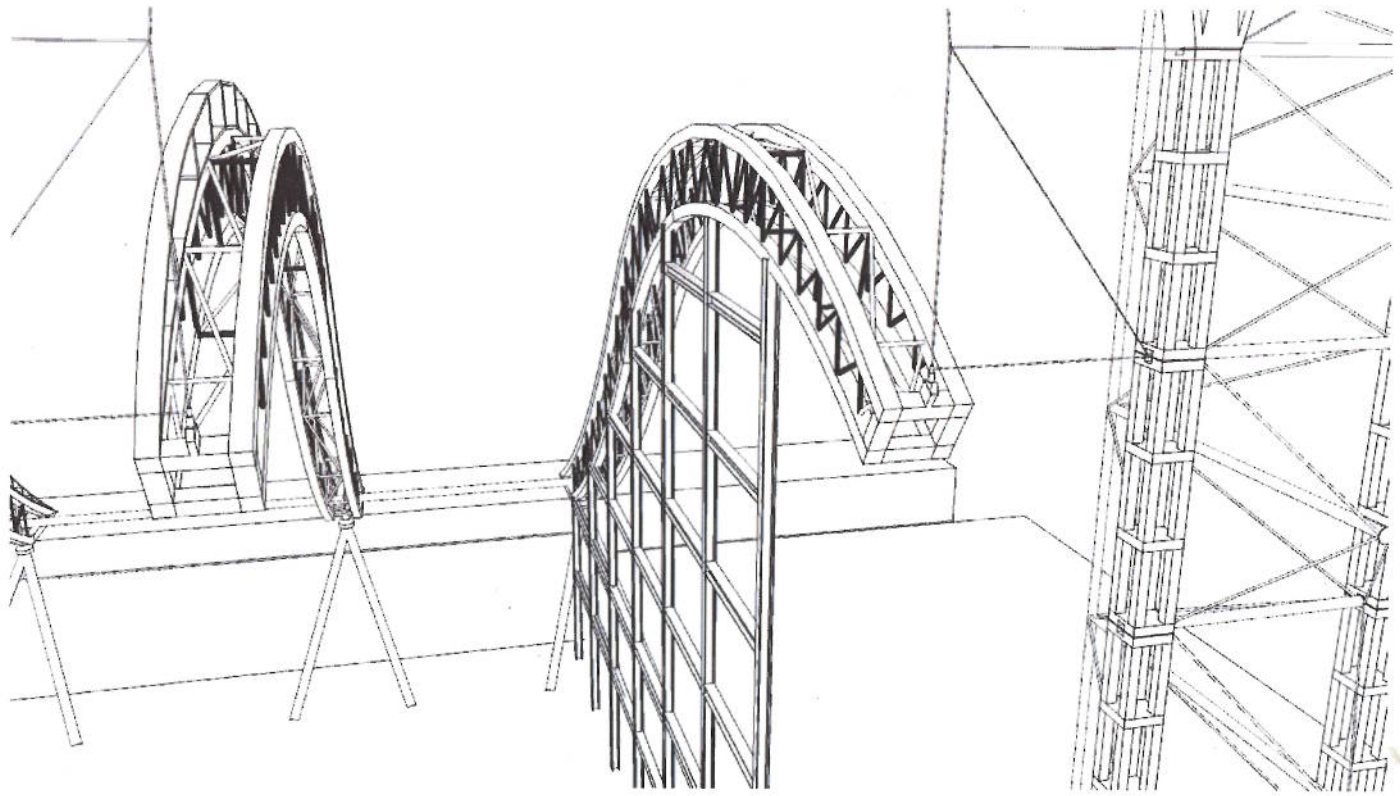
Peter leMasney
18/09/2013

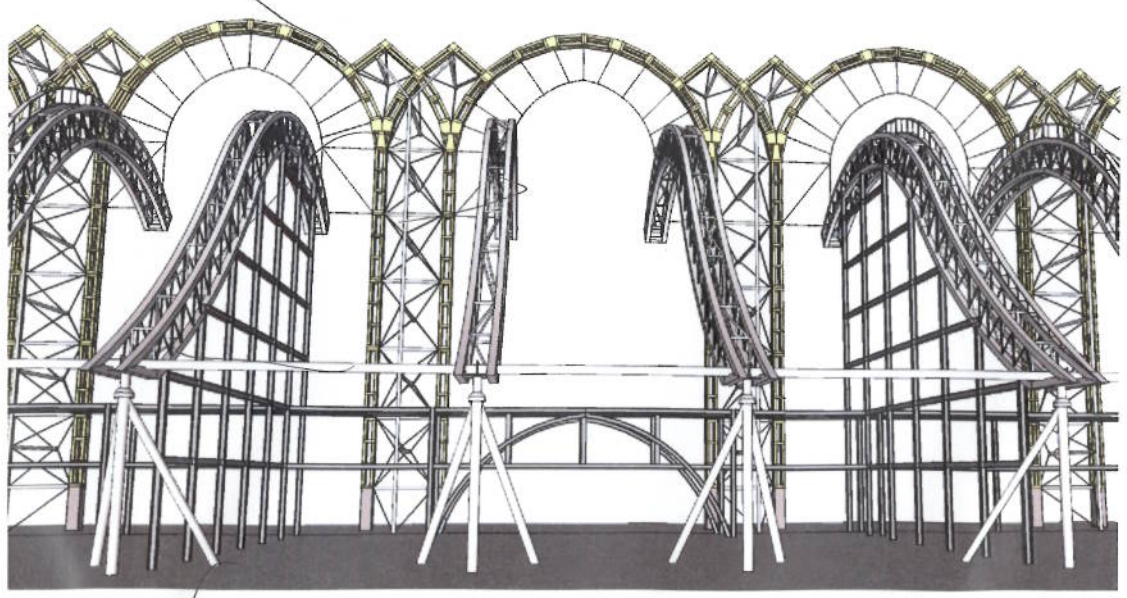


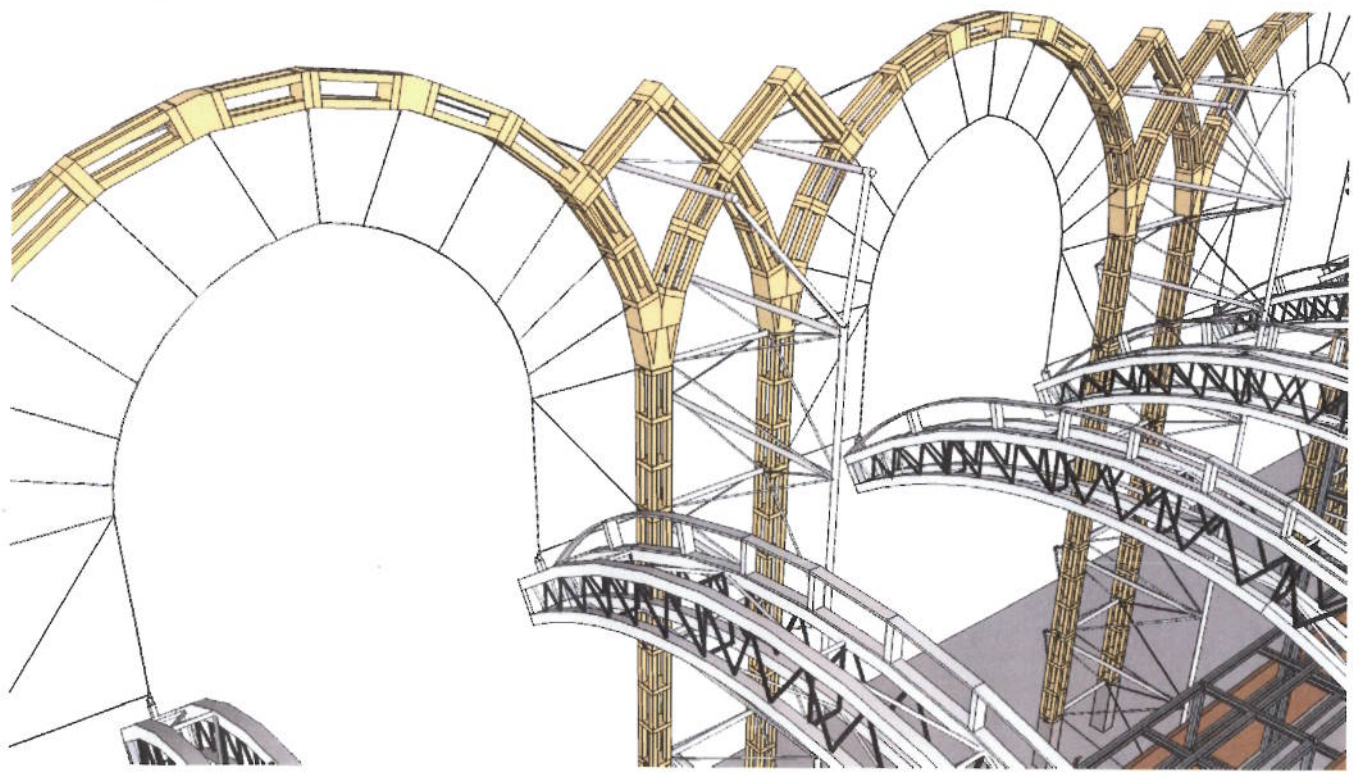


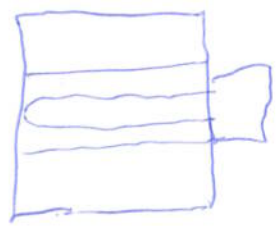
Peter LeMasney
24/09/13





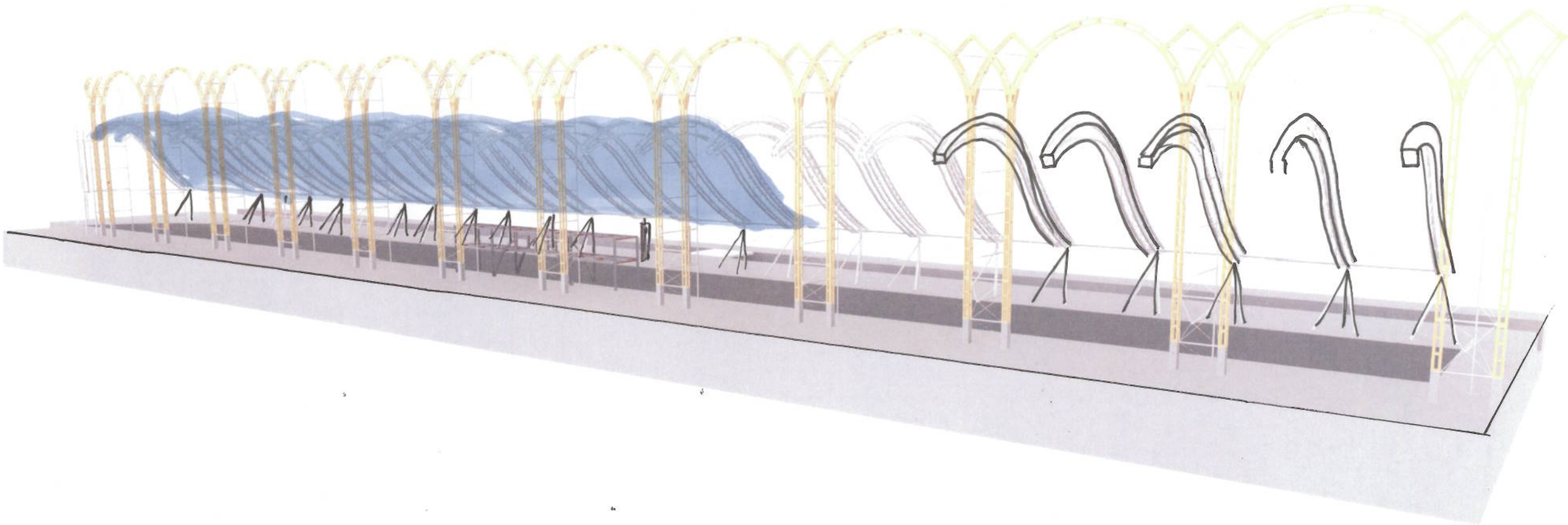


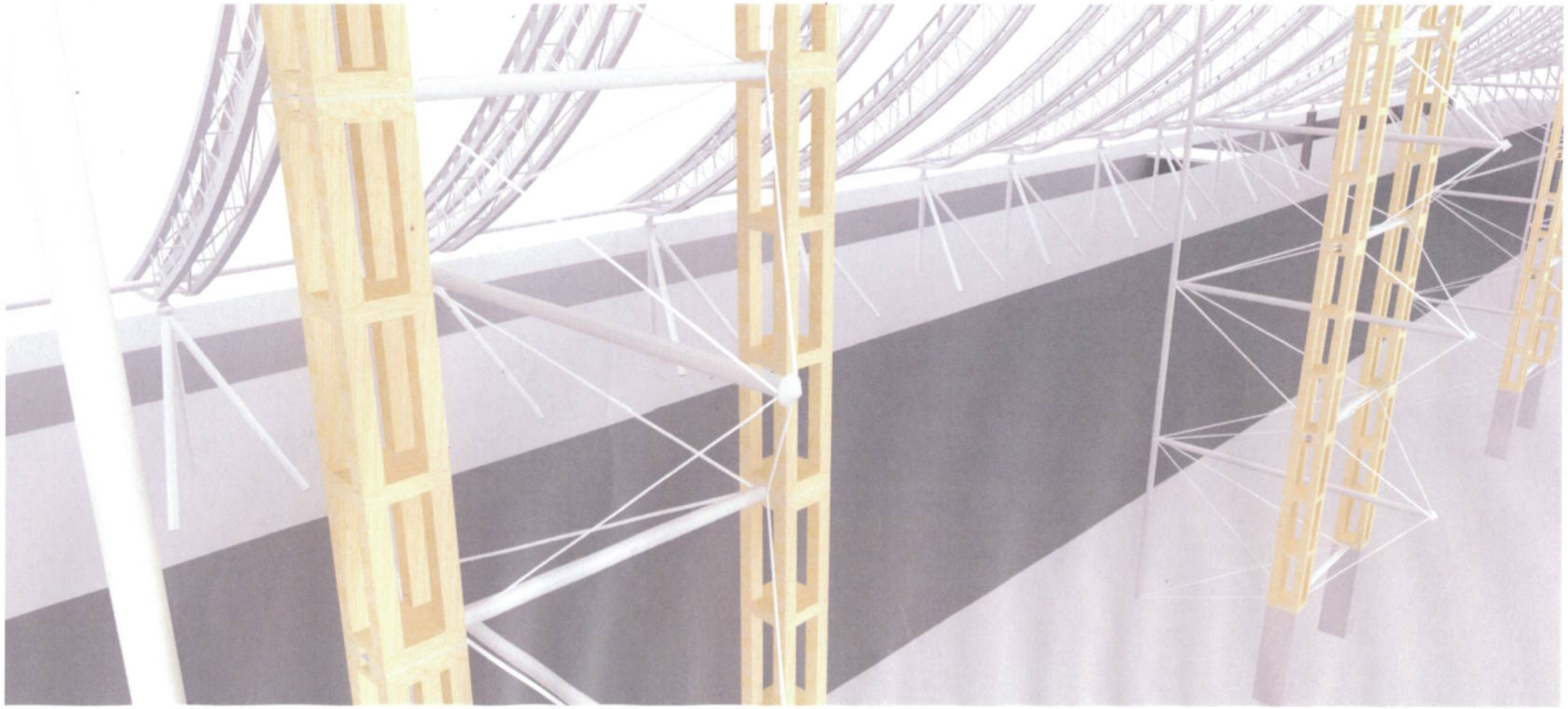




Sketch of Investigation 2

M. M





Sketches Investigation 3
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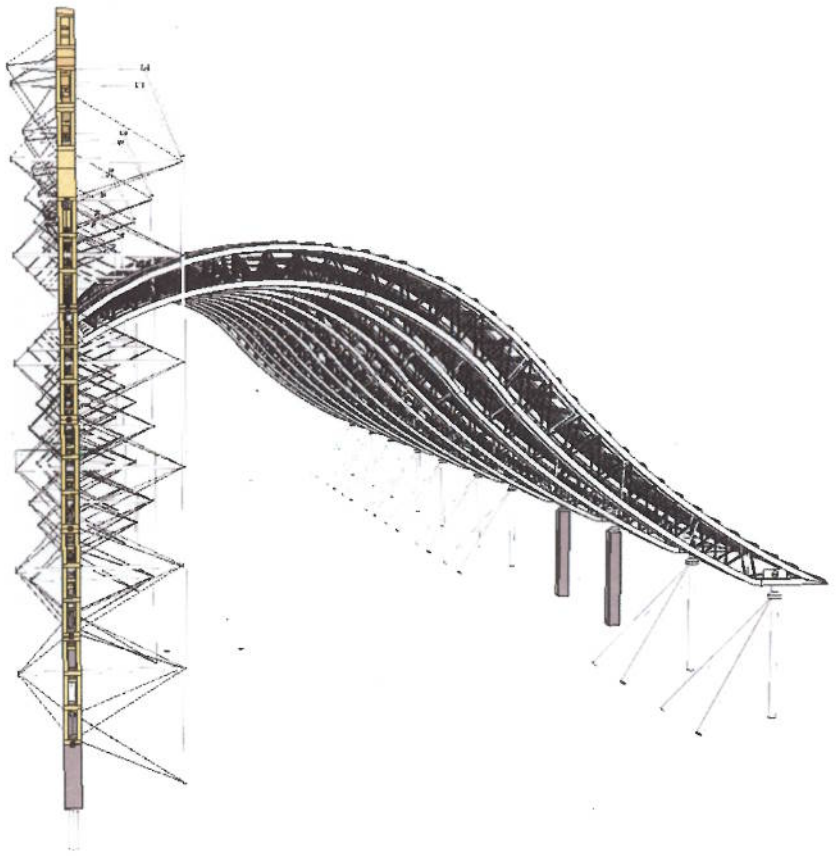

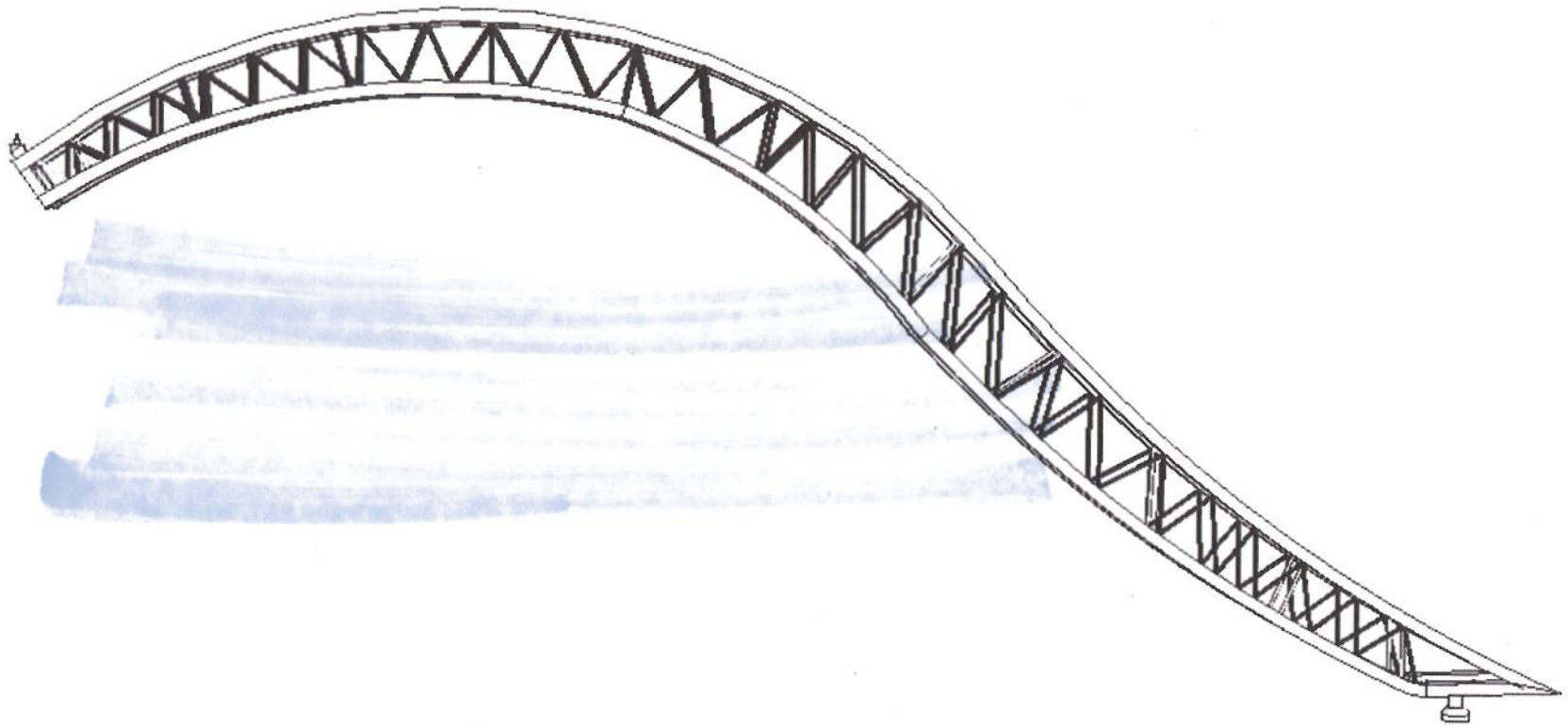

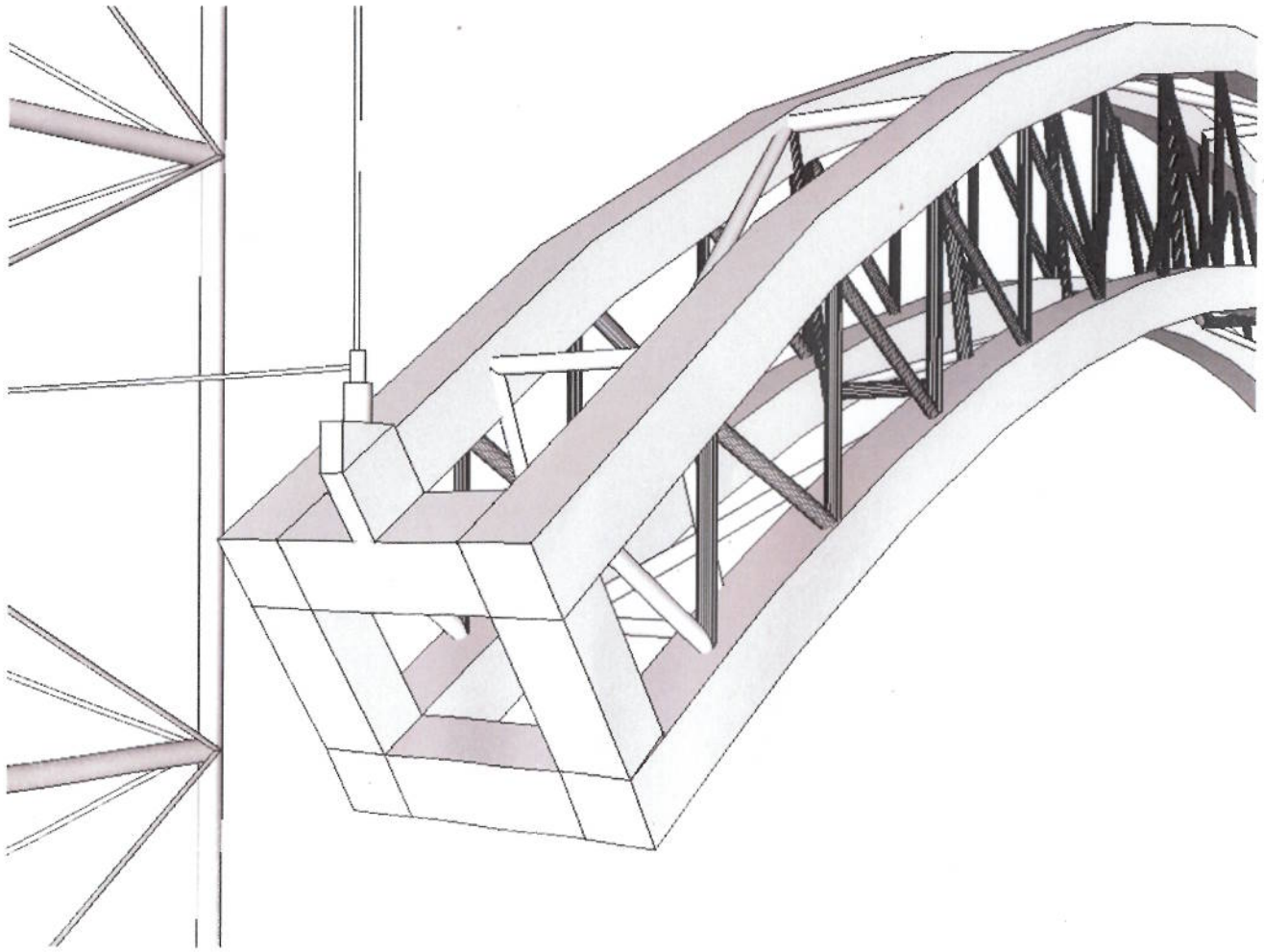

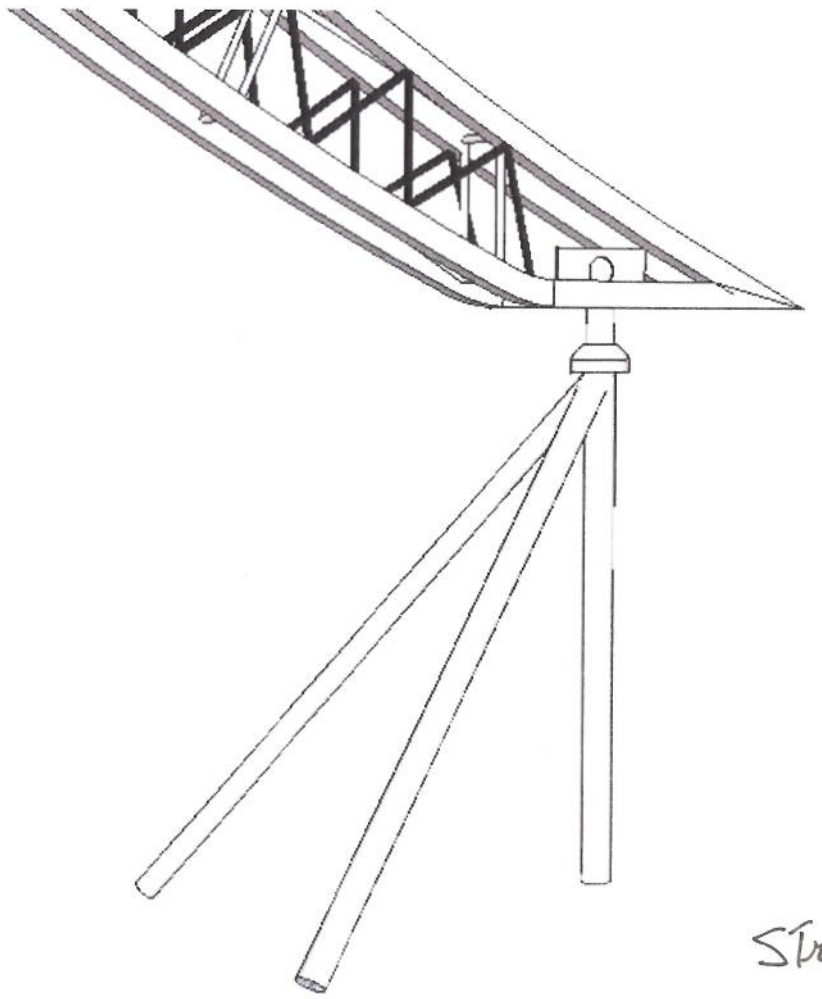

Structural Investigation 4

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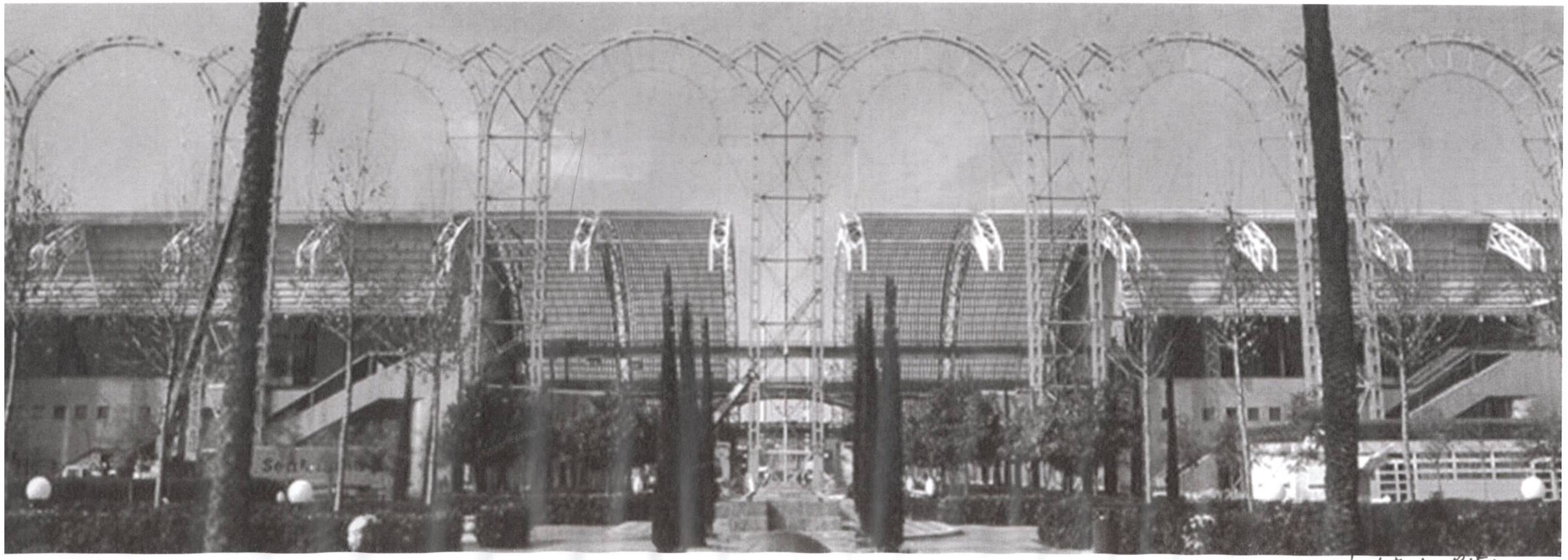
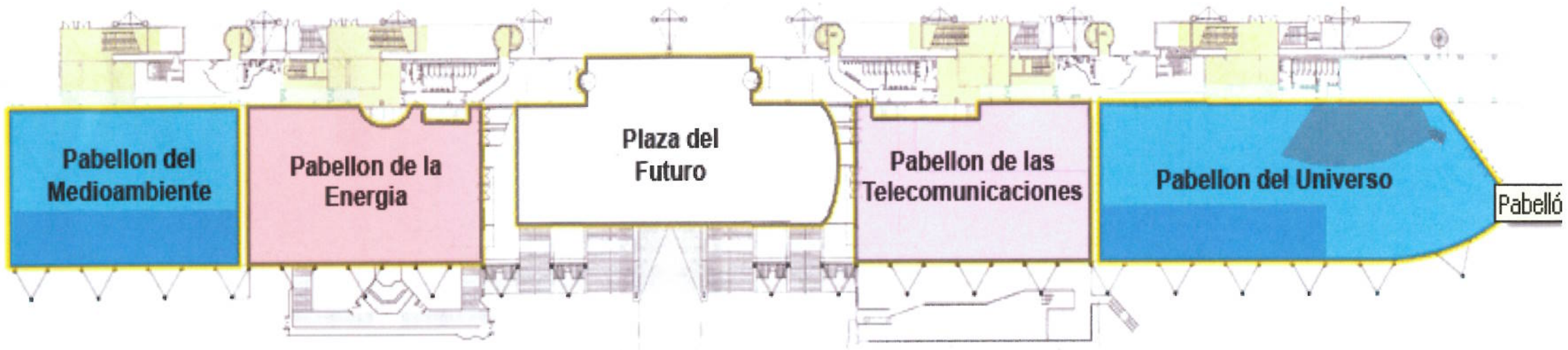
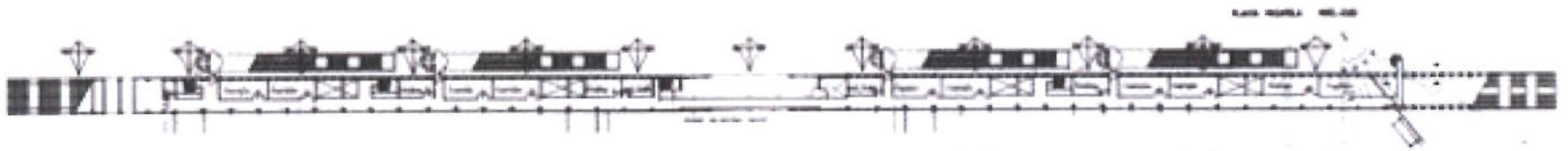
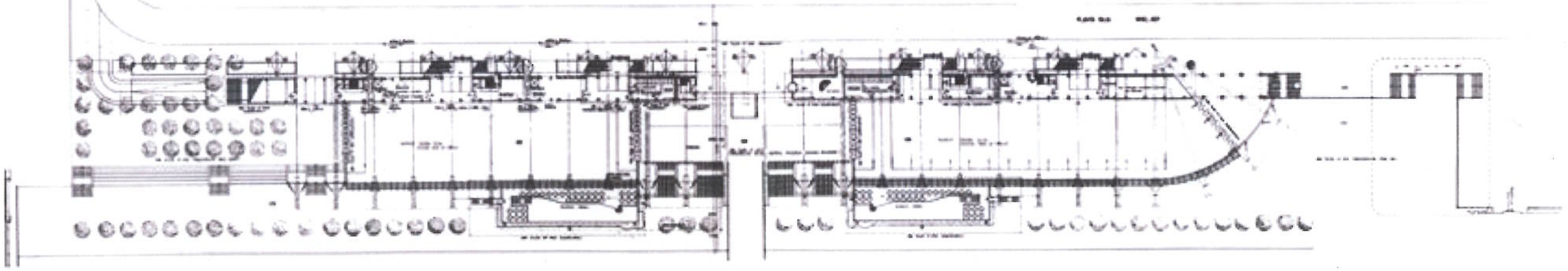
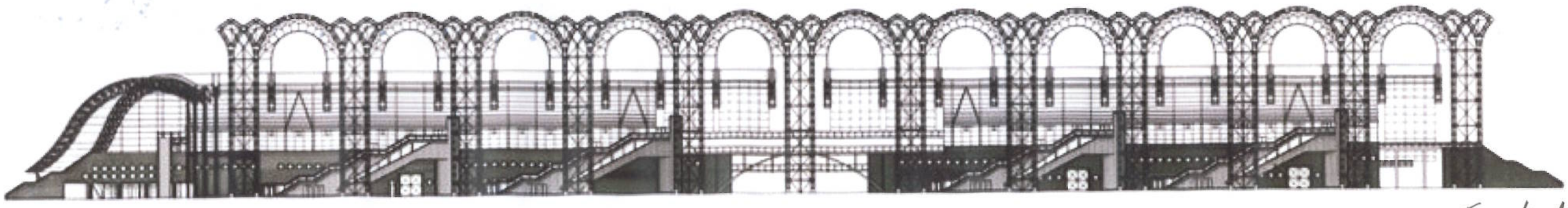


Investigate . Picture







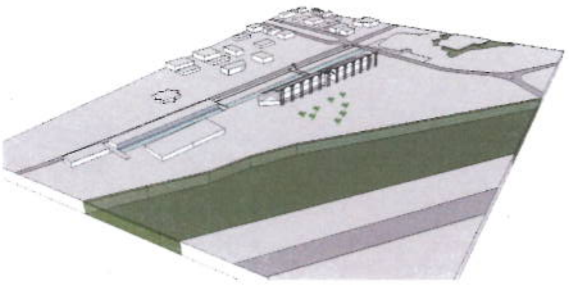


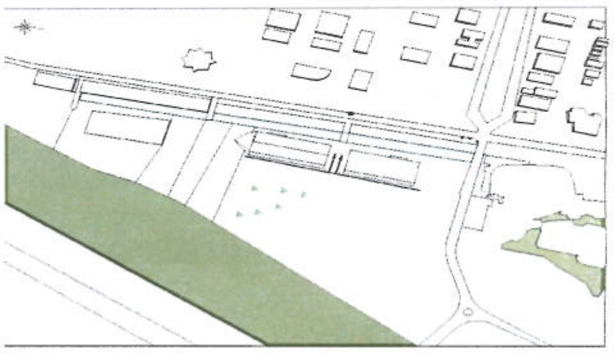
Investigation Pictures

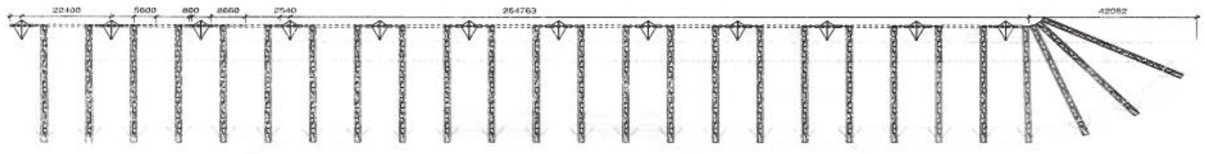
30-4-2013

PABELLON DEL FUTURO

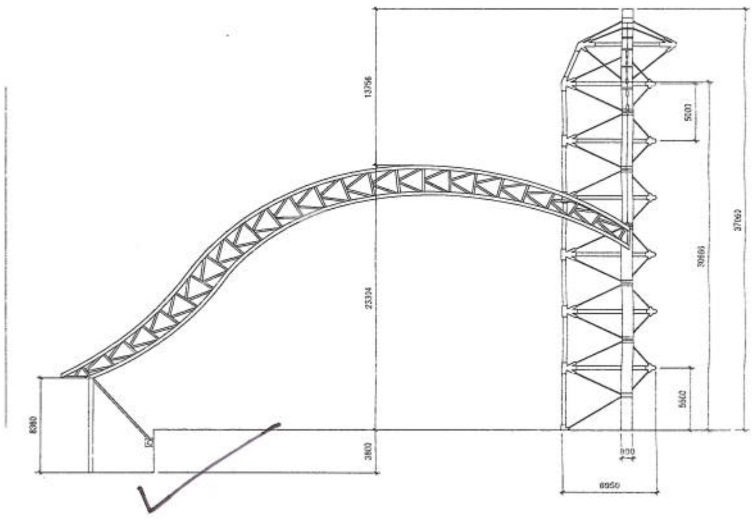
MBM & PETER RICE 1992

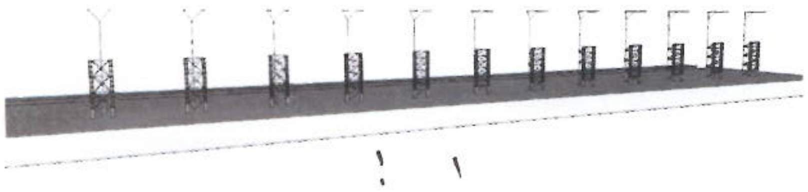






Drafting 1
1 : 750





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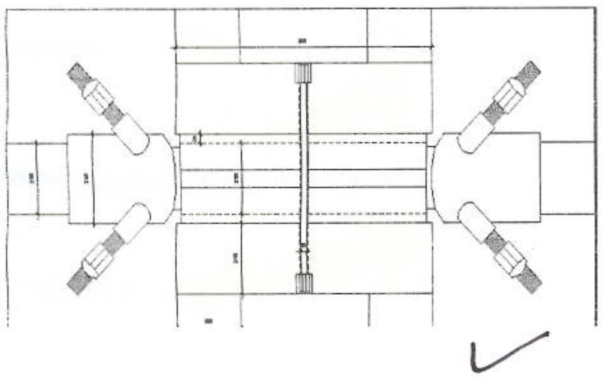

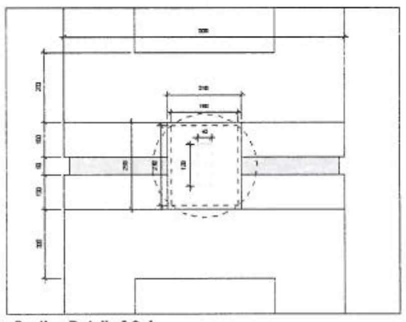

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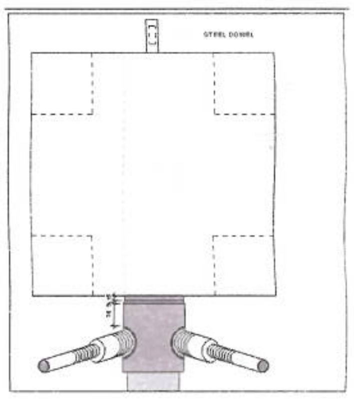
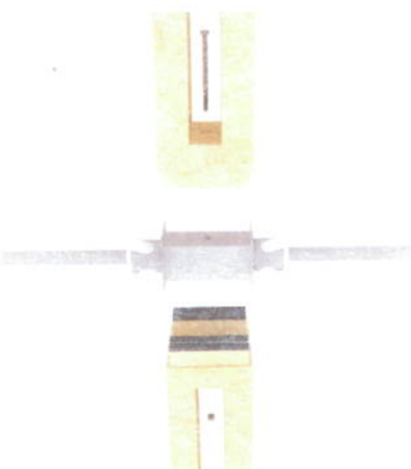
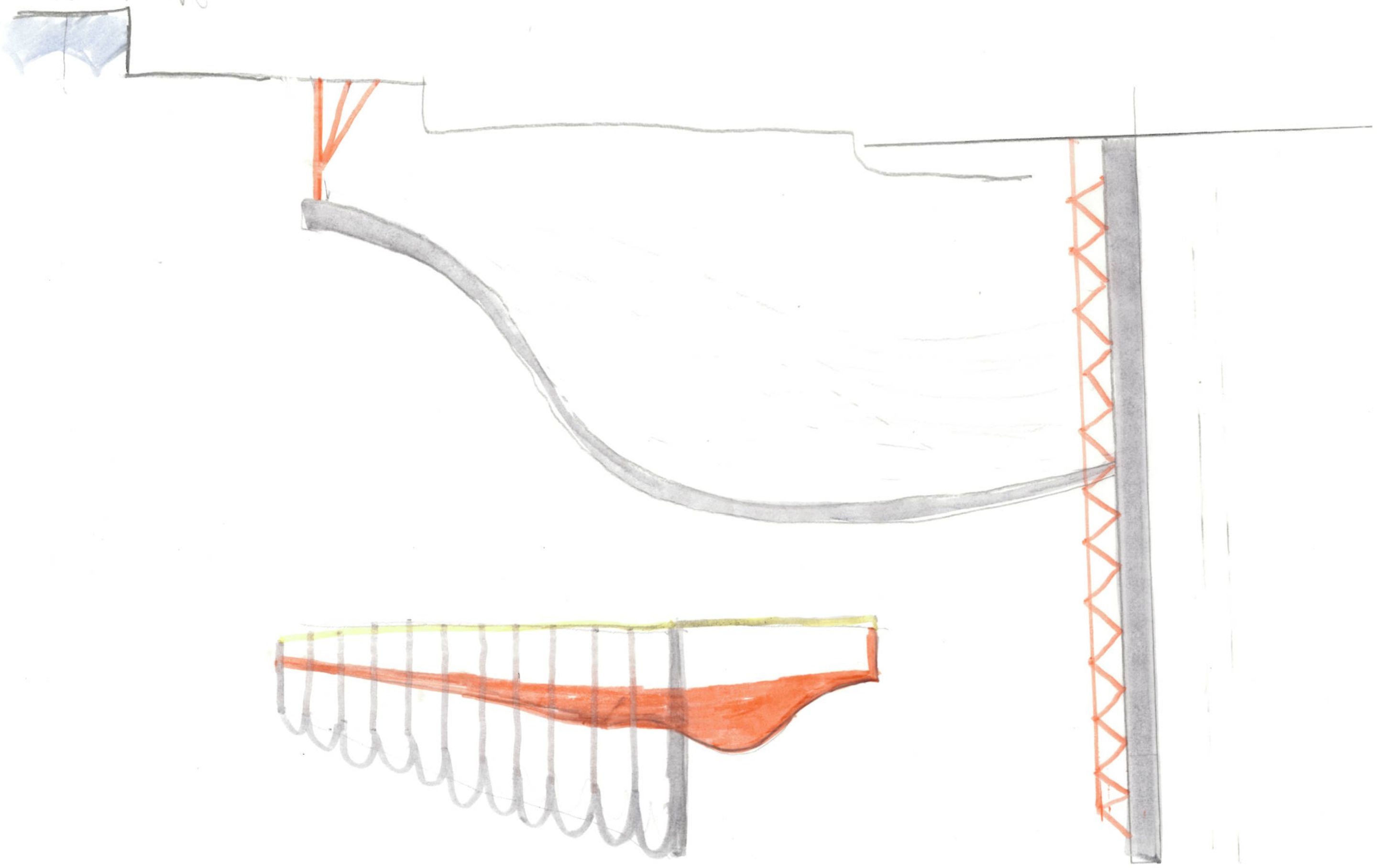
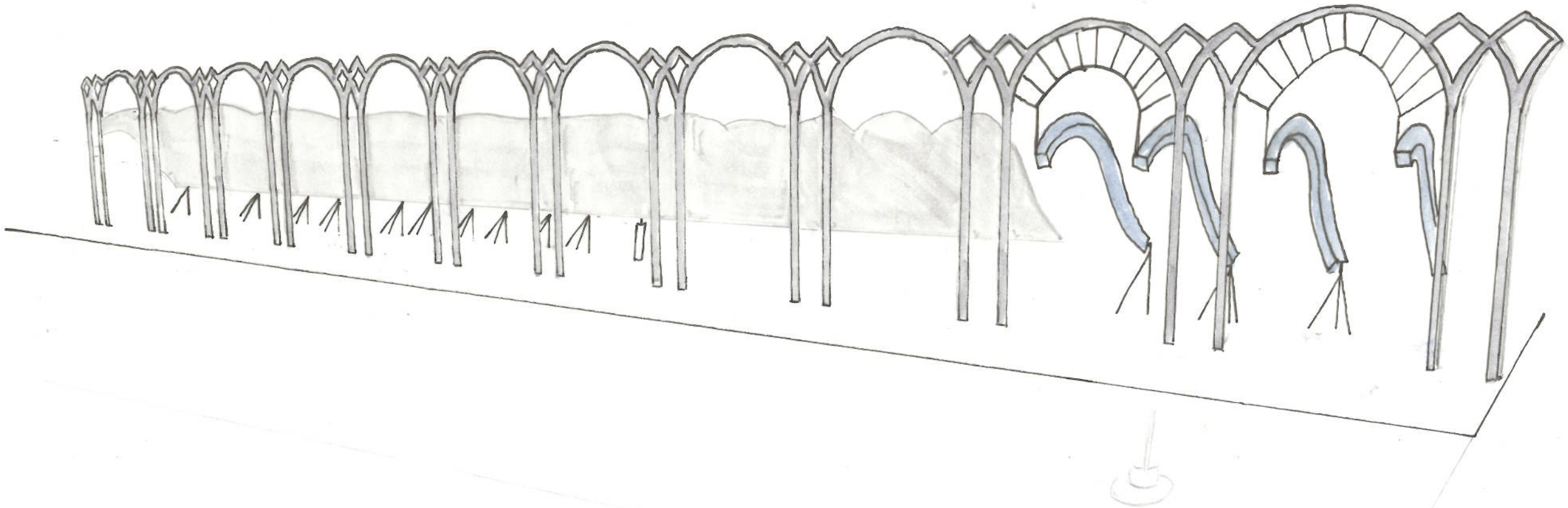


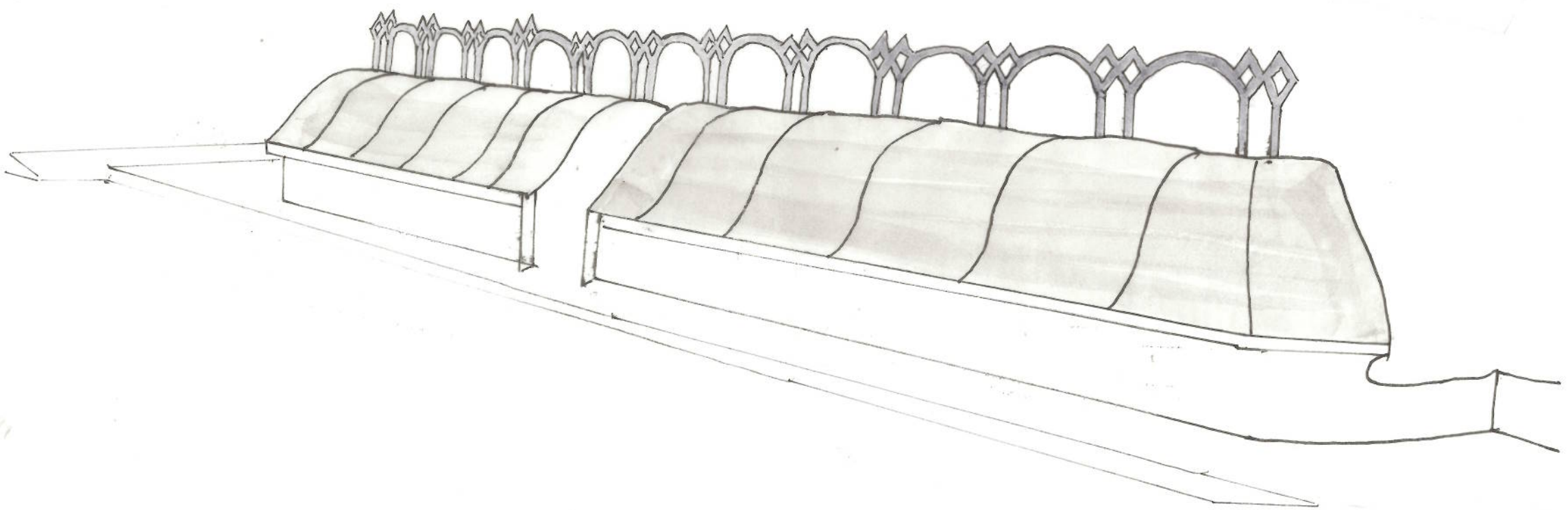


Page Proposal 1

Peter Heasley
24/04/2013

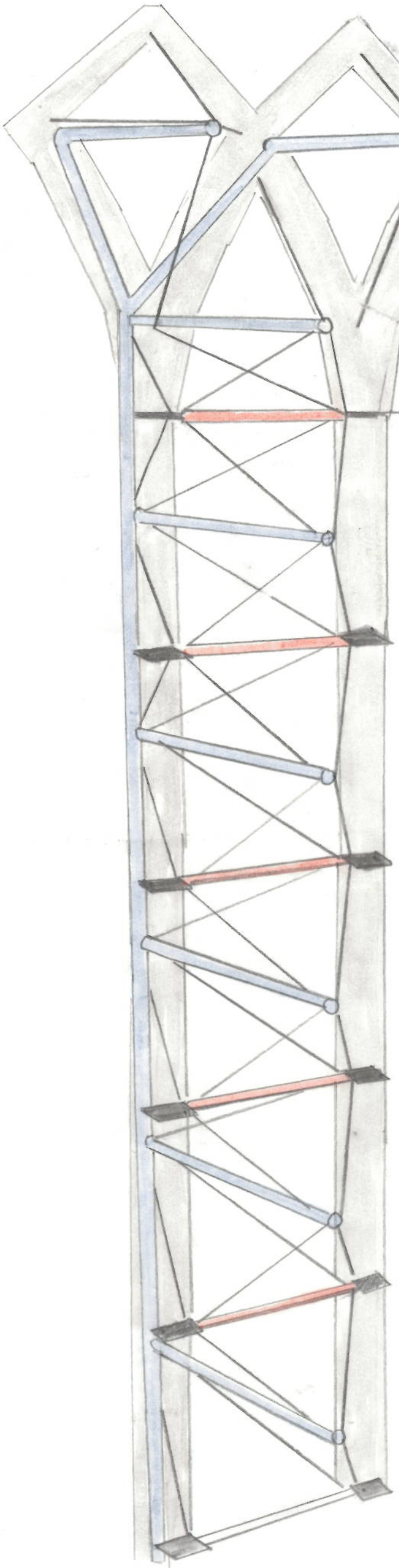


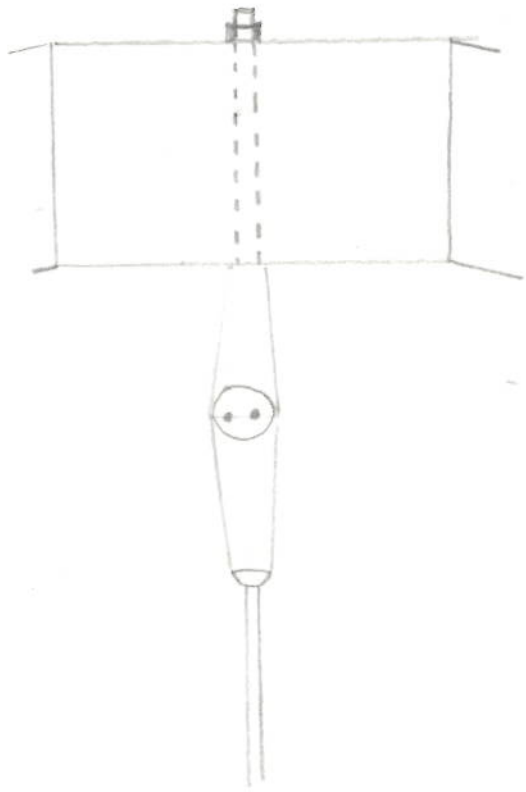


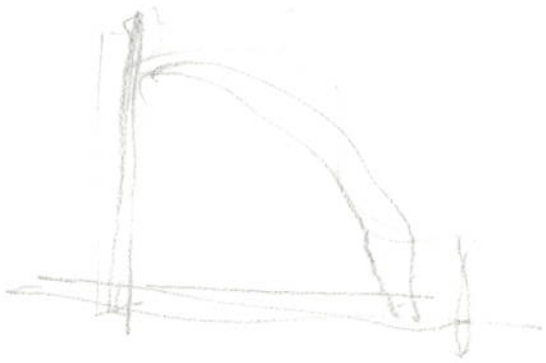


Peter LeMasney

29/09/13

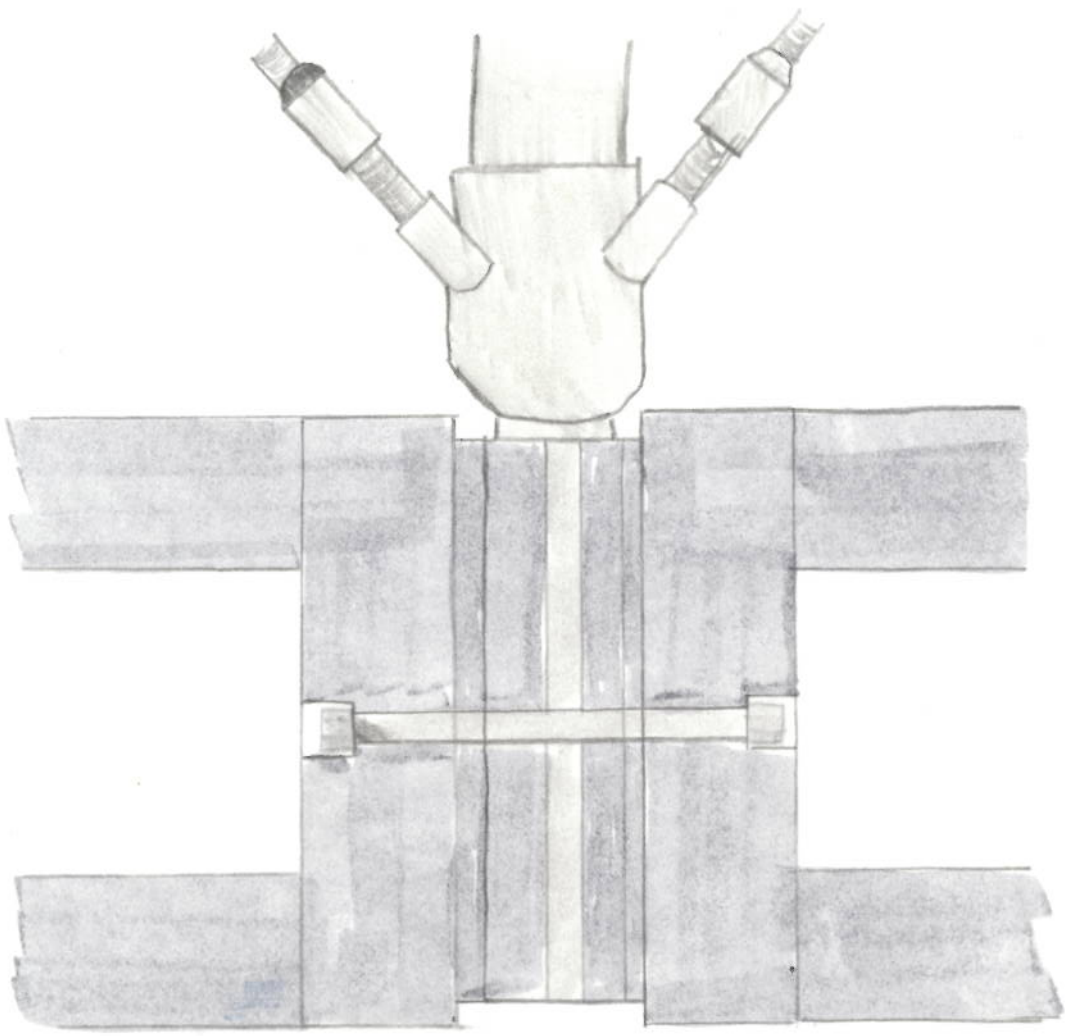


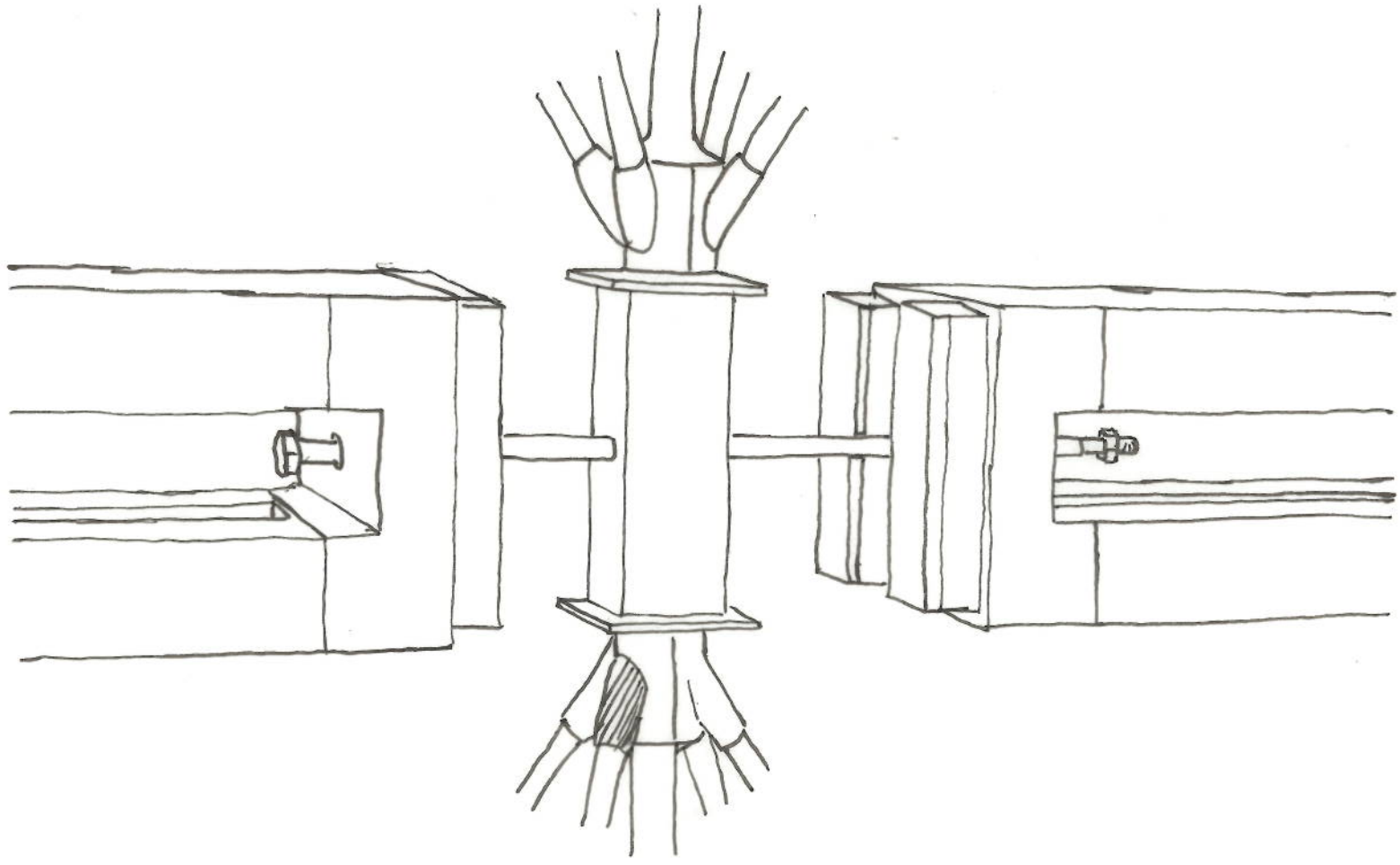


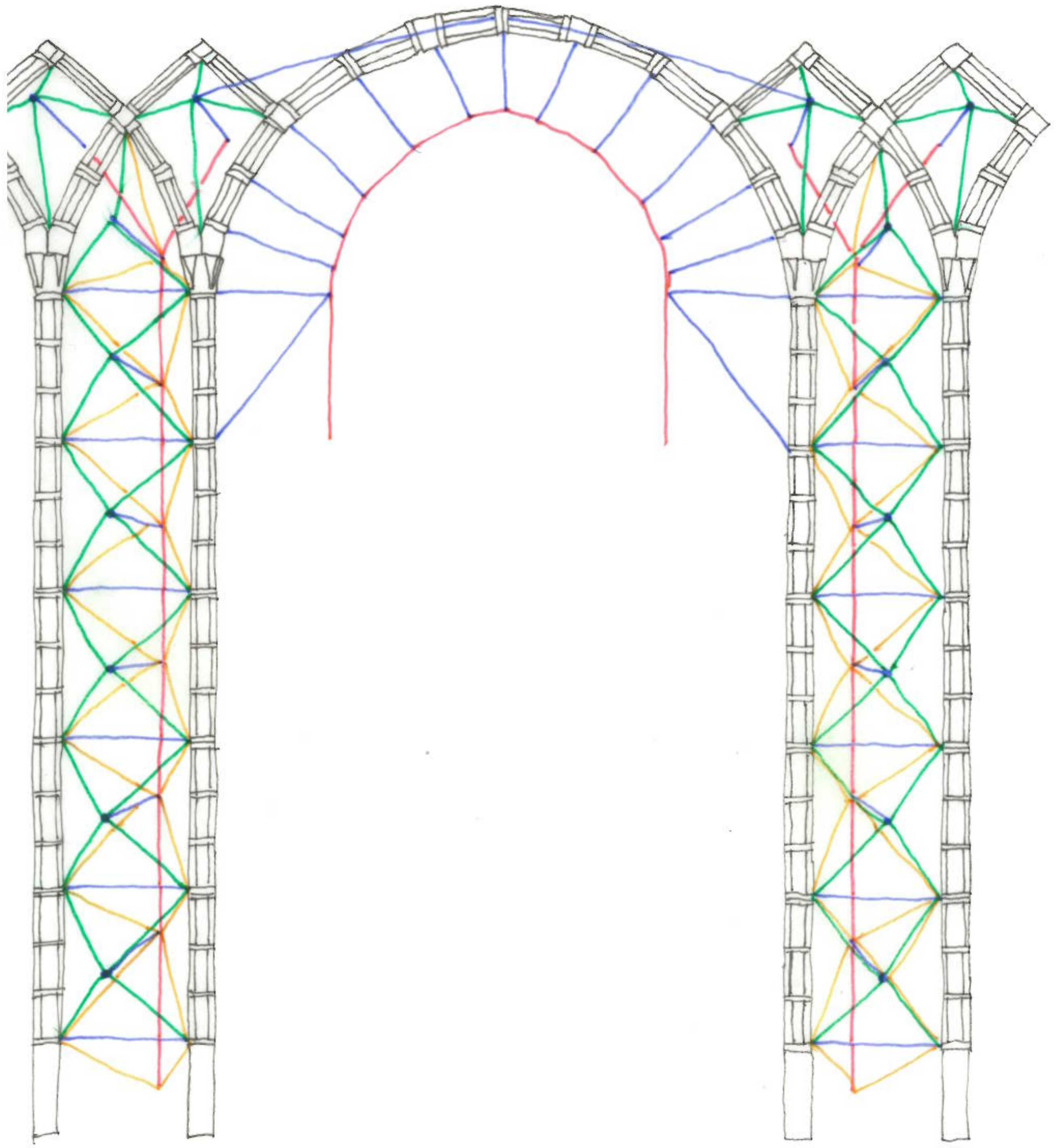


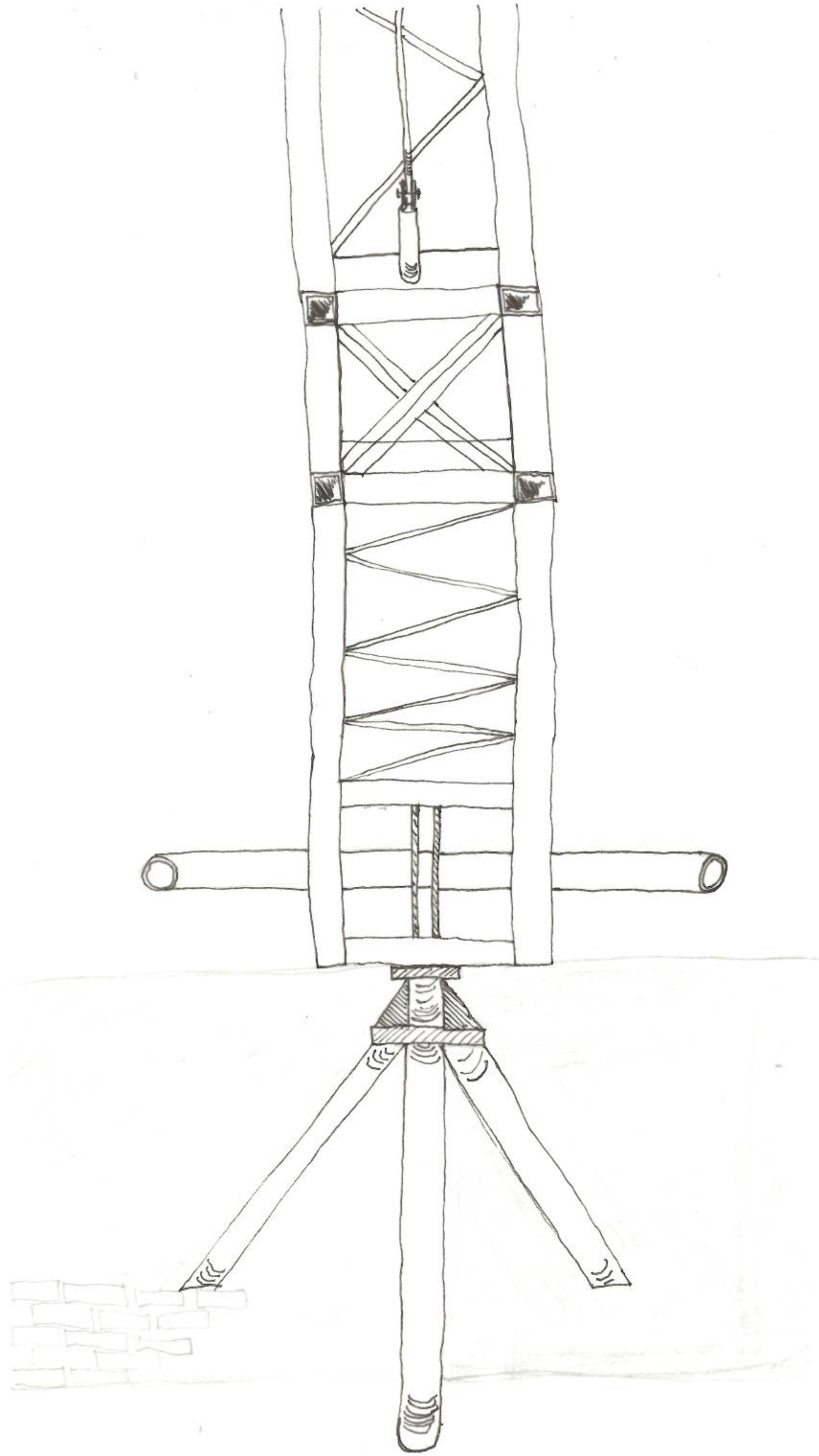
Peter

Peter McKay
01/10/2013









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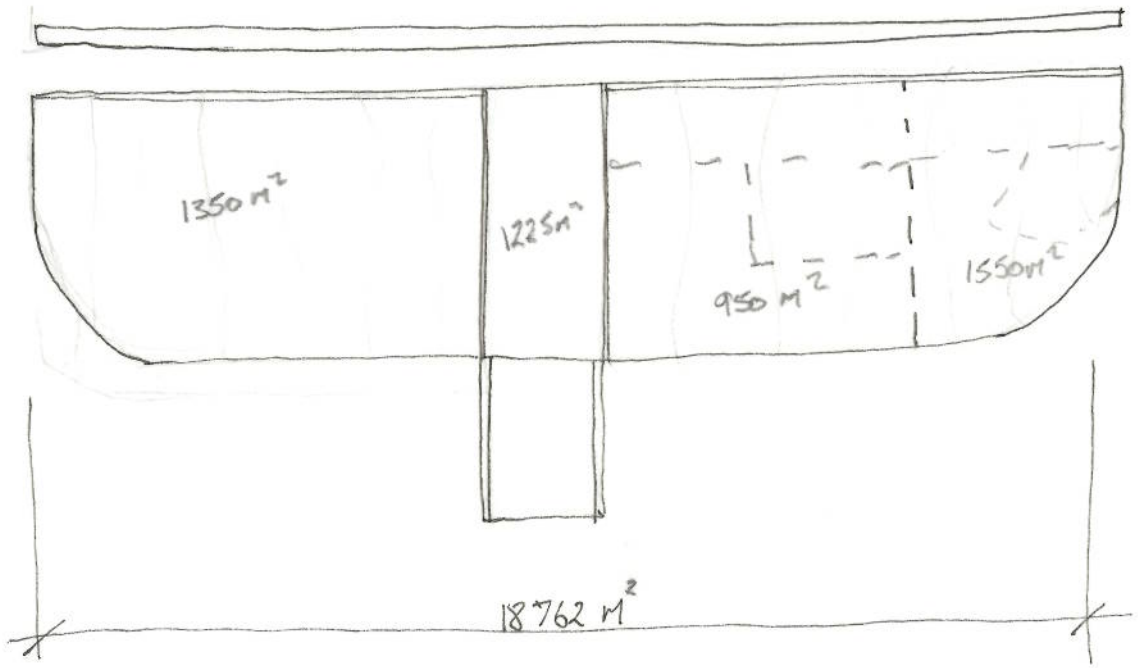
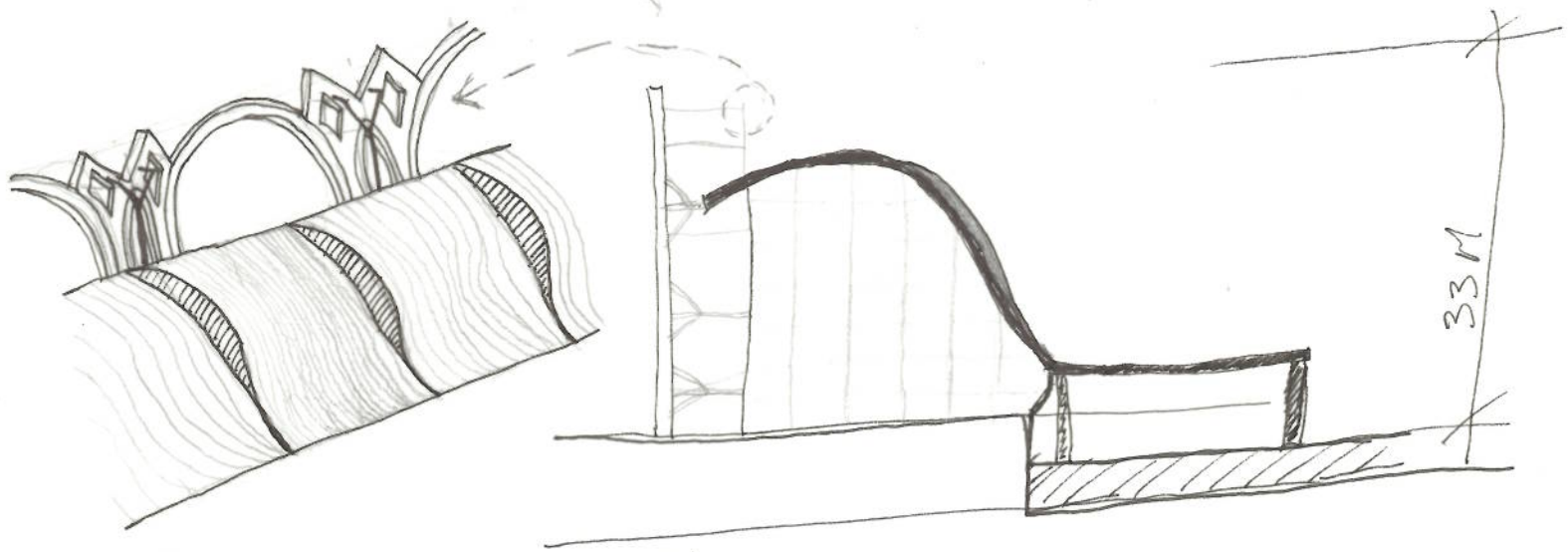
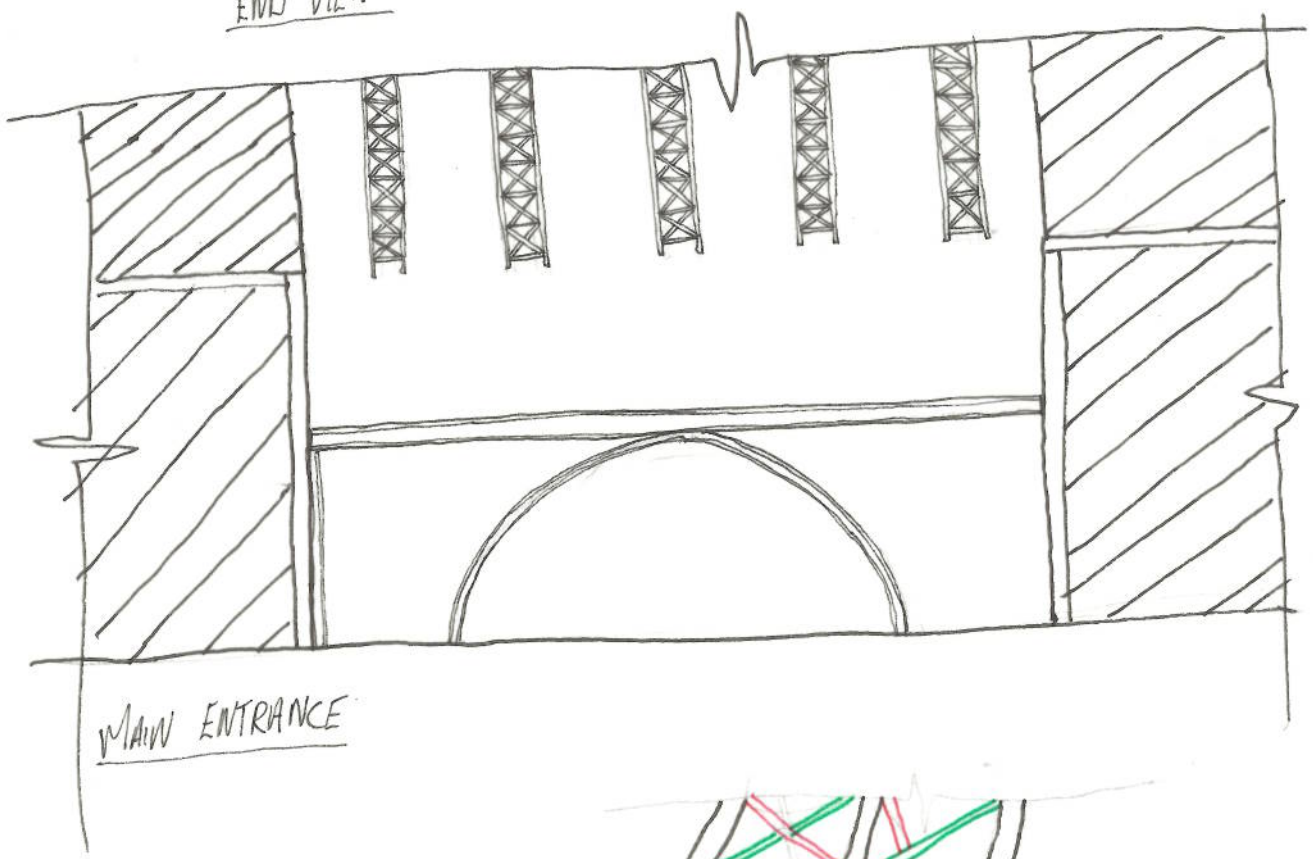


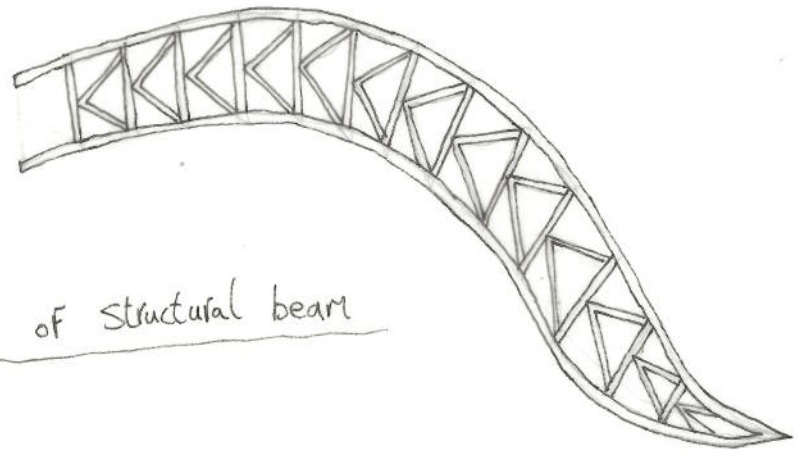
PLAN



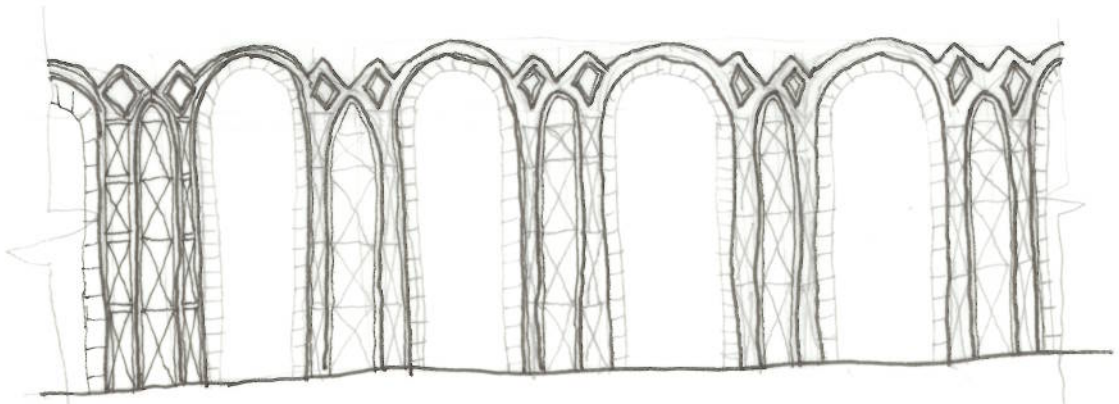
END VIEW



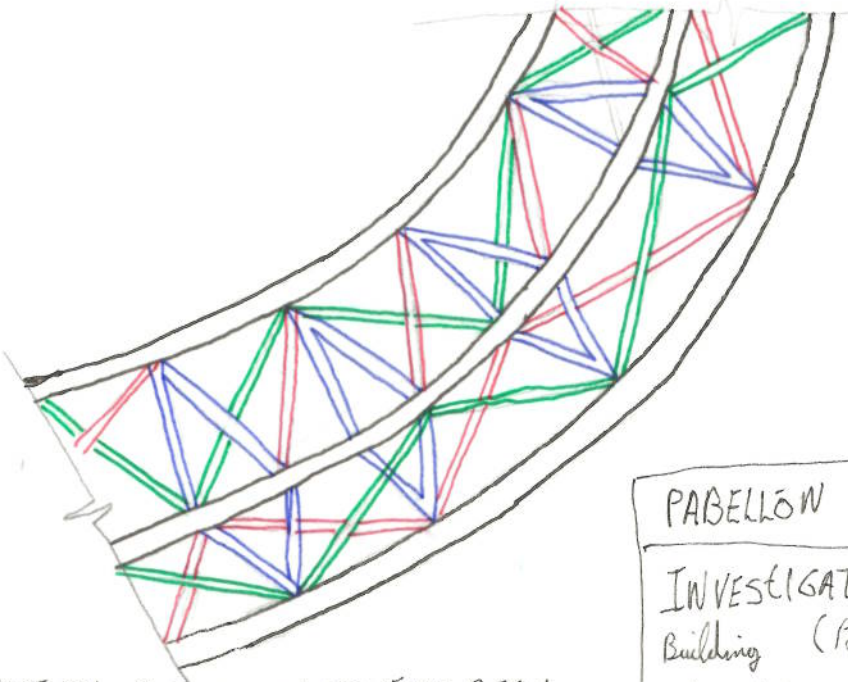
MAIN ENTRANCE



Section of structural beam



Front Facade

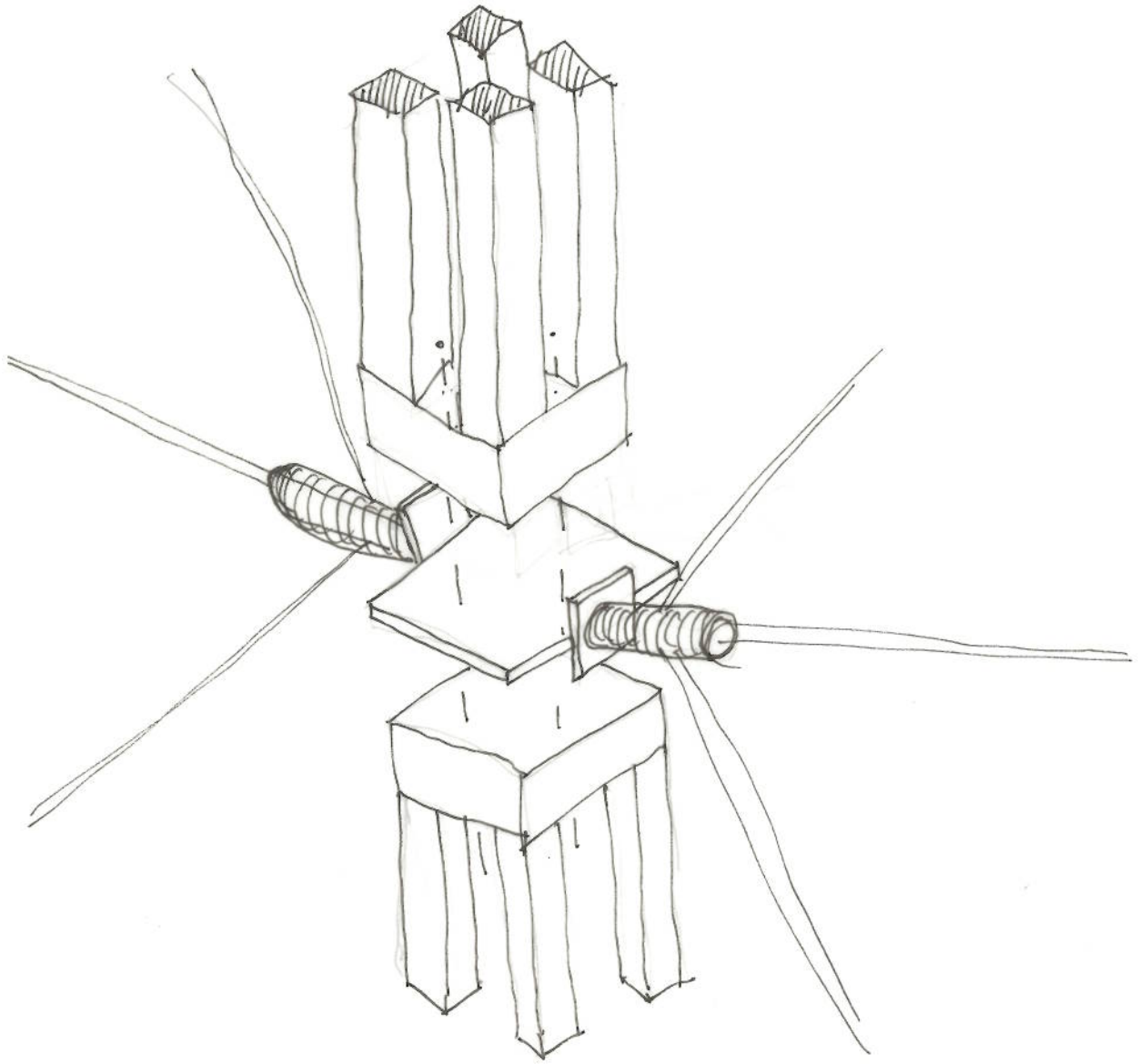


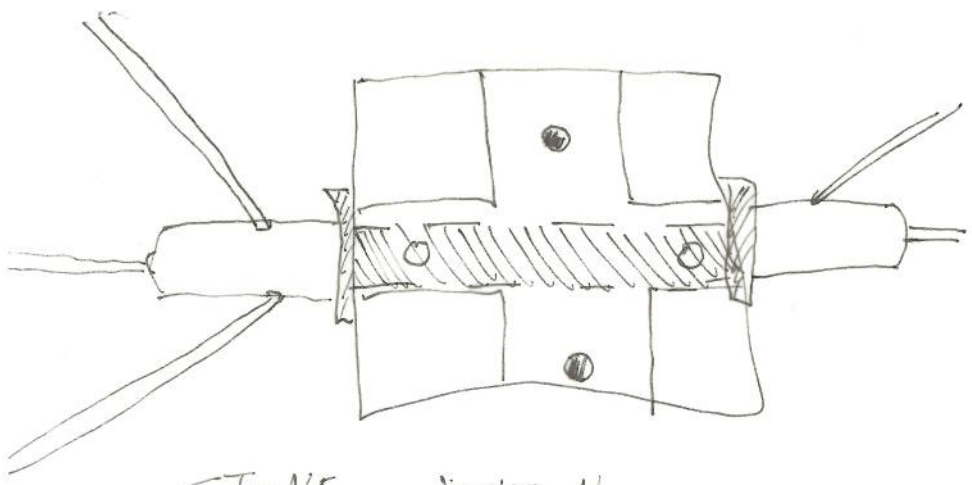
3D of structural forces on structural beam

PABELLON DEL FUTURO

INVESTIGATION OF Building (Page 1 of)

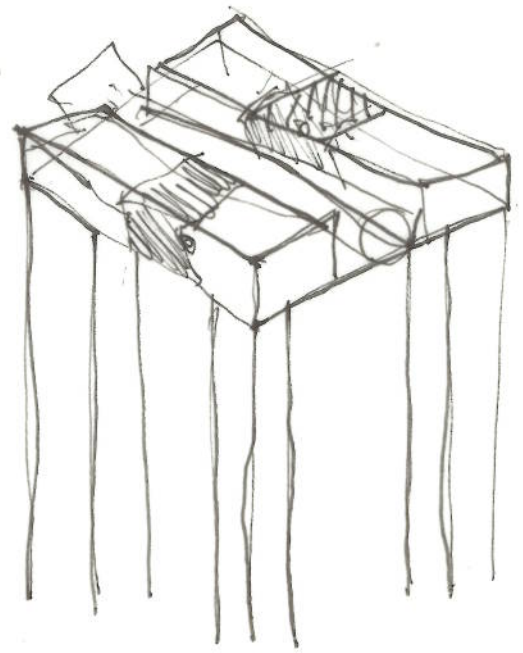
M. MALONE 17-9-13

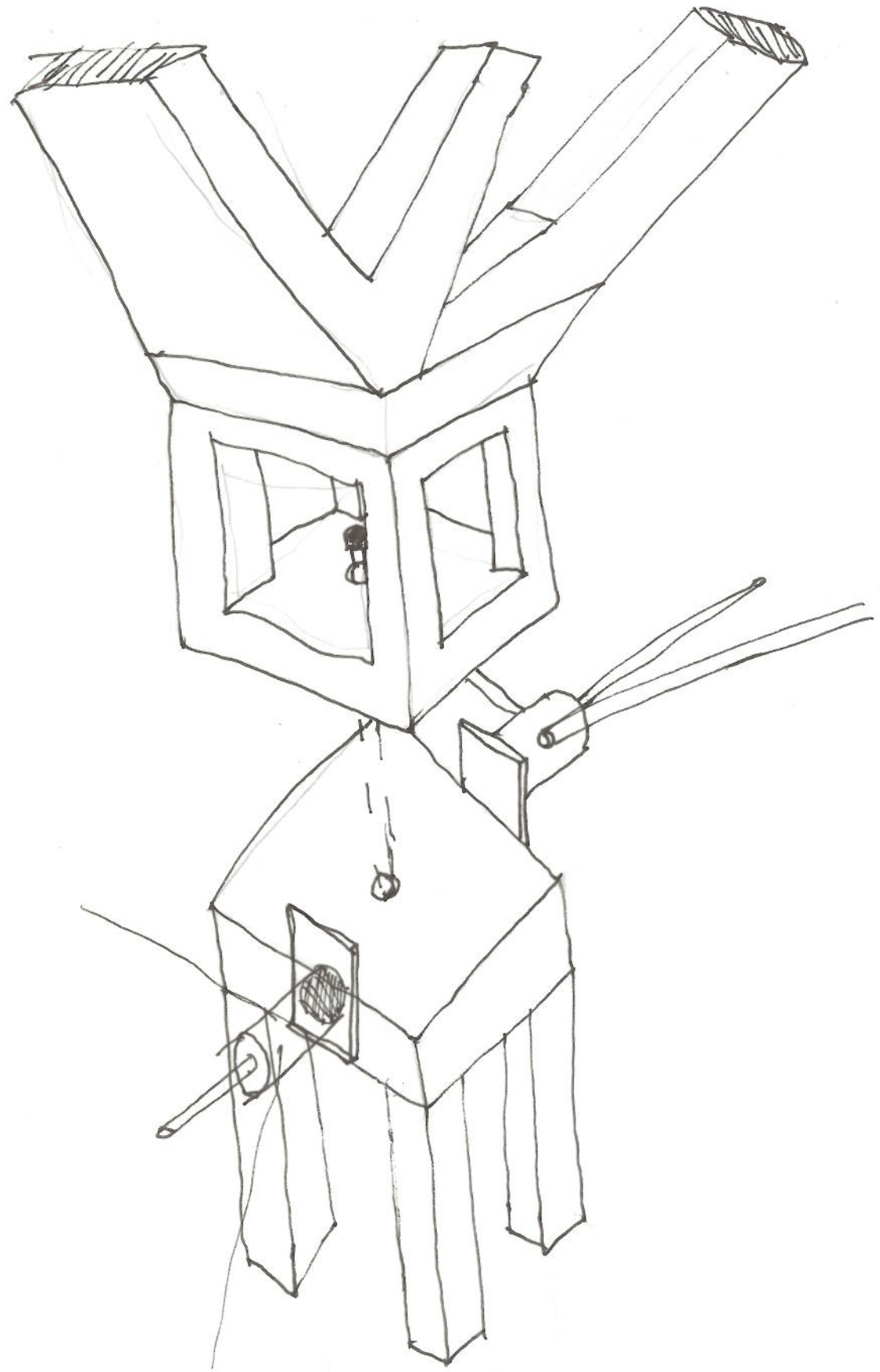




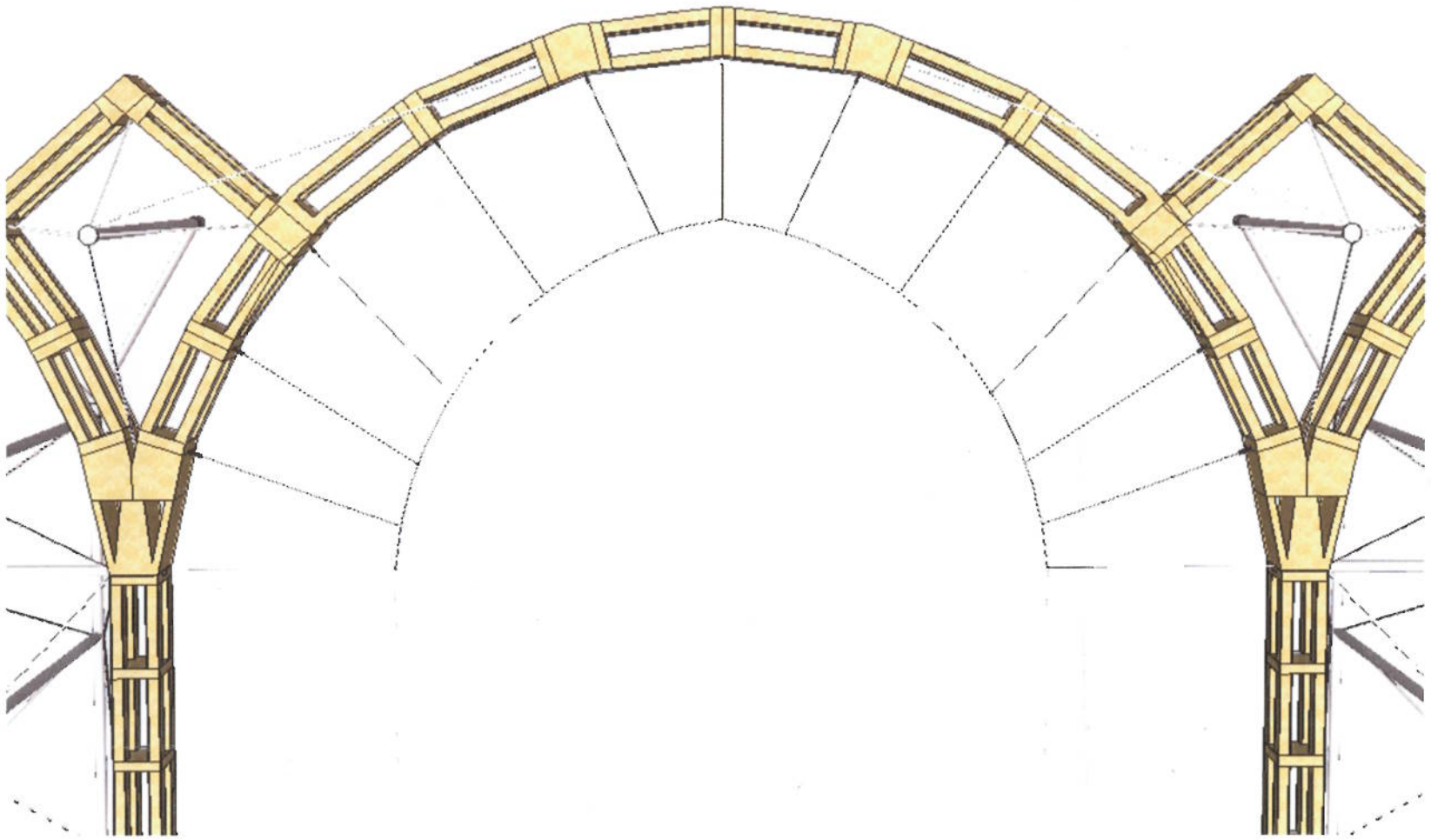
STONE JUNCTION

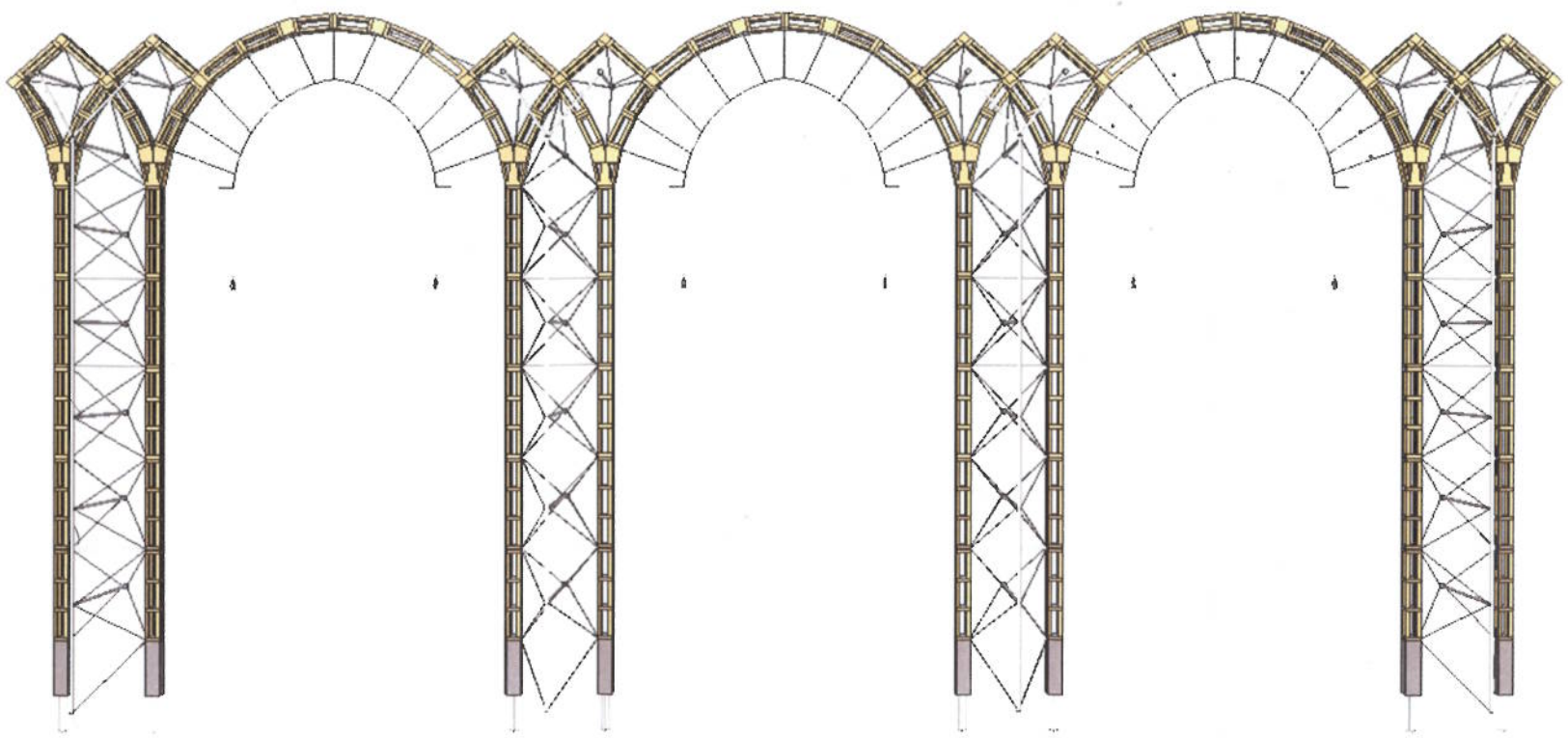
CONNECTING SLEET CABLES

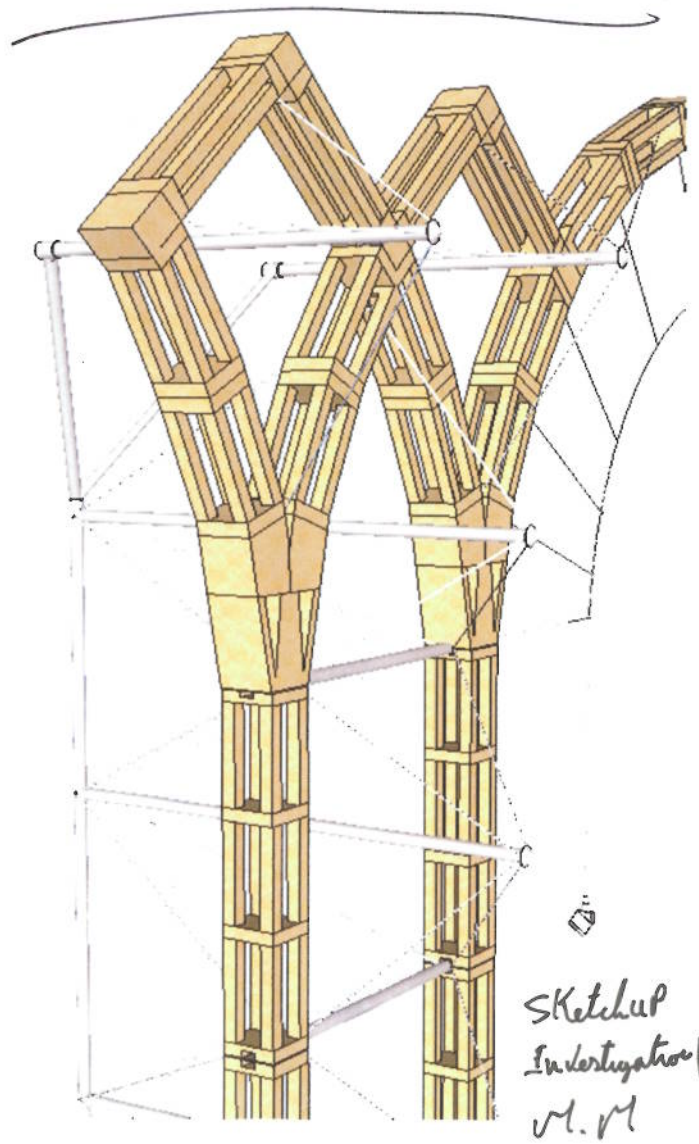


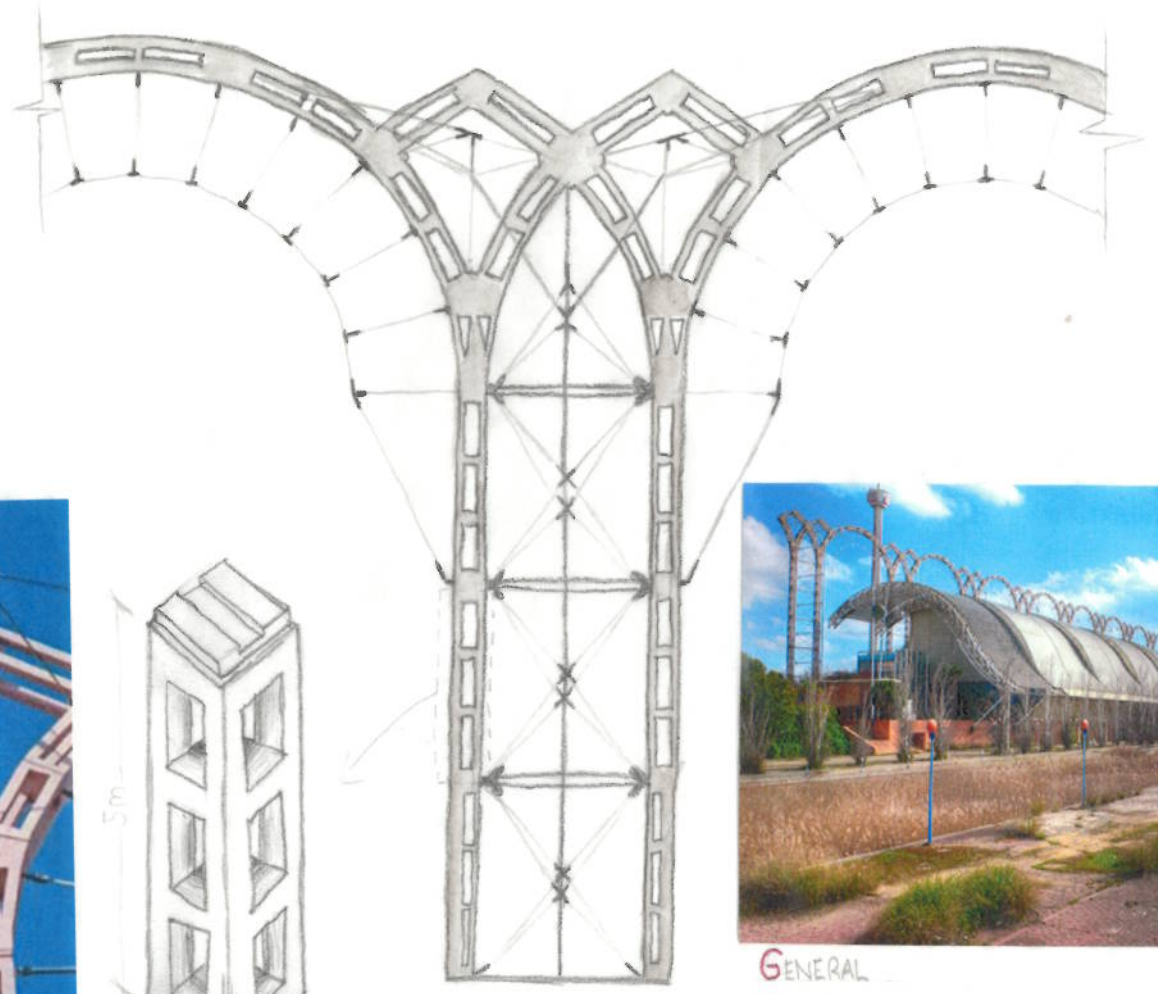


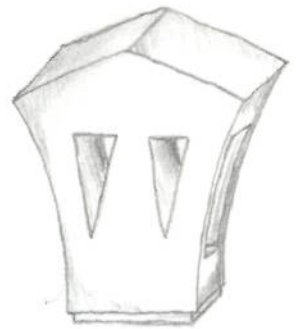
Rough work





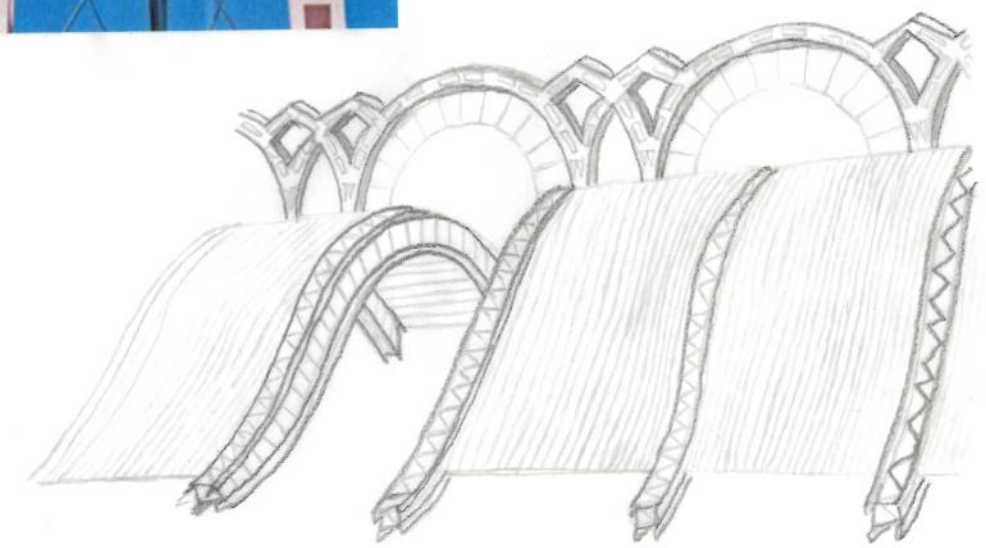

SKetchuP
Investigation
M. M





SITE

THE PABELLON DEL FUTURO OR THE PAVILION OF THE FUTURE IN SEVILLA, SPAIN ON THE ISLA DE LA CARTUJA. THIS IS SEEN MARKED IN THE ABOVE PICTURE IN RED. THE BUILDING FACES ONTO THE GUADALQUIVIR RIVER AND TO THE OLD CITY ACROSS THE RIVER ITSELF. IT IS A LARGE SITE AT 25 METRES WIDE BY 300 METRES IN LENGTH APPROXIMATELY.

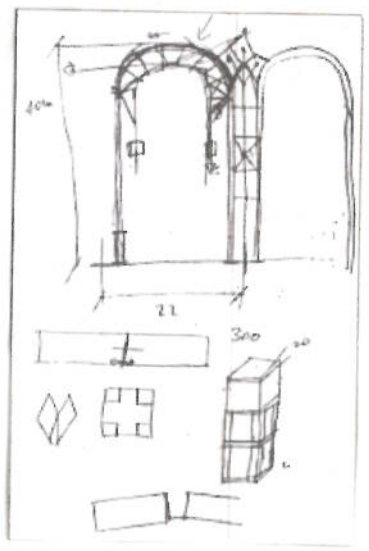


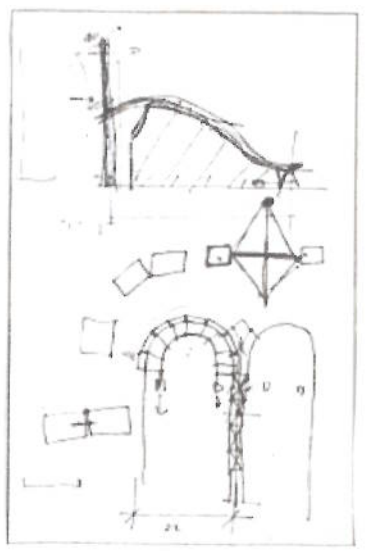
GENERAL

THE PLANNING STAGE OF THE PABELLON DEL FUTURO BEGUN IN 1988 WITH THE CONSTRUCTION BEGINNING IN 1989. THIS WAS ONE OF THE FINAL PROJECTS THAT PETER RICE PARTICIPATED IN BEFORE HIS DEATH IN 1992. THE IMAGE ABOVE SHOWS THE SOMEWHAT ABANDONED SURROUNDINGS OF THE PAVILION. IN A LOT OF CASES BUILDINGS THAT HAVE BEEN BUILT ESPECIALLY FOR EVENTS SUCH AS THE WORLD EXPO '92 BECOME USED LESS FREQUENT THE MORE YEARS THAT PASS. THIS COULD BE AN EXAMPLE.

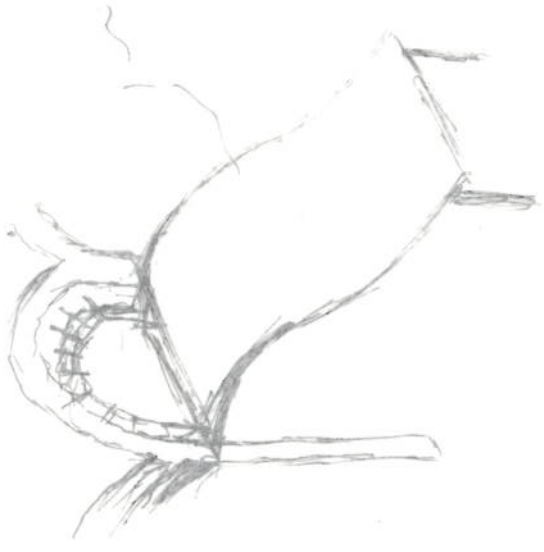
INSPIRATION

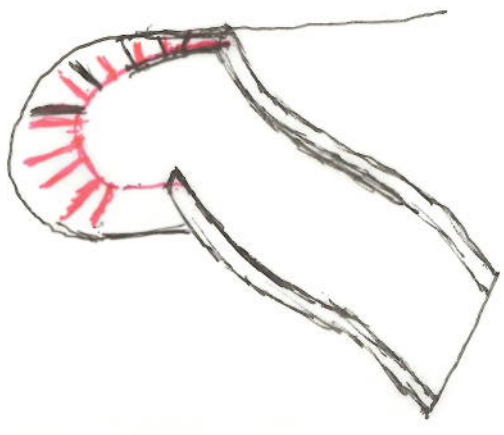
THE PALACIO DE AJUDA IS A BUILDING IN LISBON THAT PETER RICE GREW TREMENDOUS INSPIRATION FROM FOR A POSSIBLE IDEA FOR THE PABELLON DEL FUTURO. THE PALACIO DE AJUDA HAS A WHOLE FACADE UNFINISHED DUE TO THE ATTACK OF NAPOLLON WHILE THE BUILDING WAS BEING CONSTRUCTED. WORK ON IT CAME TO A HOLT DURING THE ATTACKS AND TO THIS DAY HAS NEVER BEEN COMPLETED. RICE WAS AMAZED THAT THIS FACADE SUPPORTED ITSELF FOR SO LONG SO HE DECIDED TO DESIGN A FACADE WITH THE SAME PRINCIPLES AS IN LISBON. RICE, WITH THE CHOSEN ARCHITECTS - MARTORELL BOHIGAS MACKAY EVENTUALLY DESIGNED THE VIADUCT LOOKING FACADE WITH ARCHWAYS AND STEEL CABLE SUPPORTS THROUGHOUT

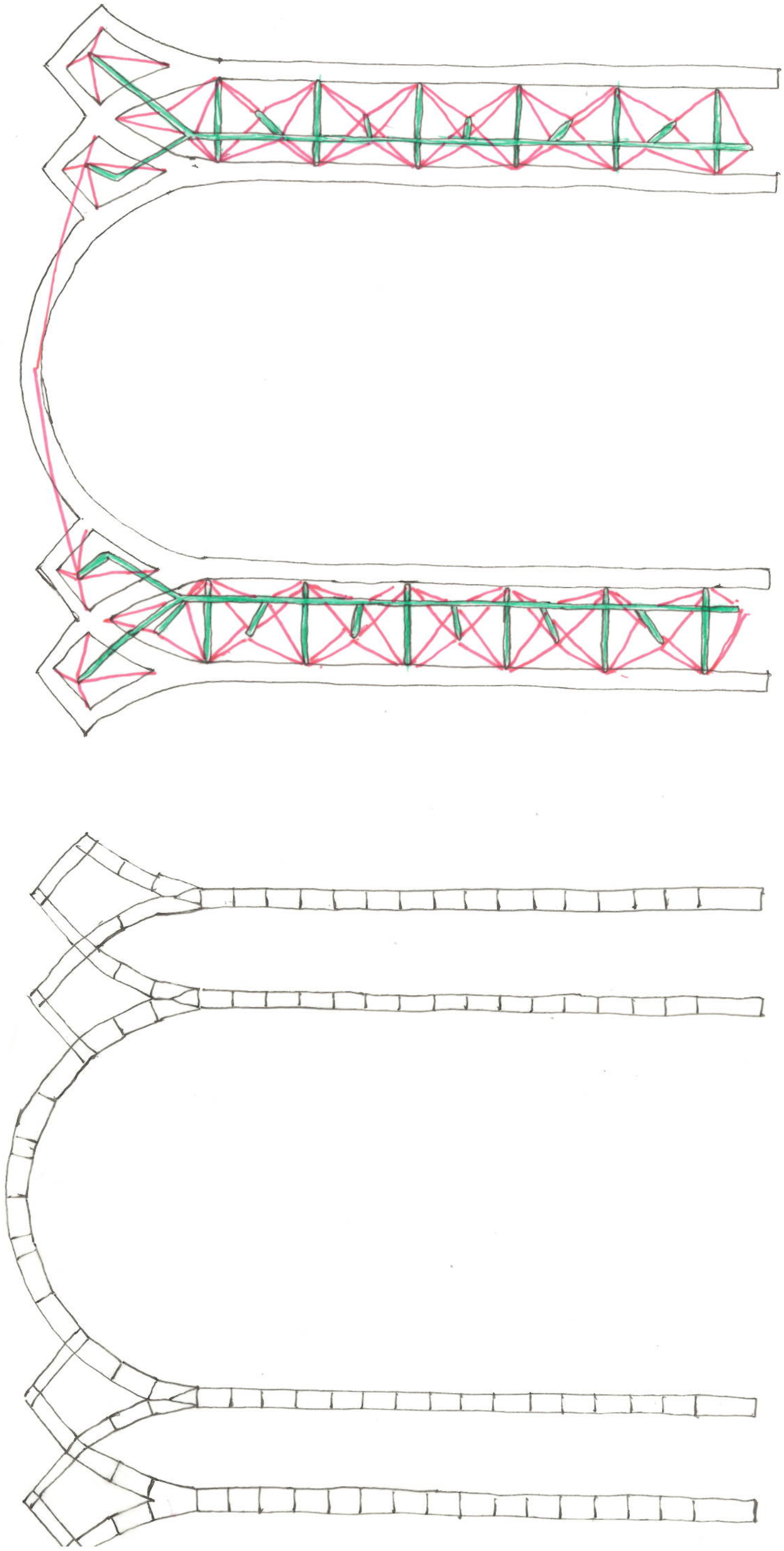


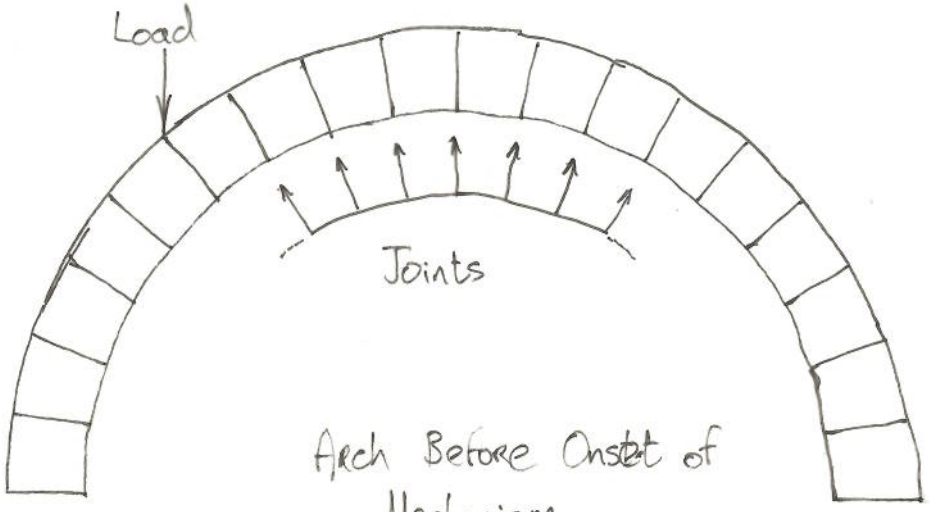


TO THE LEFT IS A SECTION OF THE PAVILION SHOWING THE GRANITE FACADE WITH STEEL BRACINGS AND THE STEEL WAVE-LIKE ROOF

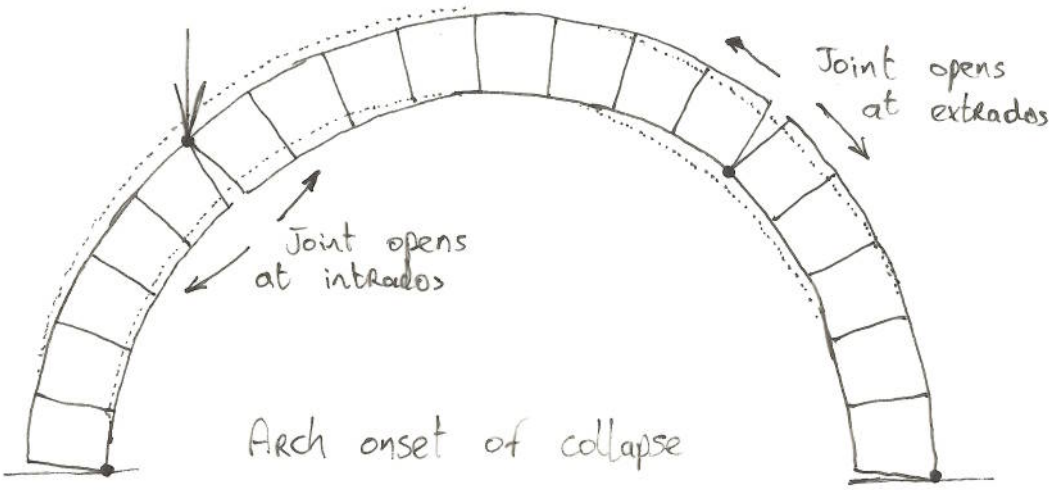








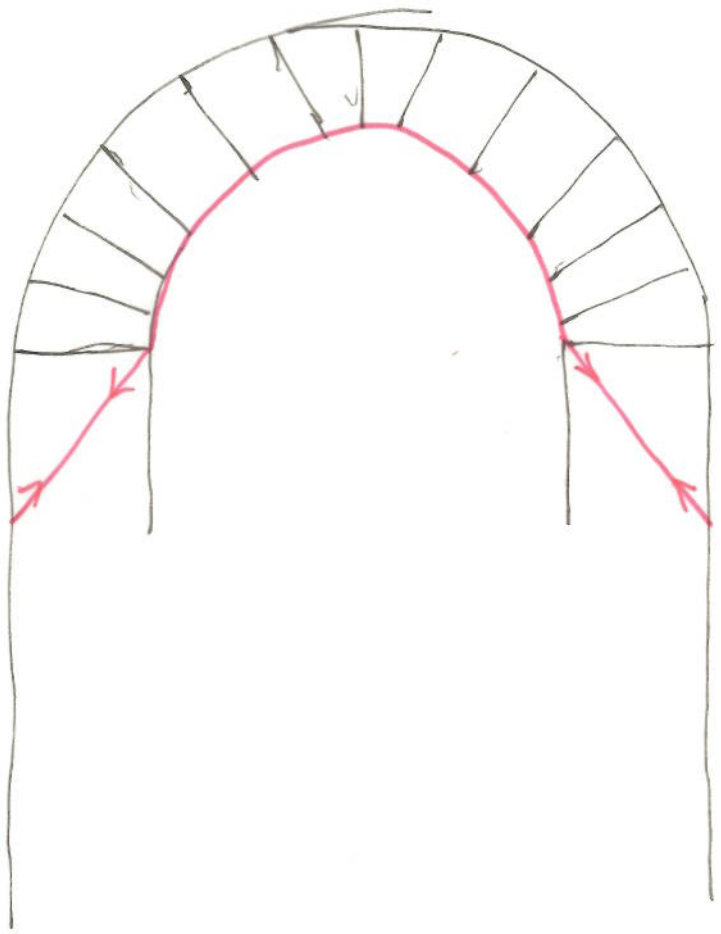
Arch Before Onset of Mechanism

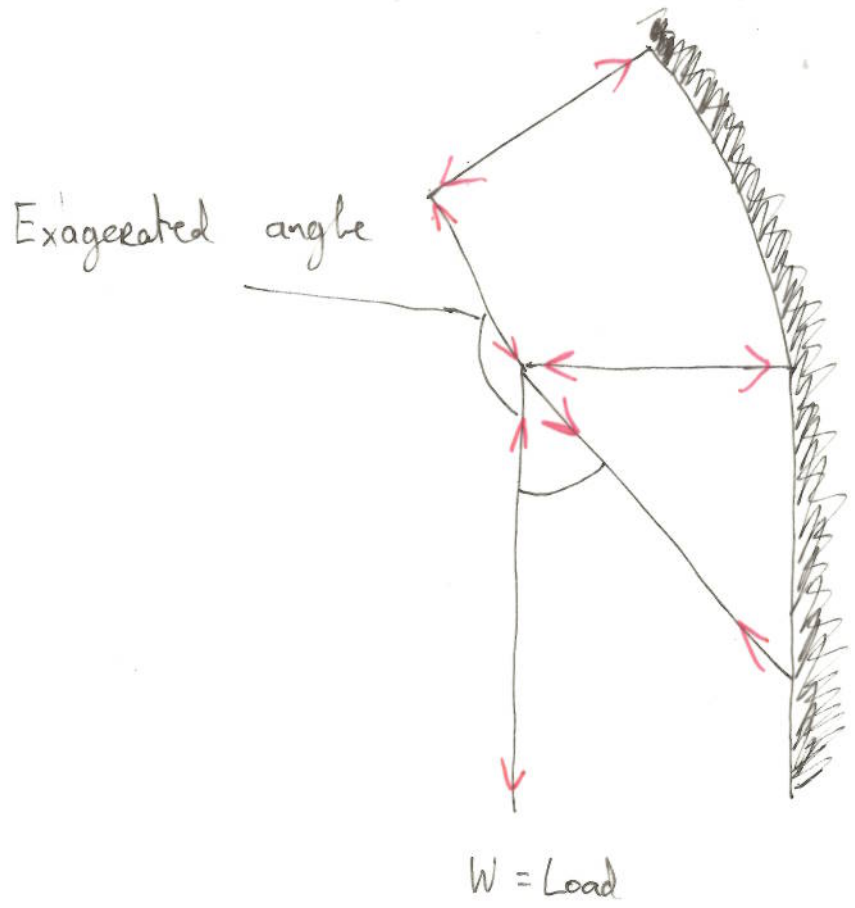


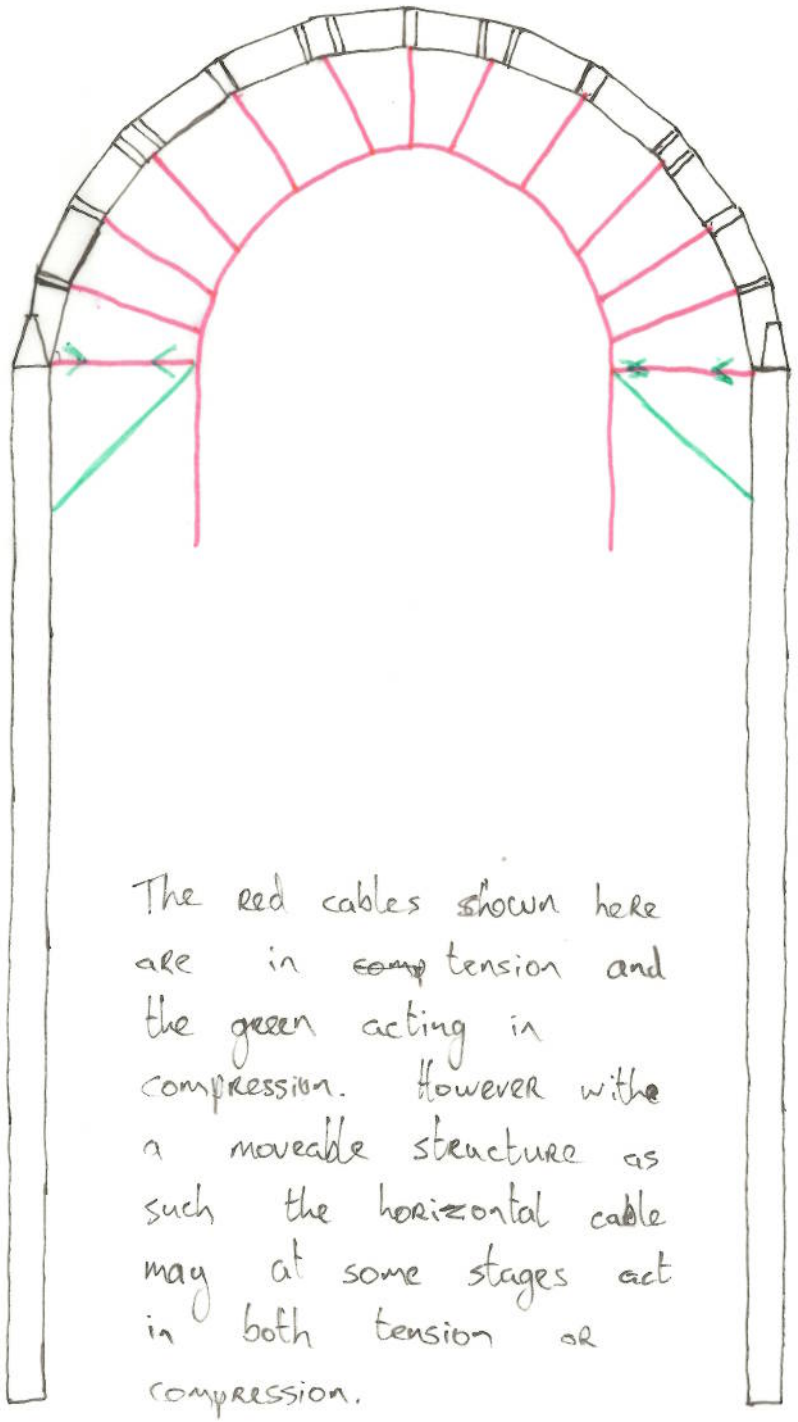
Arch onset of collapse

The top 3D image shows how the tension cables act with a downward force of wind, Rain or snow. Most of the cables are in tension with two bottom cables in compression.

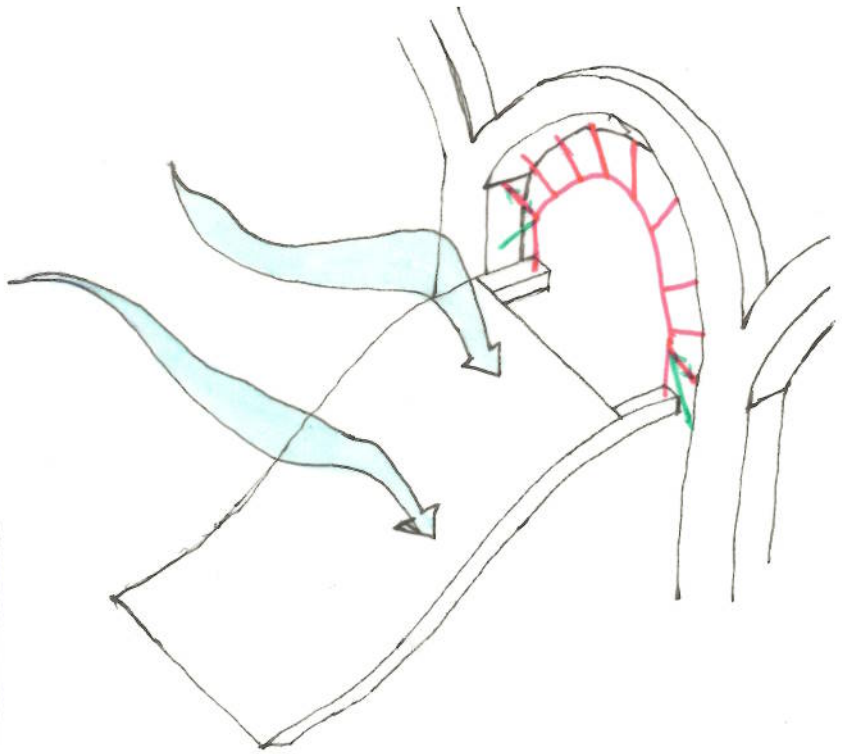
The bottom image shows the bottom cables along with the horizontals act as anchors to stop an upwind from ruining the structure.




Exaggerated angle
W = Load

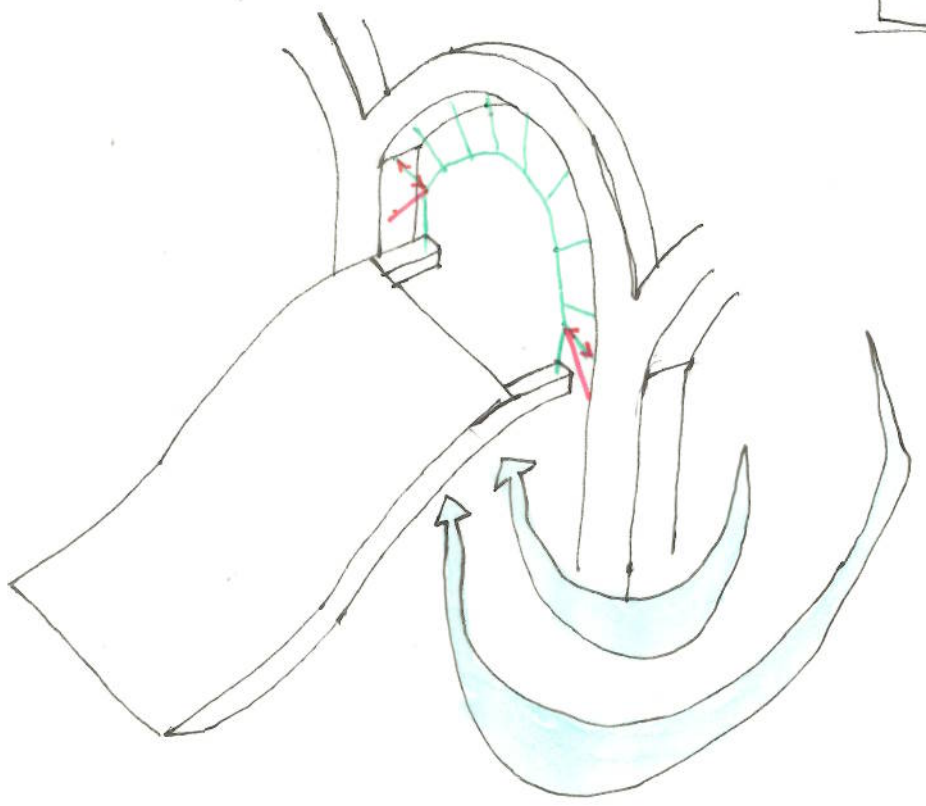


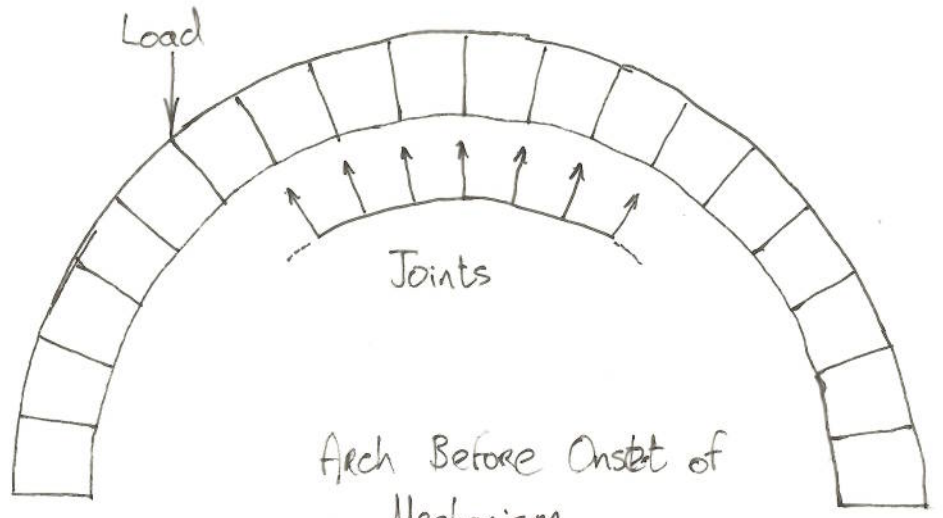
The red cables shown here are in ~~comp~~ tension and the green acting in compression. However with a moveable structure as such the horizontal cable may at some stages act in both tension or compression.



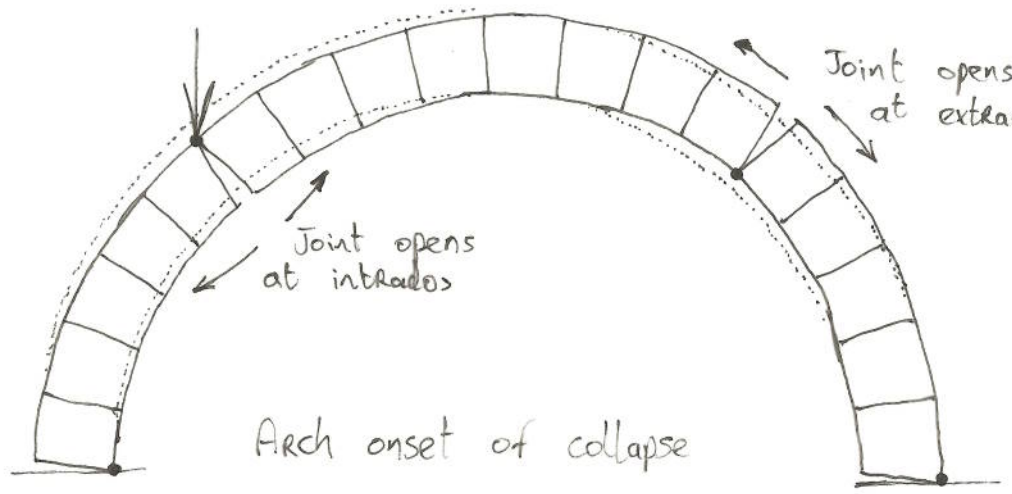
Wire in tension

Wire in Compression





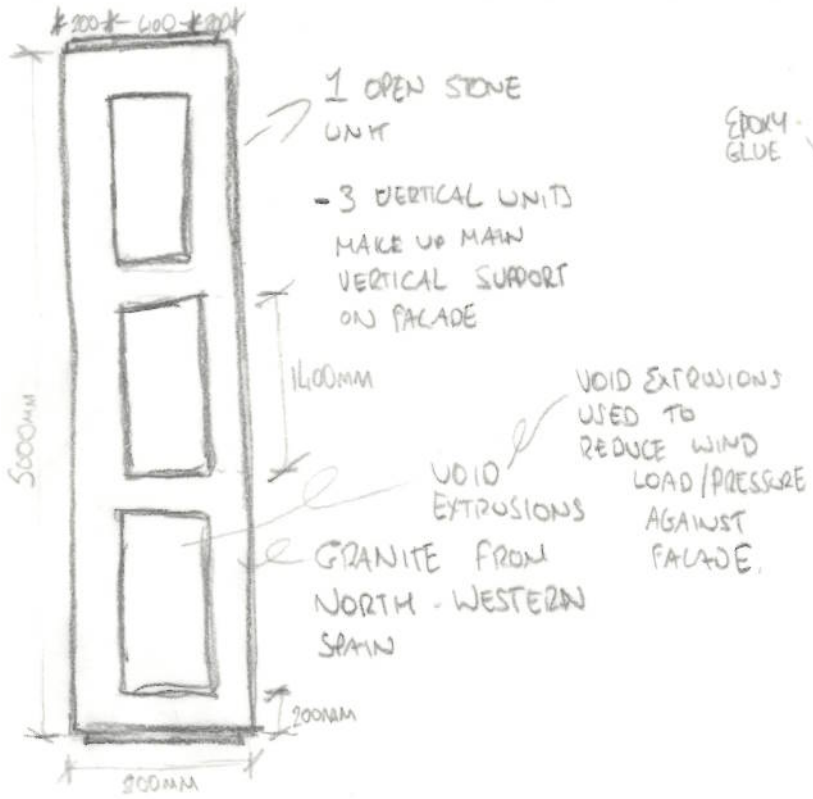
Arch Before Onset of Mechanism

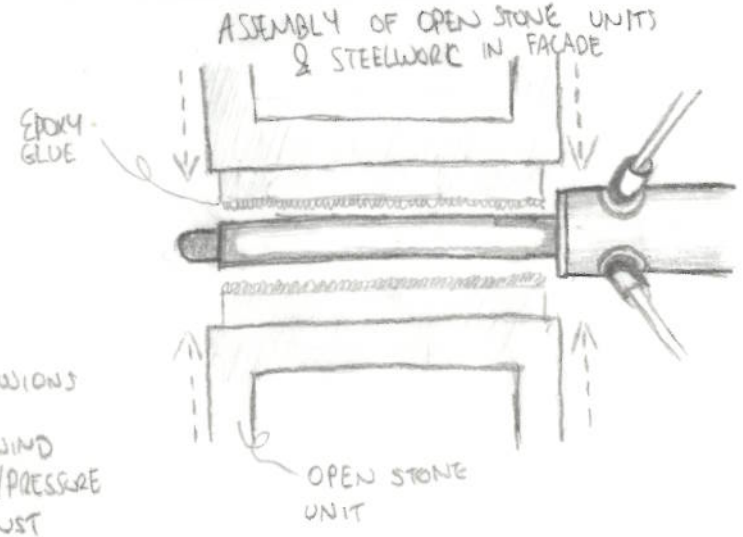


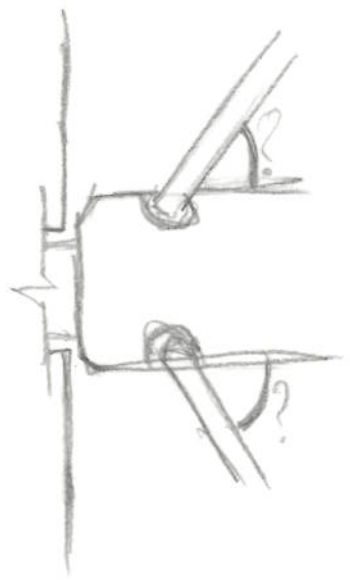
Arch onset of collapse

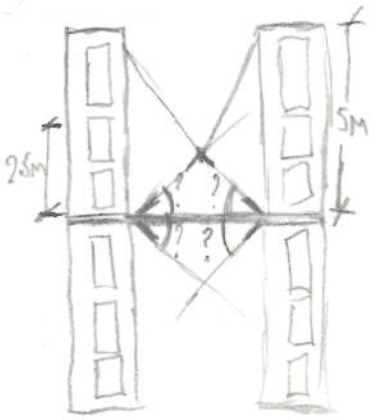
The top 3D image shows how the tension cables ~~at~~ act with a downward force of wind, Rain or snow. Most of the cables are in tension with two bottom cables in compression.

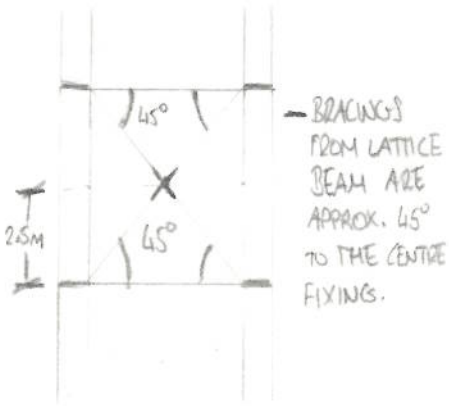
The bottom image shows the bottom cables along with the ~~ve~~ horizontals act as anchors to stop ~~&~~ an upwind from ruining the structure.

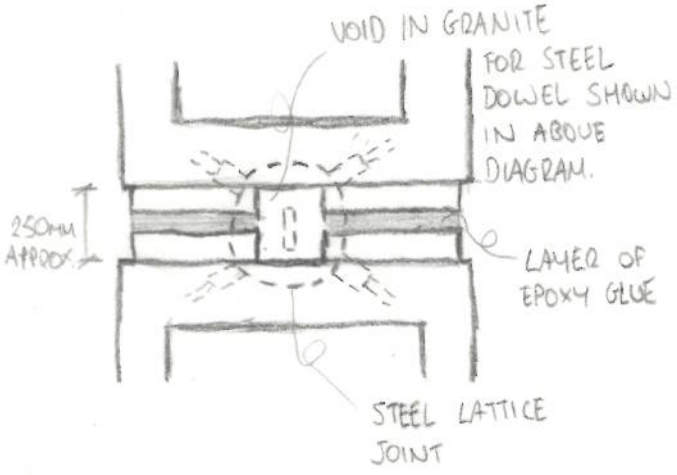

300
600
300
1 OPEN STONE UNIT
- 3 VERTICAL UNITS MAKE UP MAIN VERTICAL SUPPORT ON FACADE
1,600MM
5000MM
VOID EXTRUSIONS USED TO REDUCE WIND LOAD/PRESSURE AGAINST FACADE.
VOID EXTRUSIONS
GRANITE FROM NORTH-WESTERN SPAIN
300MM
900MM

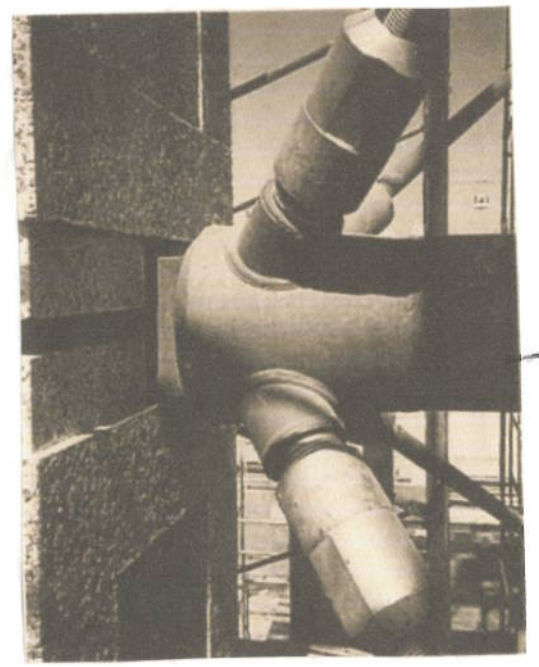

ASSEMBLY OF OPEN STONE UNITS & STEELWORK IN FACADE
EPOXY GLUE
OPEN STONE UNIT

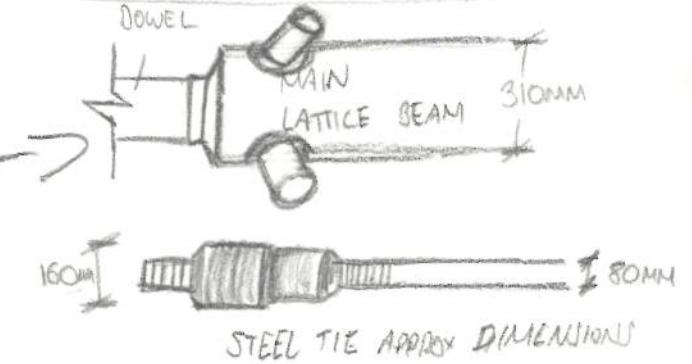


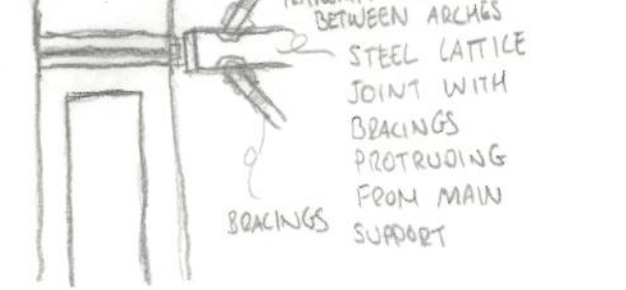

BRACING MEETS AT HALFWAY APPROX (NO EXACT FIG. FOUND)
- 5M HEIGHT OF OPEN STONEWORK
5M
2.5M

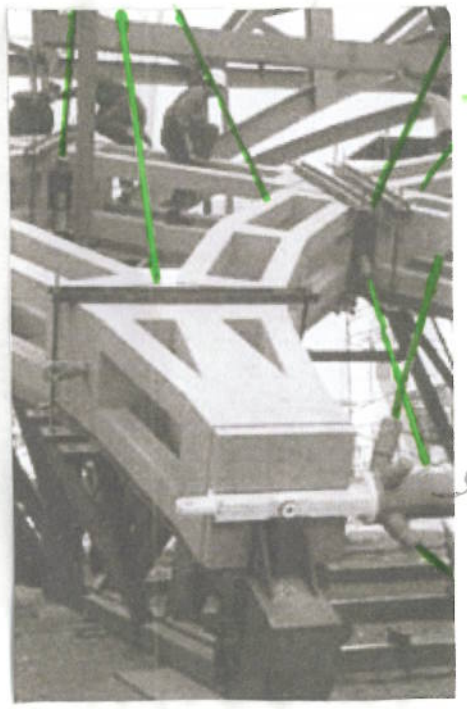

45°
45°
2.5M
- BRACINGS FROM LATTICE BEAM ARE APPROX. 45° TO THE CENTRE FIXINGS.


VOID IN GRANITE FOR STEEL DOWEL SHOWN IN ABOVE DIAGRAM.
250MM APPROX
LAYER OF EPOXY GLUE
STEEL LATTICE JOINT

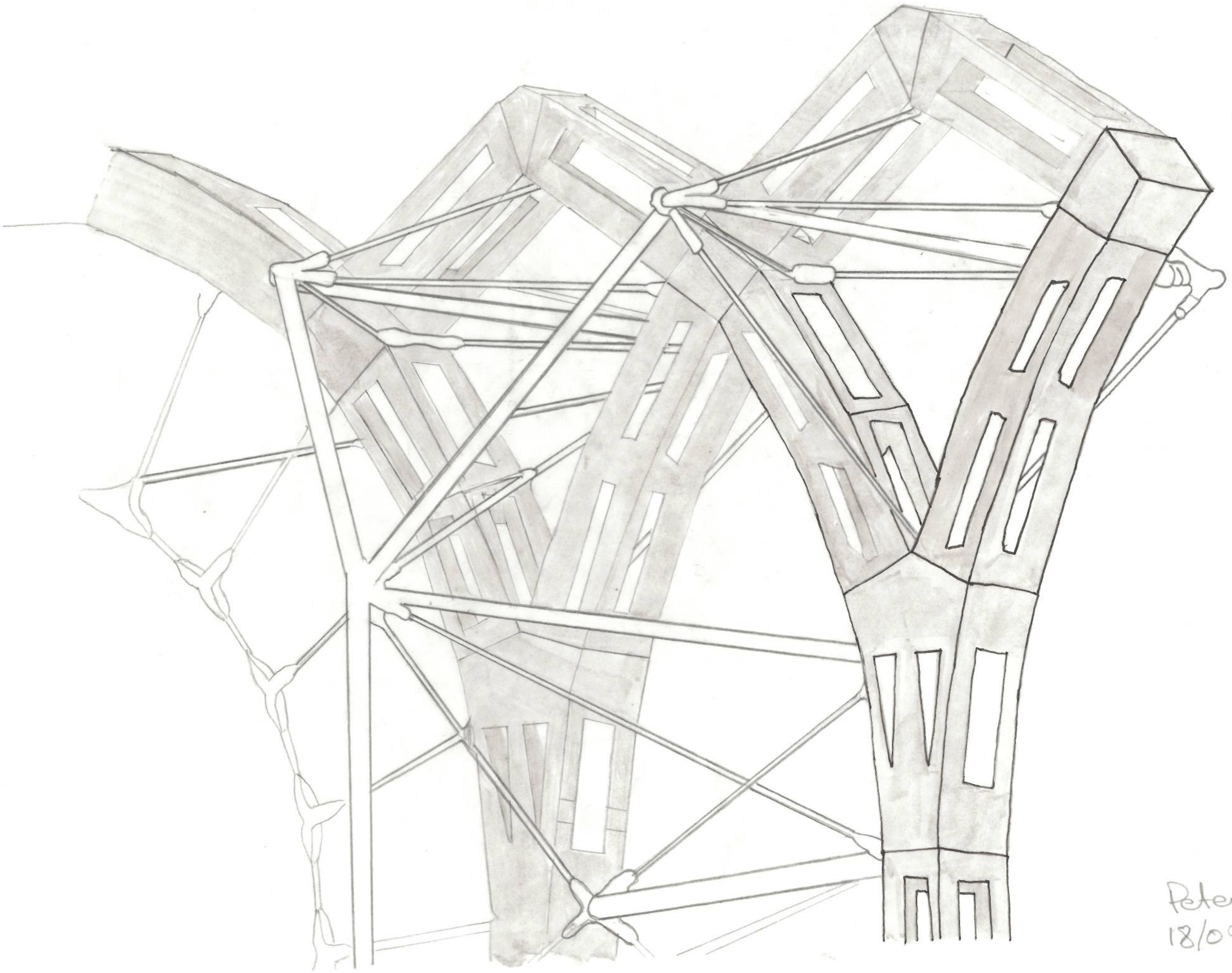



APPROXIMATE DIMENSIONS OF STEEL LATTICES & TIES
DOWEL
MAIN LATTICE BEAM
310MM
160MM
80MM
STEEL TIE APPROX DIMENSIONS

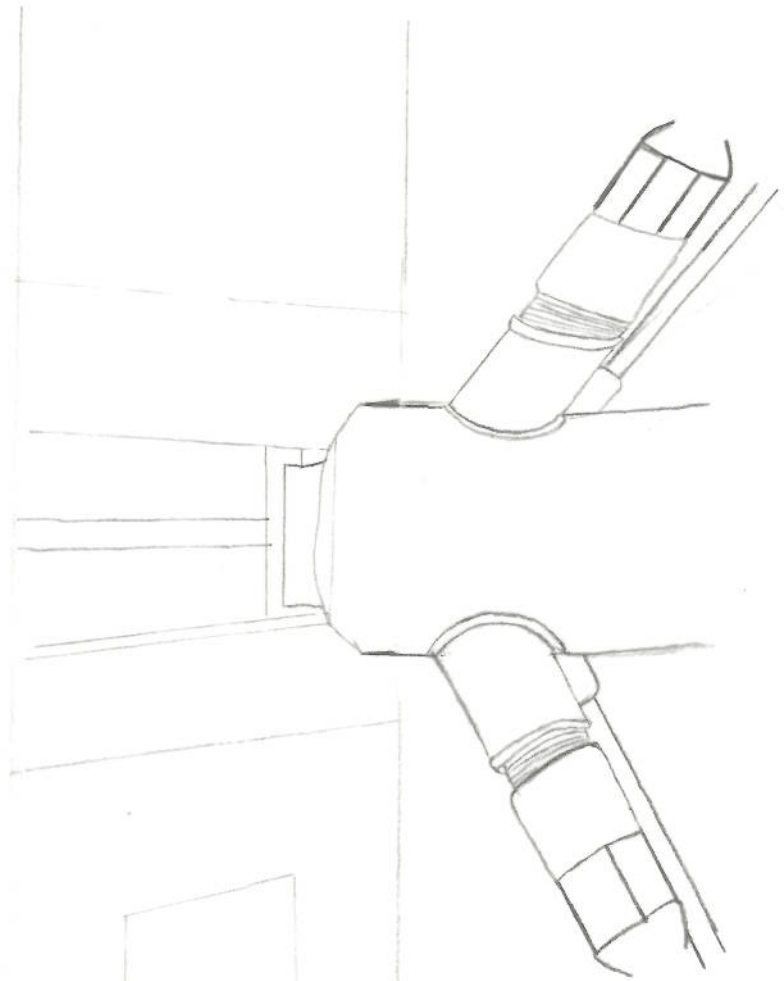

CONNECTION BETWEEN 2 UNITS:
- EPOXY GLUE & STEEL DOWELS
LATTICE JOINT
- STEEL DOWEL & SUPPORT BRACING
- EACH STEELWORK SUPPORT OCCURS AT EVERY CONNECTION POINT OF THE OPEN UNITS. (EVERY 5 METRES)

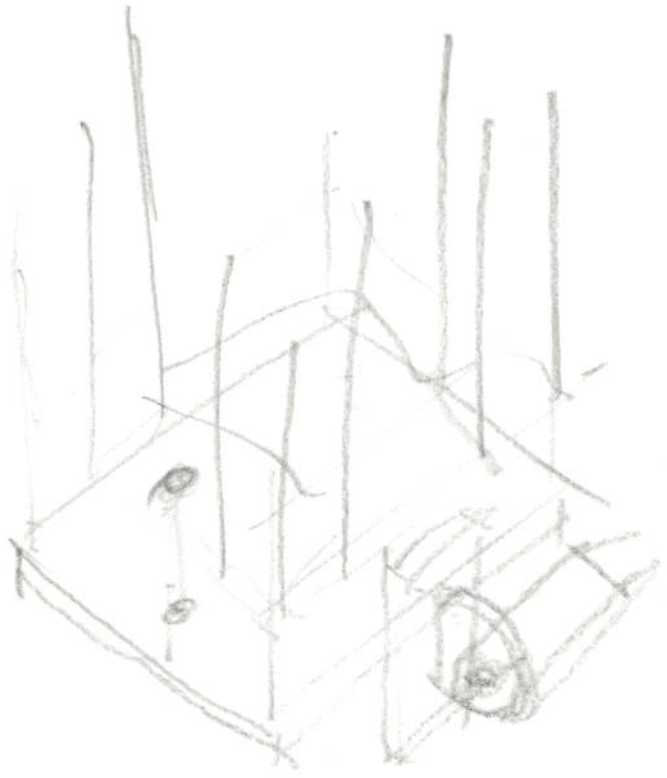

GREEN HIGHLIGHTER REPRESENTS THE STEEL BRACING. NOTE THAT THEY ARE FIXED ON TO STONE FACADE AND THEN CRANED AFTERWARDS.
IT IS VISIBLE IN THIS PICTURE TO SEE THE STAINLESS STEEL DOWEL USED TO SUPPORT THE LATERAL BEAM.

GRANITE UNIT TO CONNECT SINGLE VERTICAL UNIT TO PRODUCE ARCHWAY AND TO TRANSMIT VERTICAL LOADS BETWEEN ARCHES
STEEL LATTICE JOINT WITH BRACINGS PROTRUDING FROM MAIN SUPPORT
BRACINGS

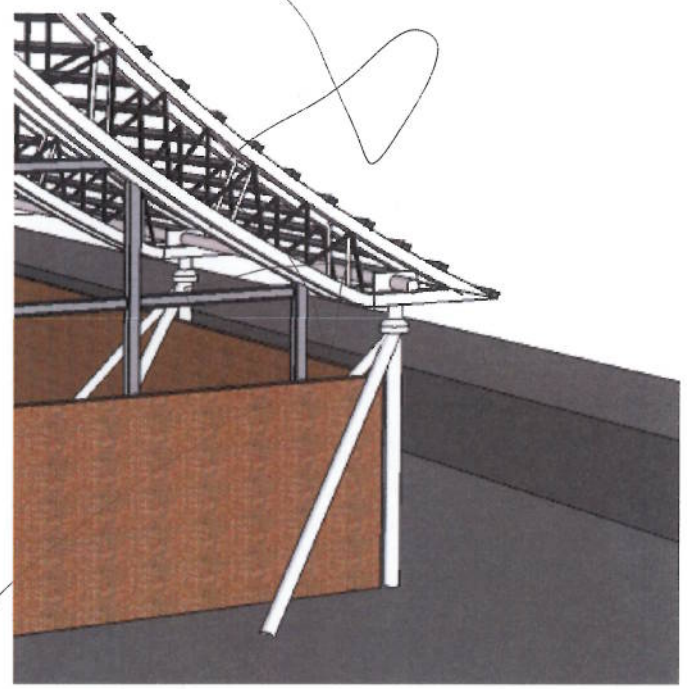


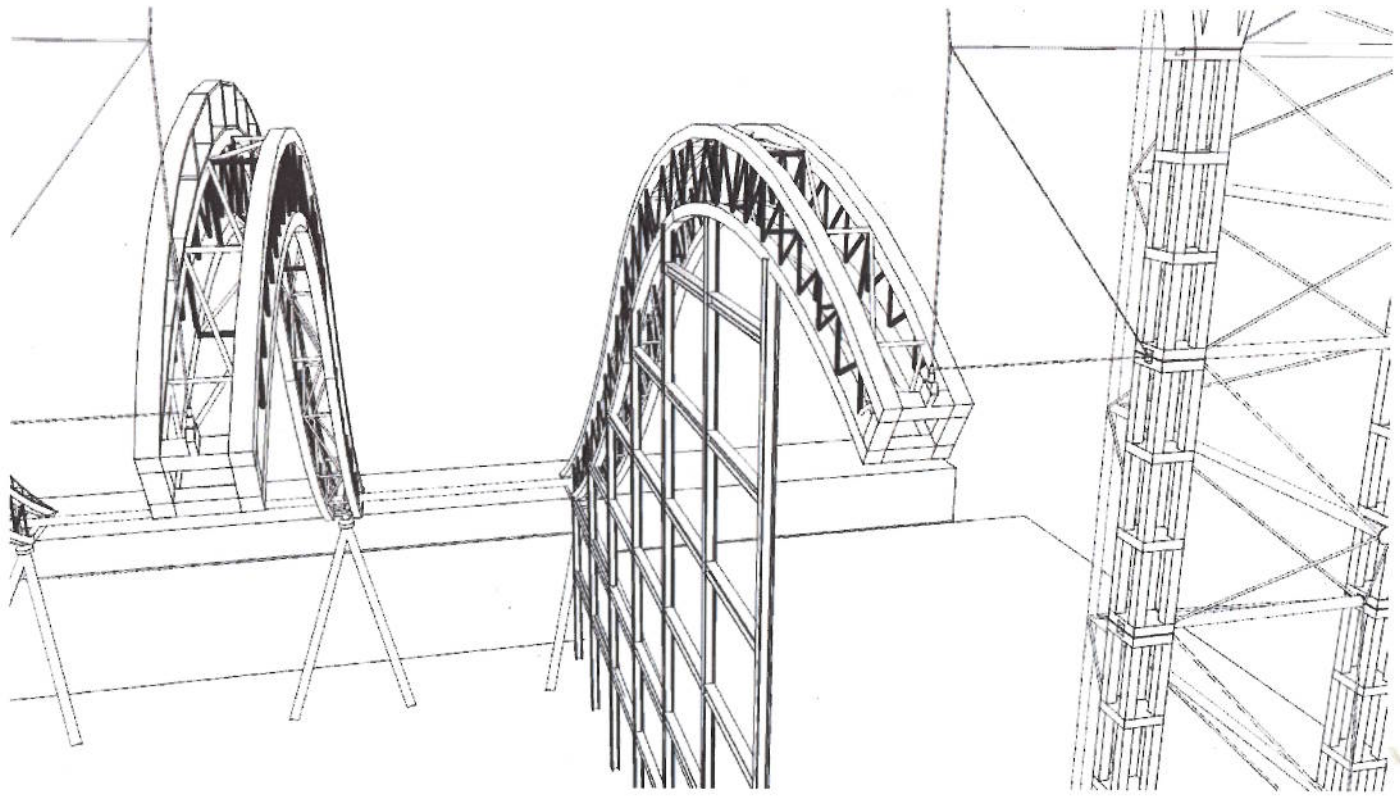
Peter leMasney
18/09/2013

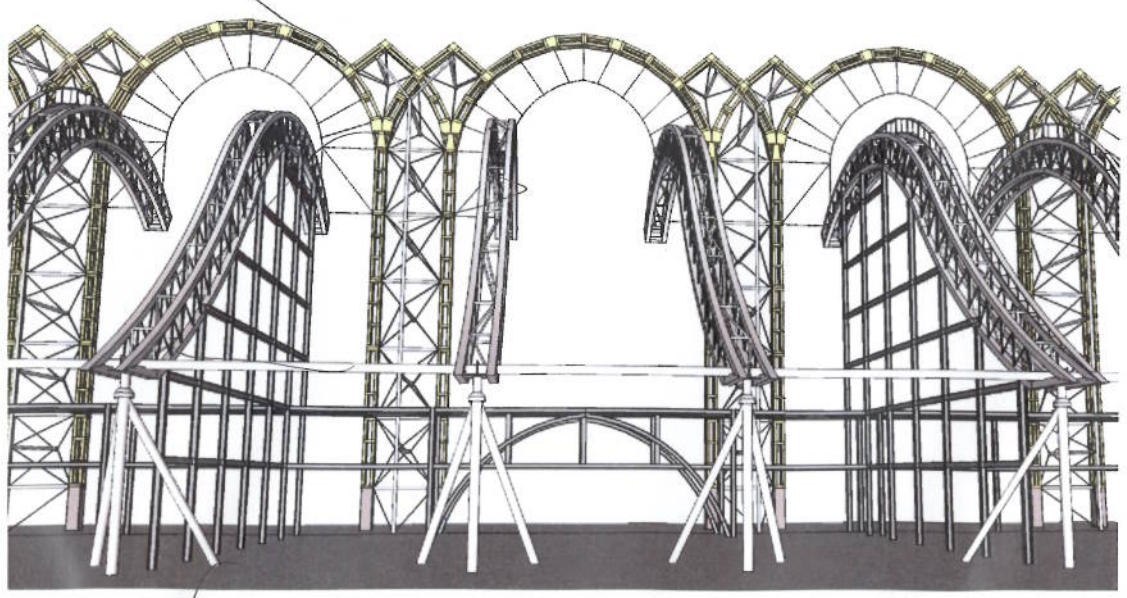


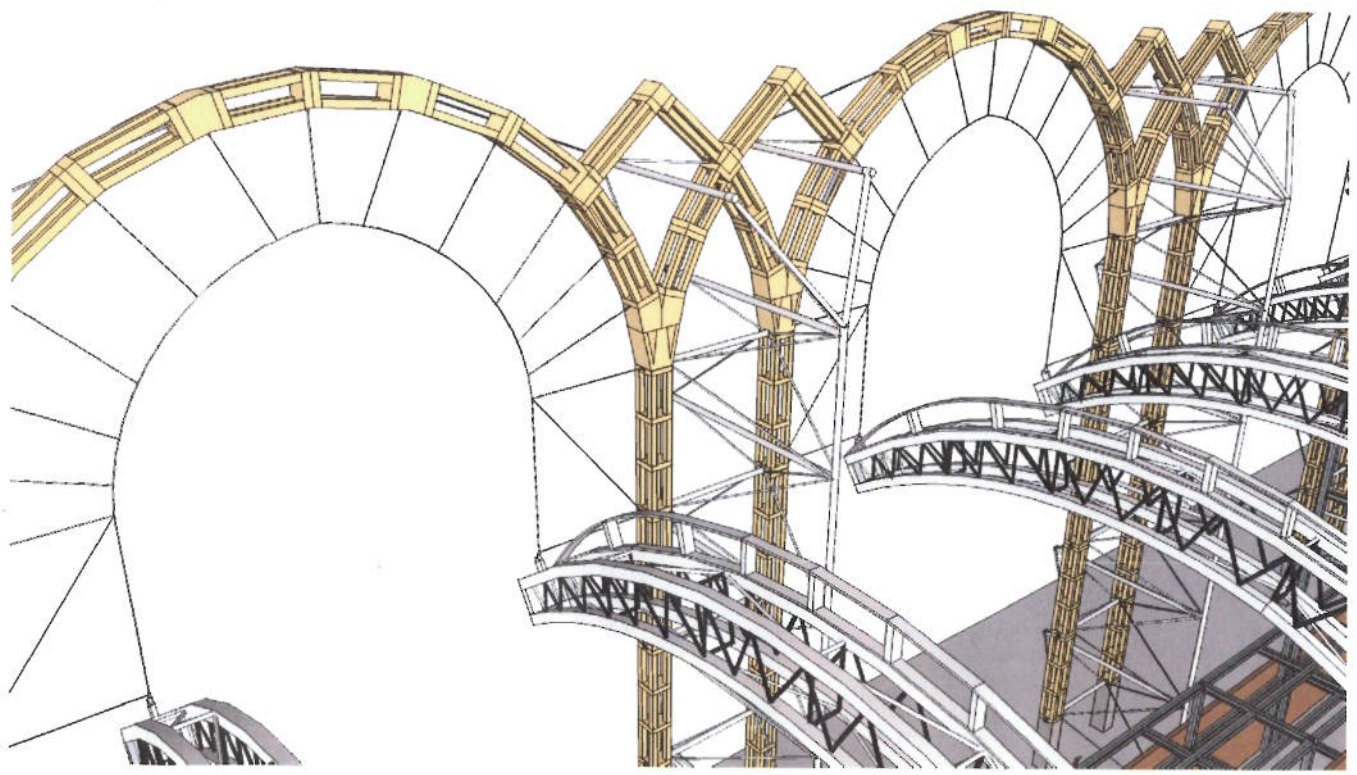


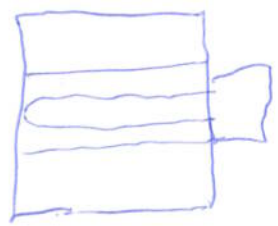
Peter LeMasney
24/09/13





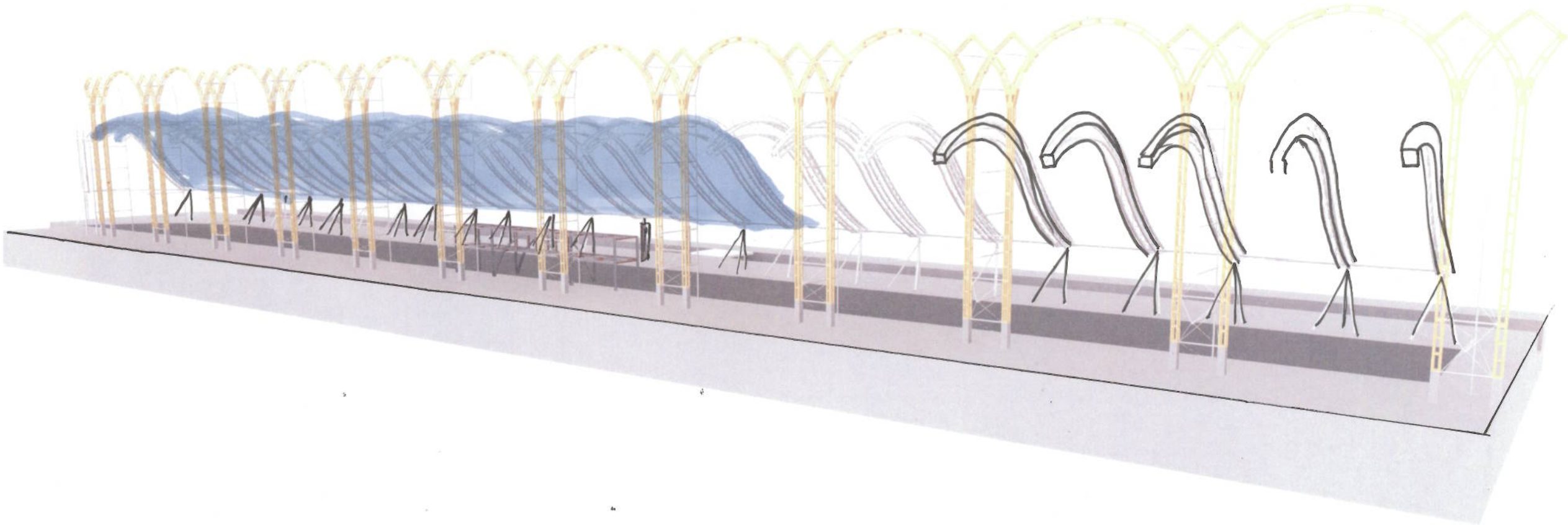


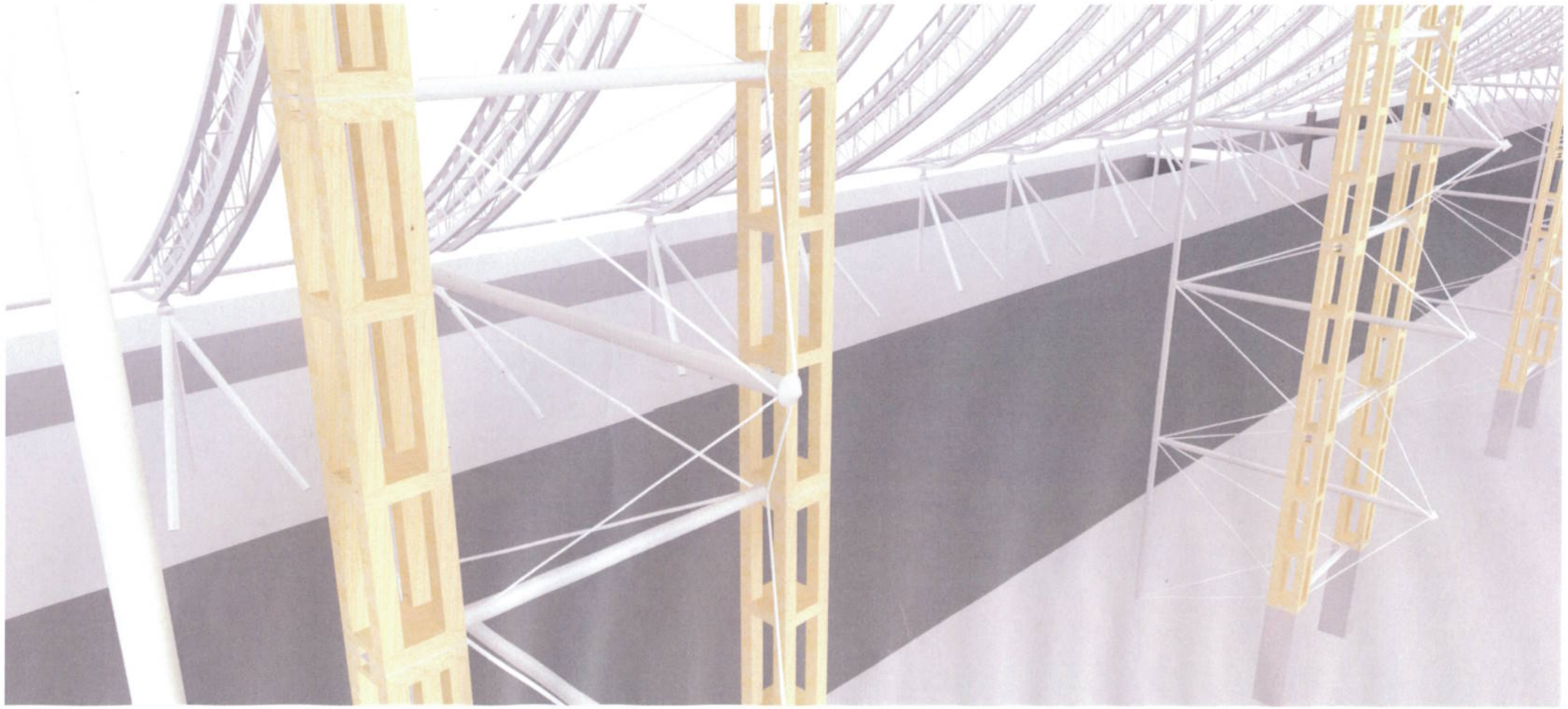




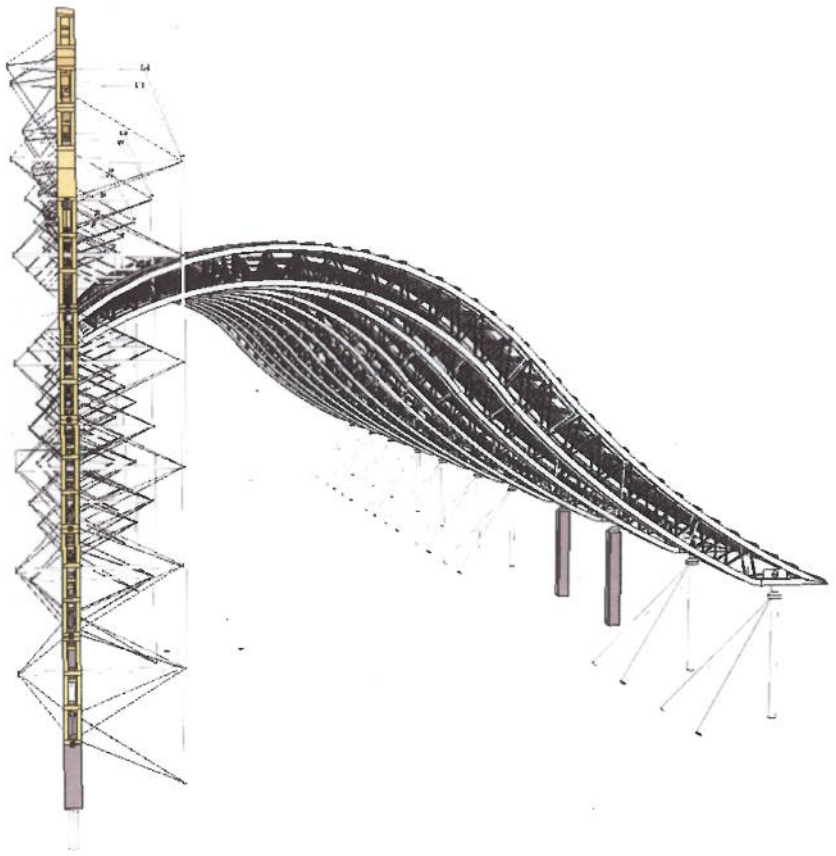
Sketch of Investigation 2

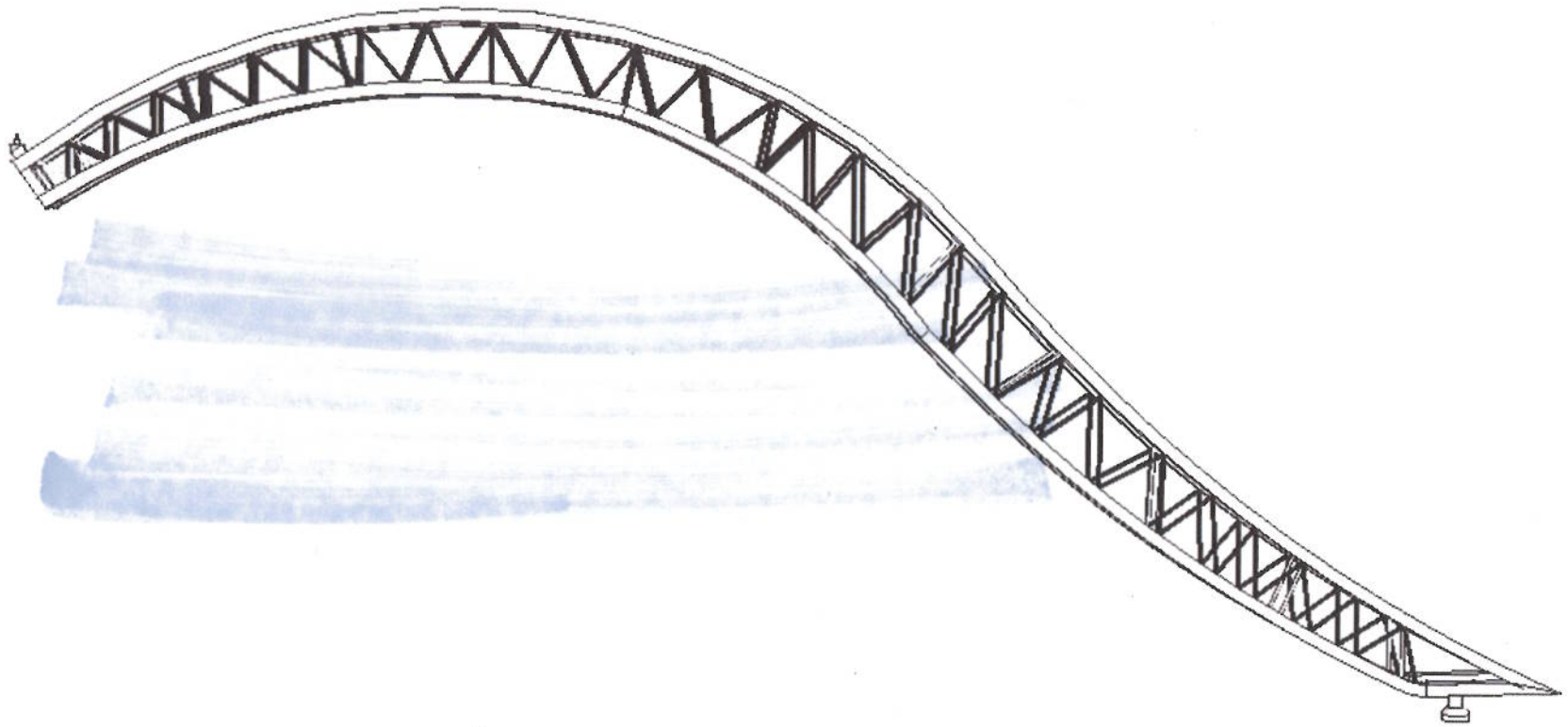
M. M

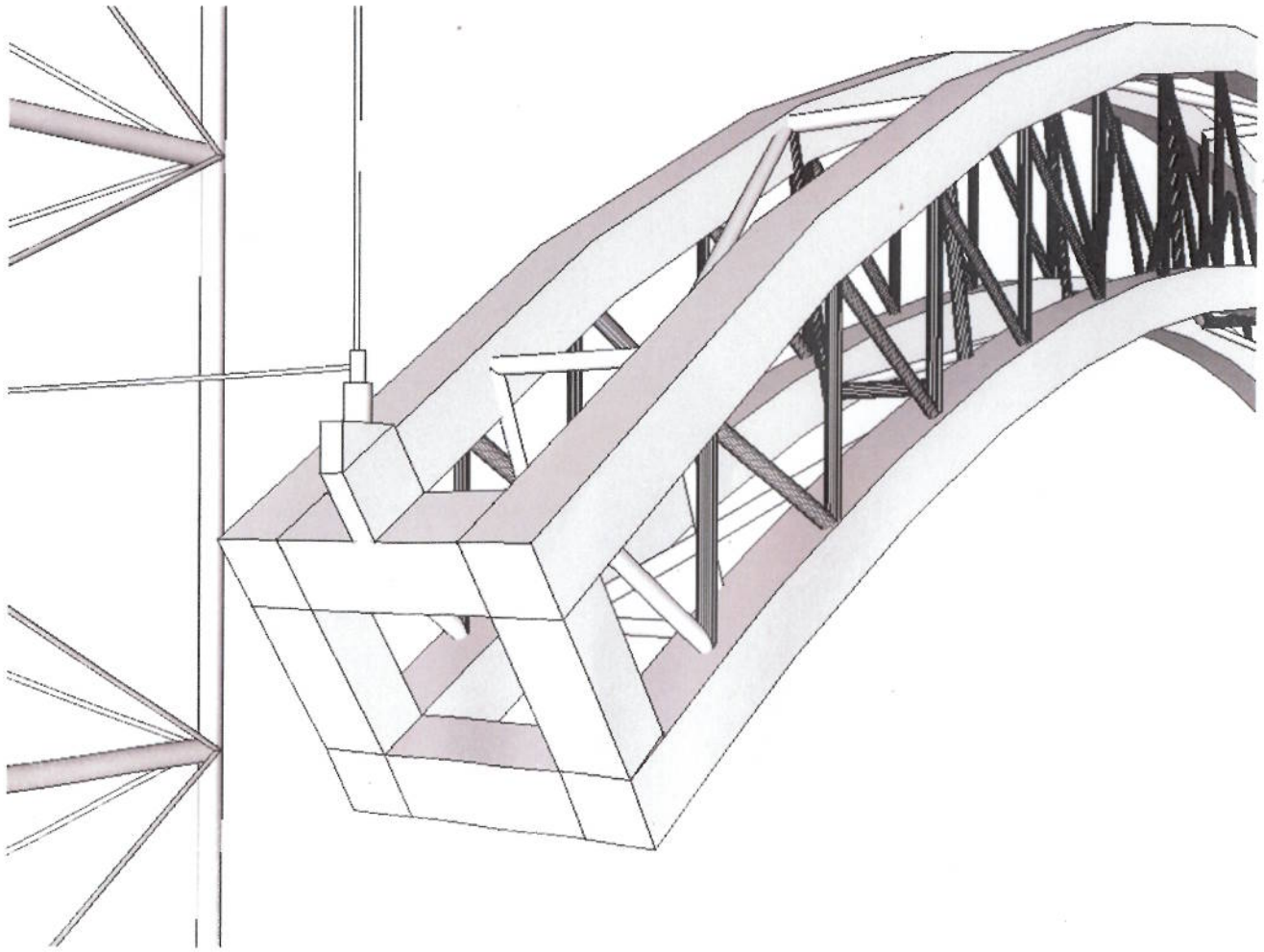


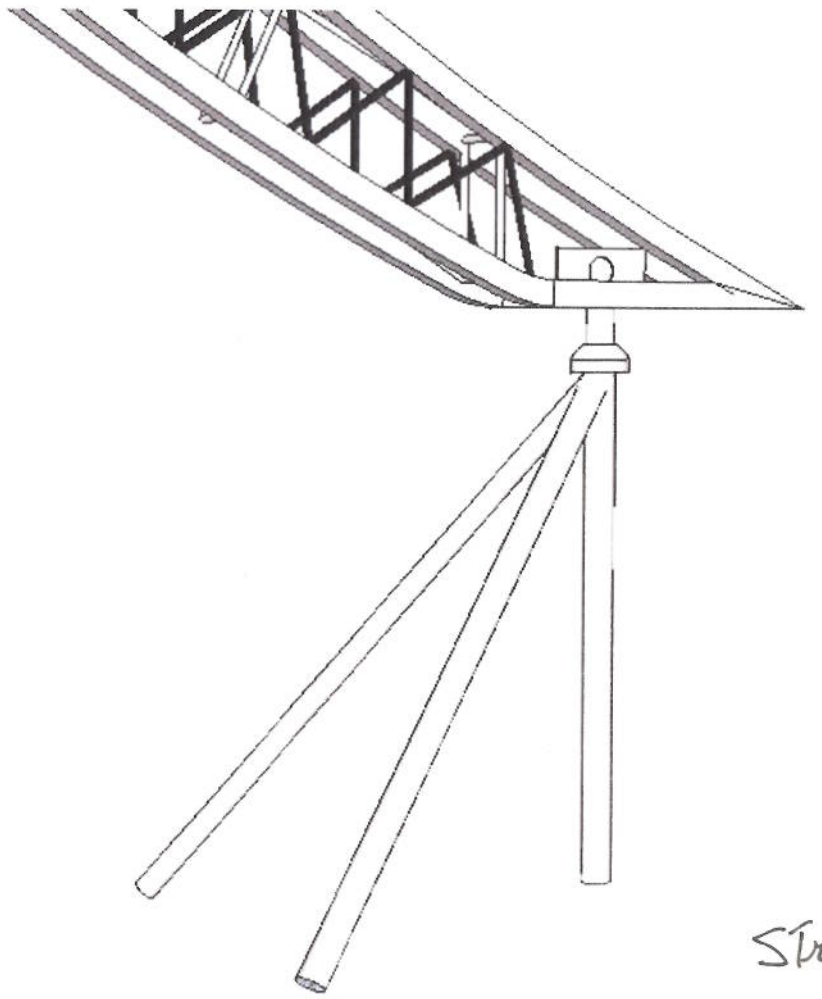


Sketches Investigation 3
M.M



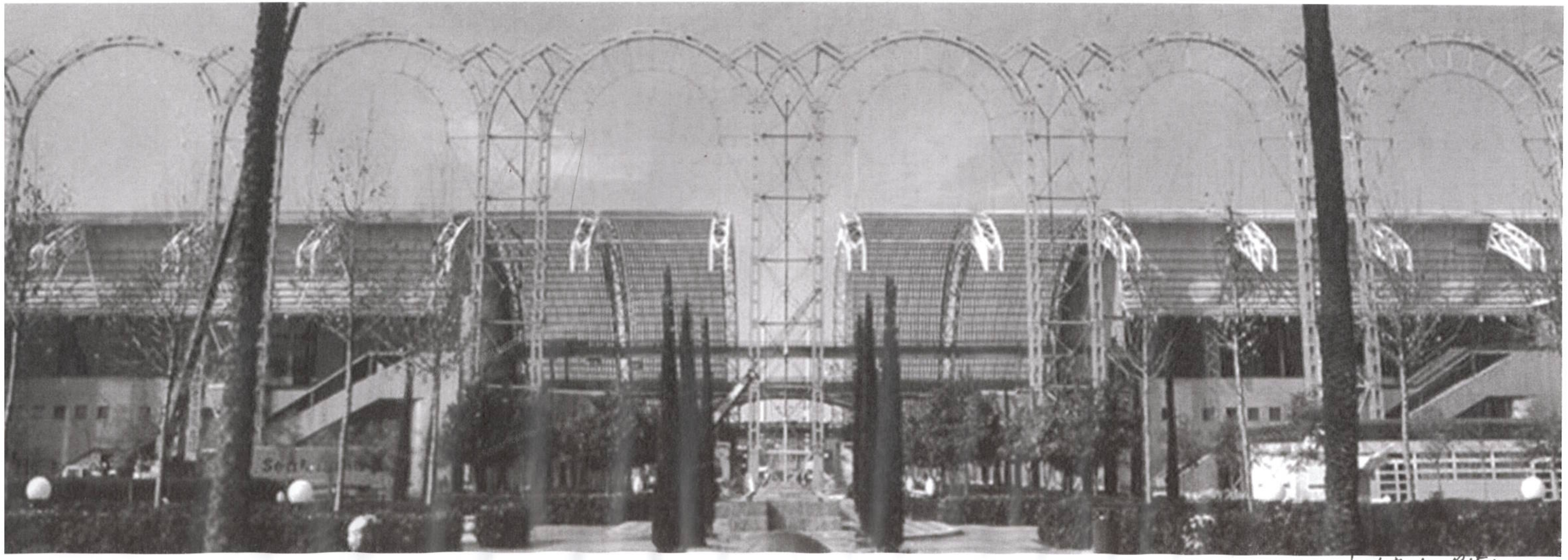




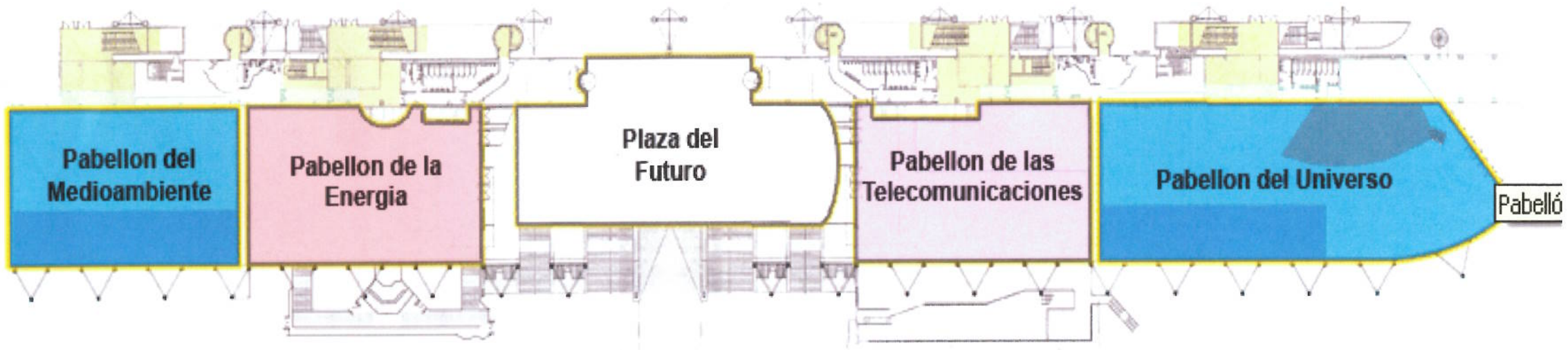


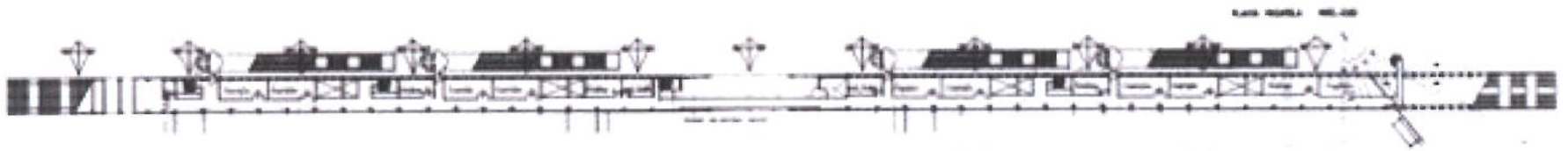
Structural Investigation 4

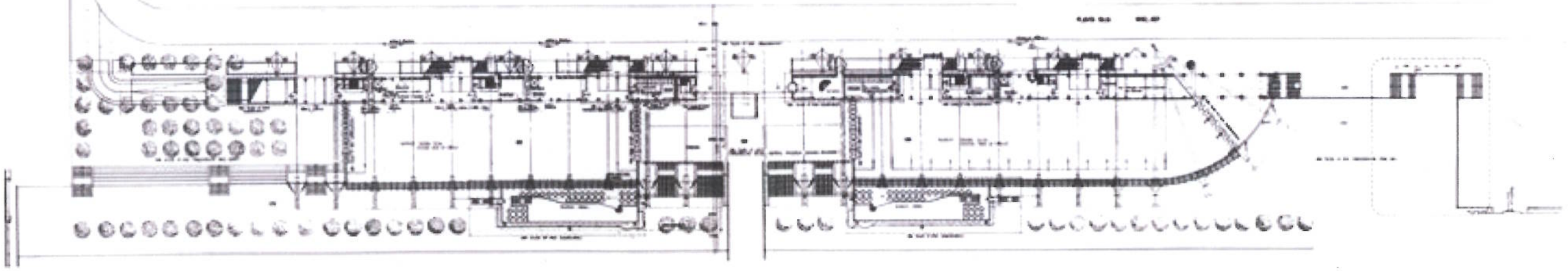
ם

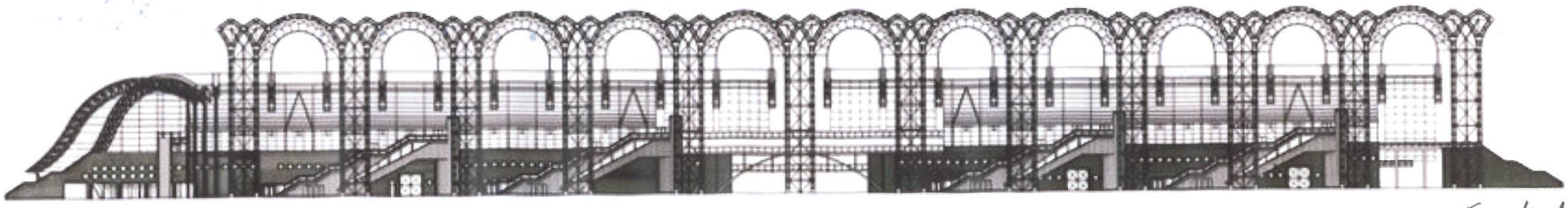


Investigate . Picture







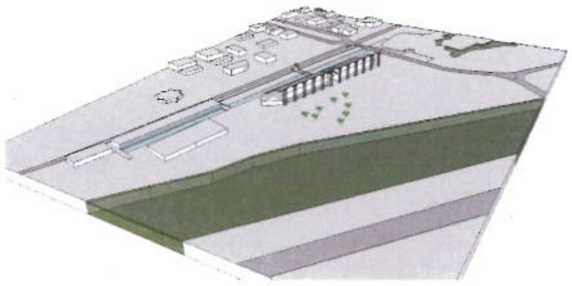


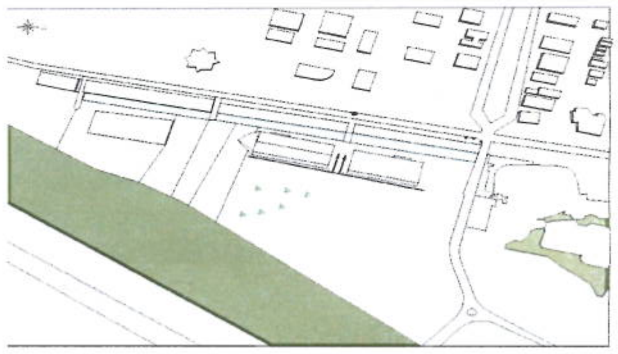
Investigation Pictures

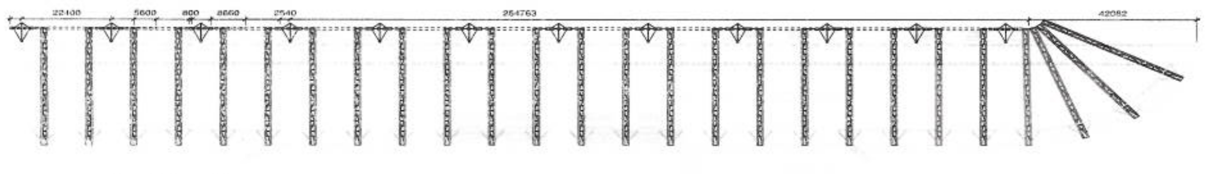
30-4-2013

PABELLON DEL FUTURO

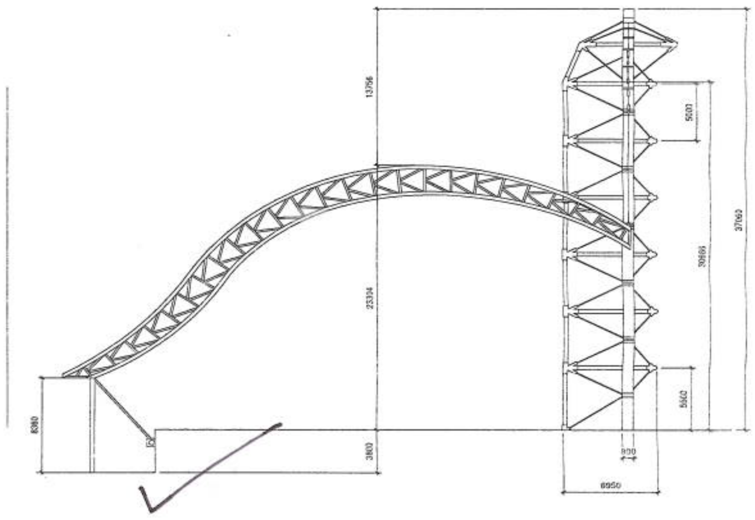
MBM & PETER RICE 1992

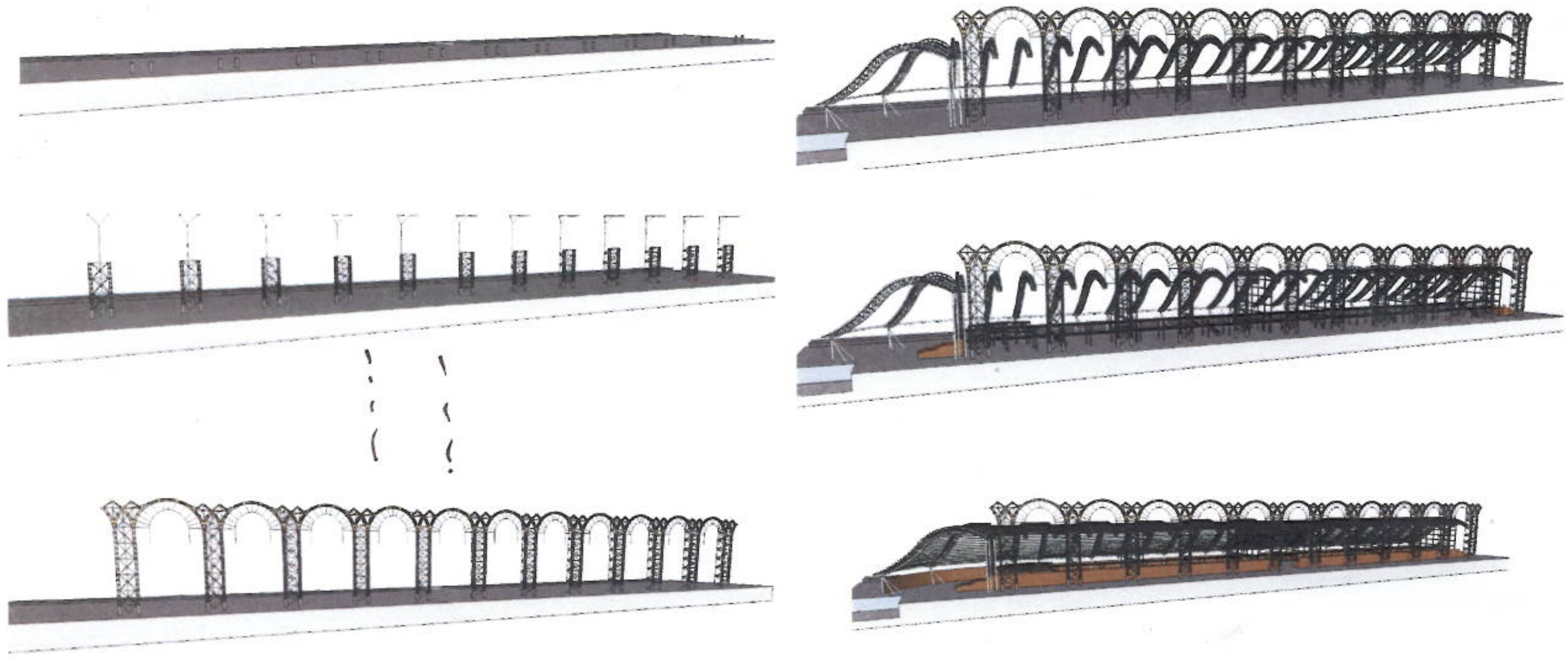




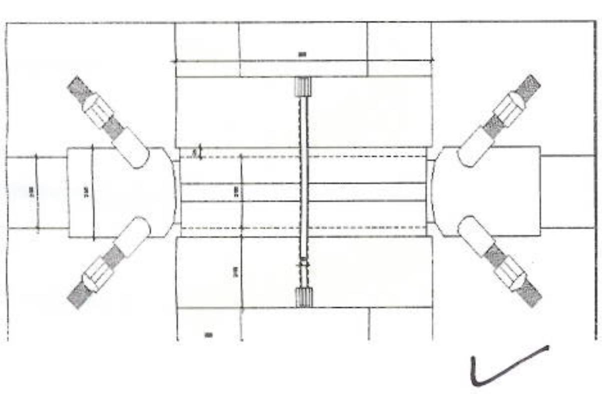


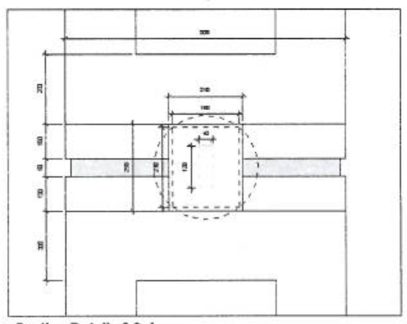
Drafting 1
1 : 750



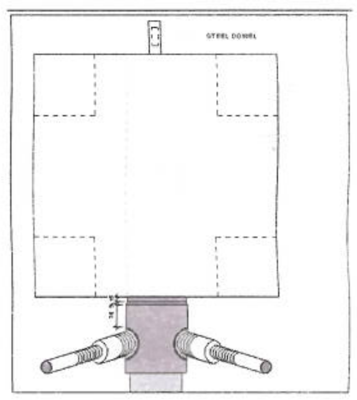


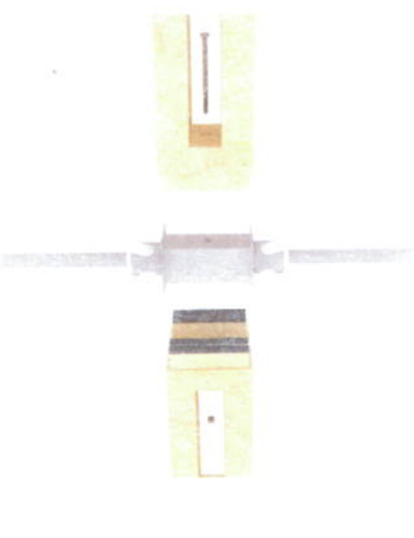
General text should be Arial font 14 justified. General text should be Arial font 14 justified.





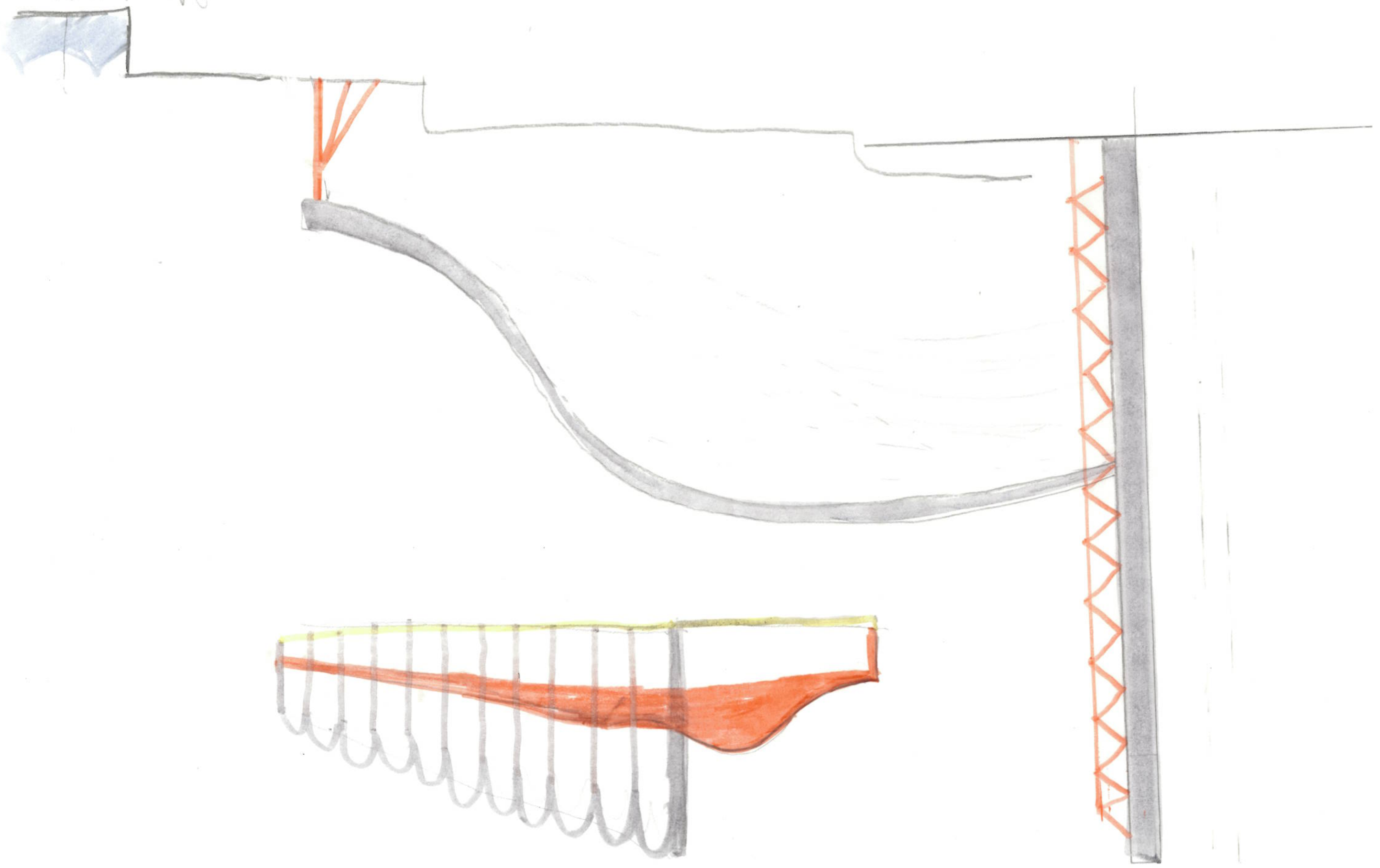
Section Detail of Column

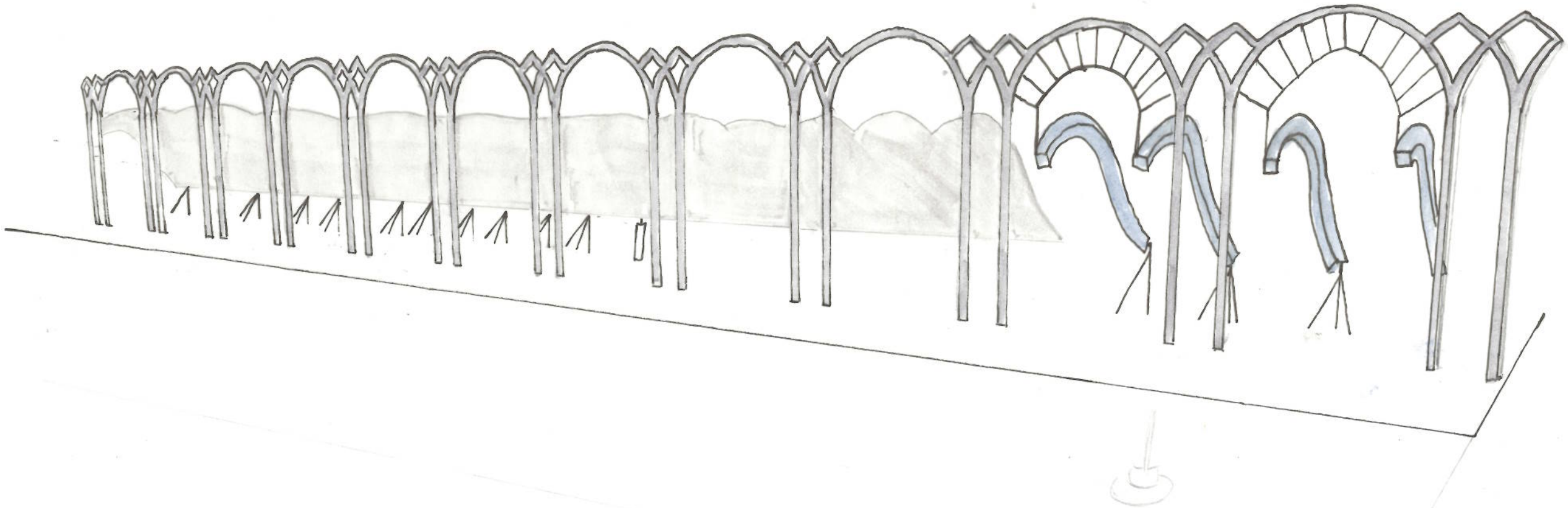


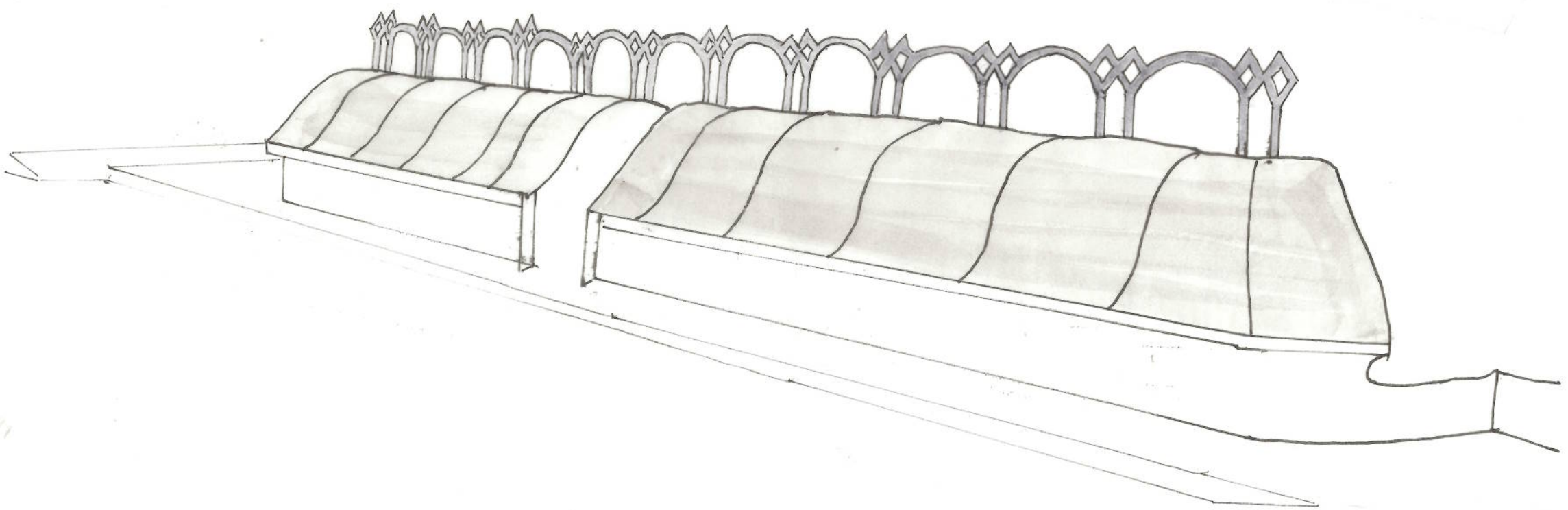


Page Proposal 1

Peter Heasley
24/04/2013

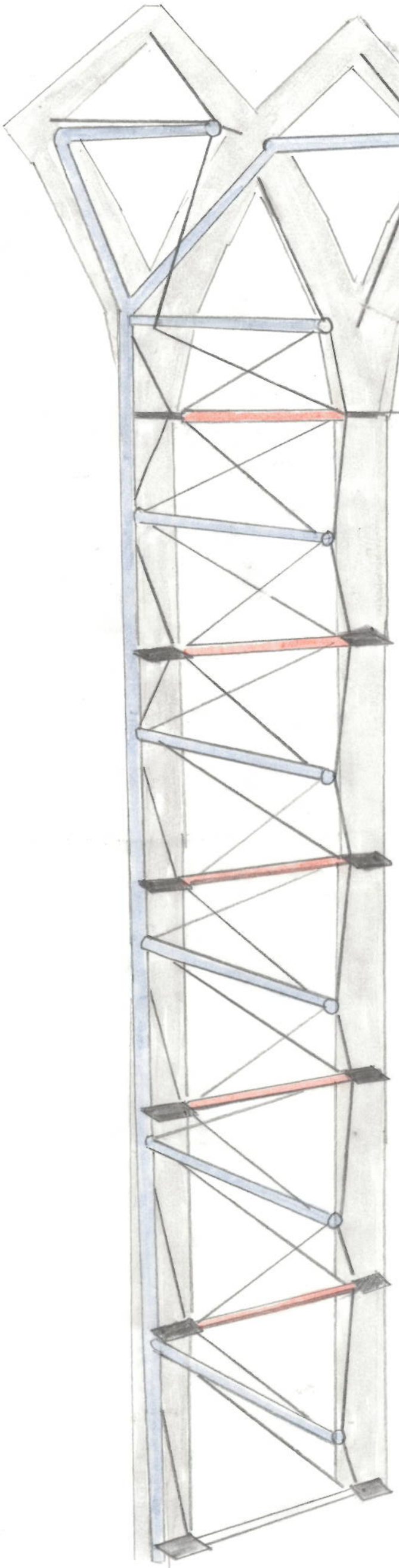


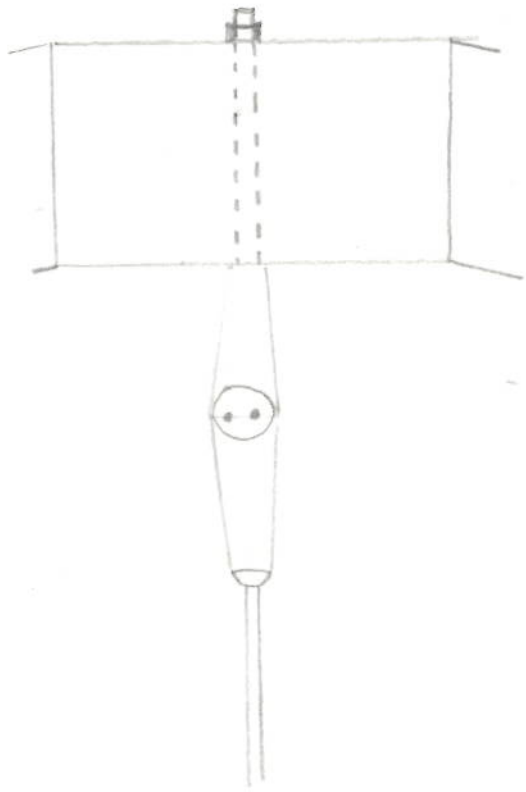


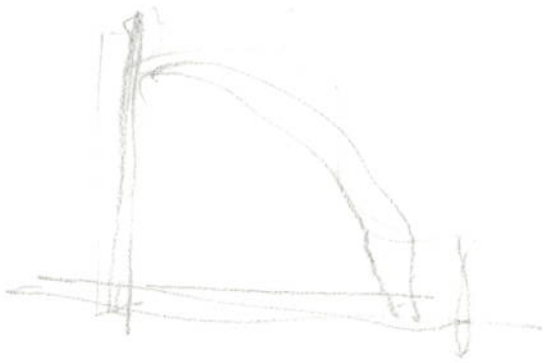


Peter LeMasney

29/09/13

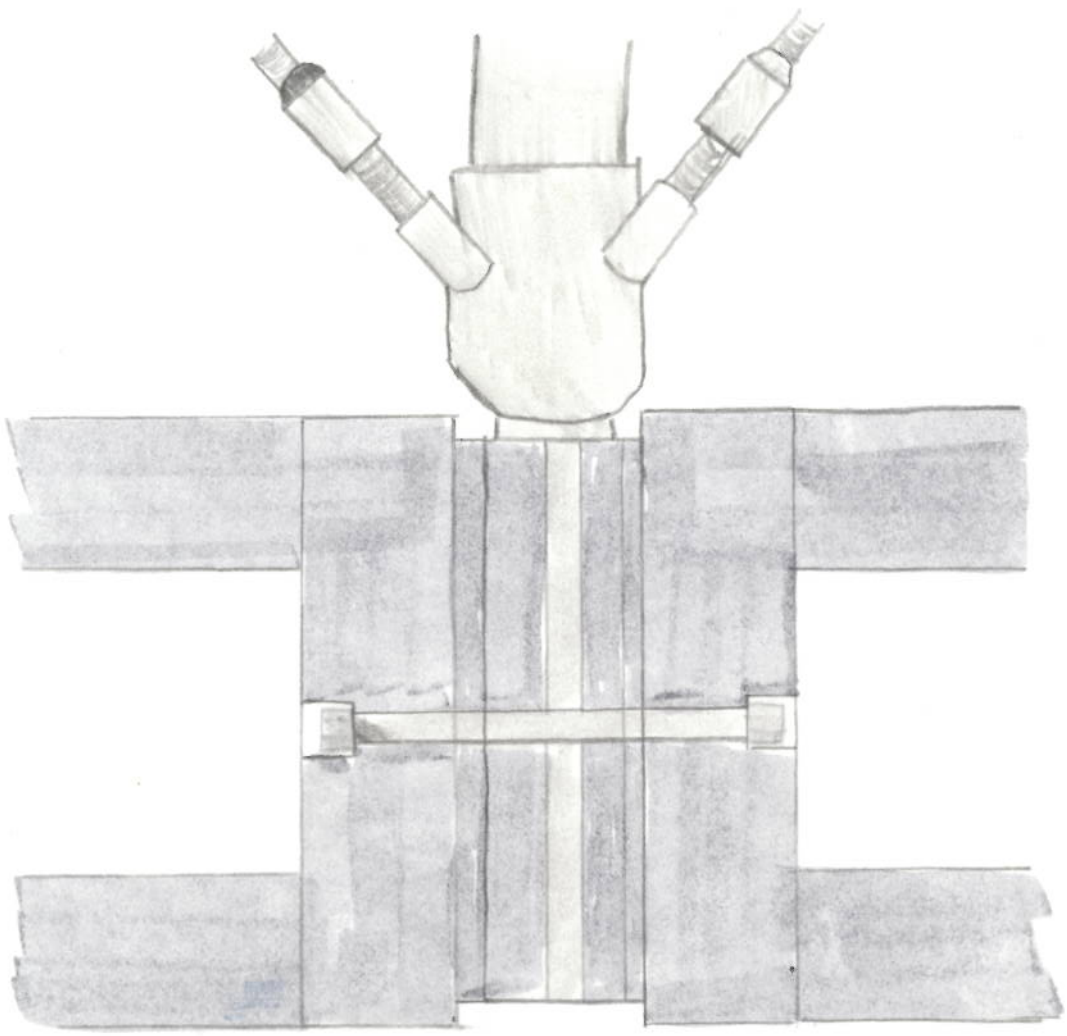


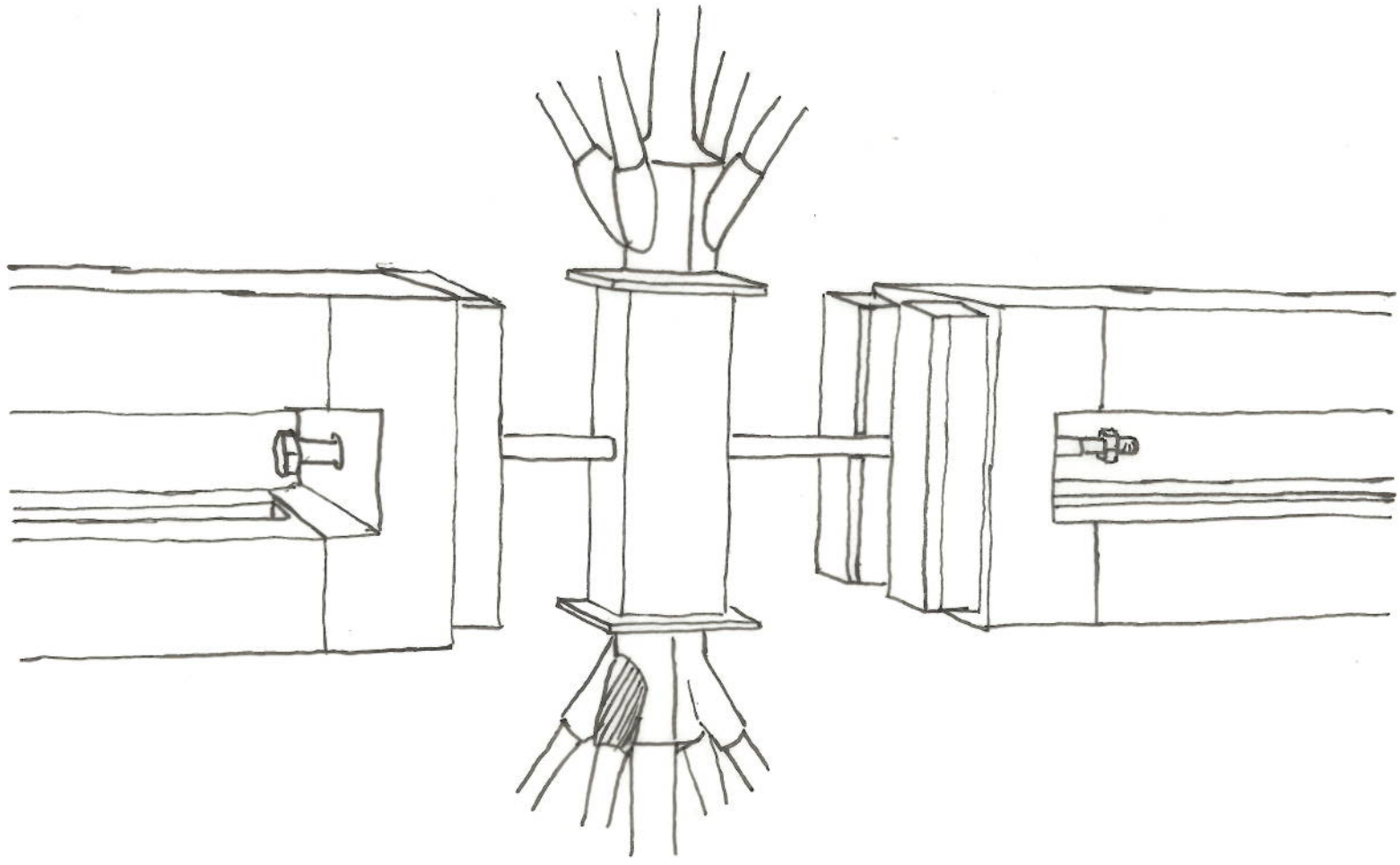


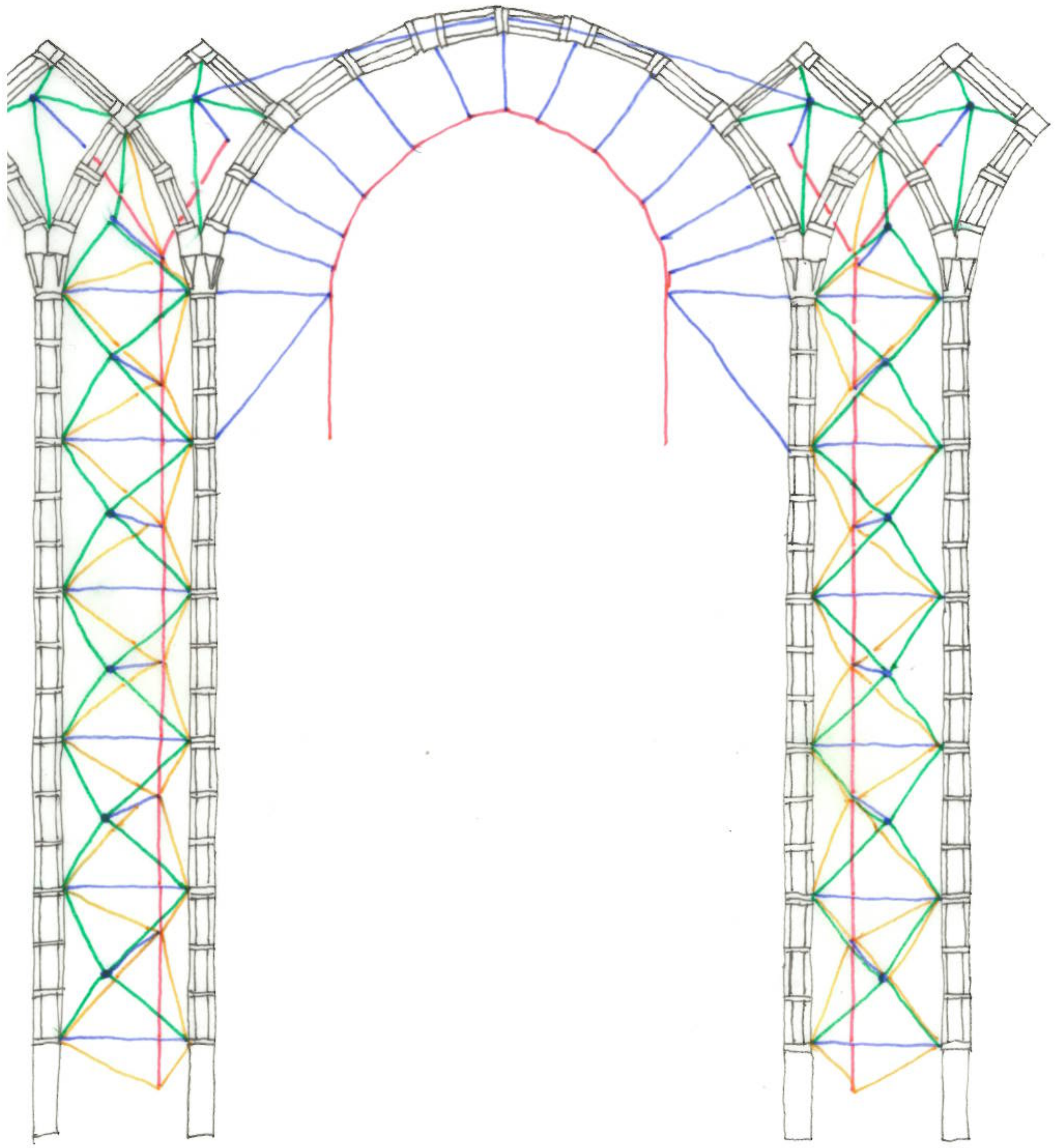


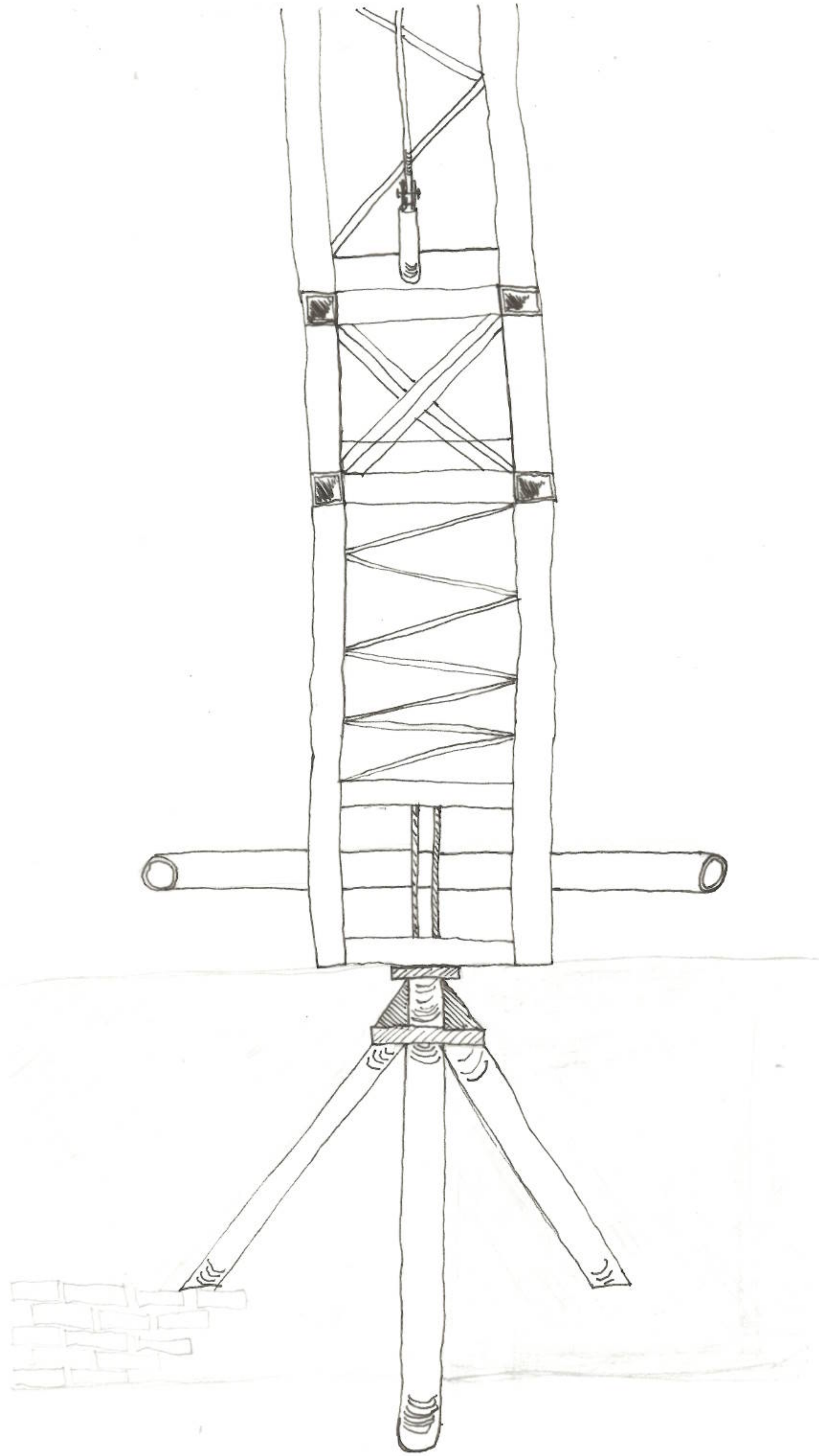
Peter

Peter McKay
01/10/2013

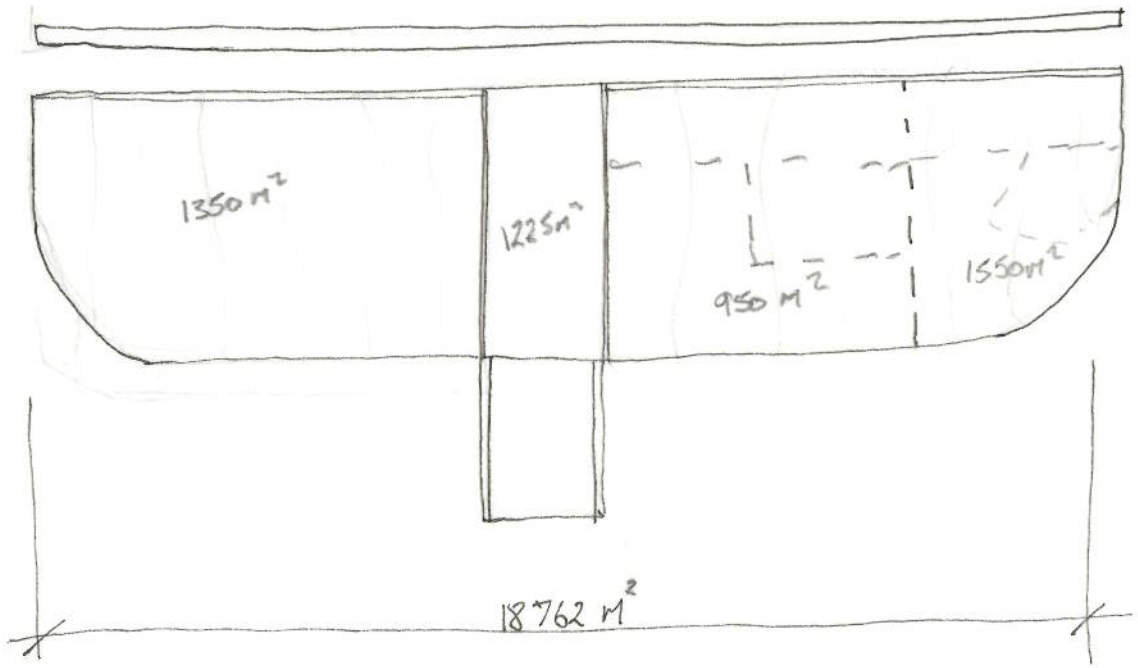




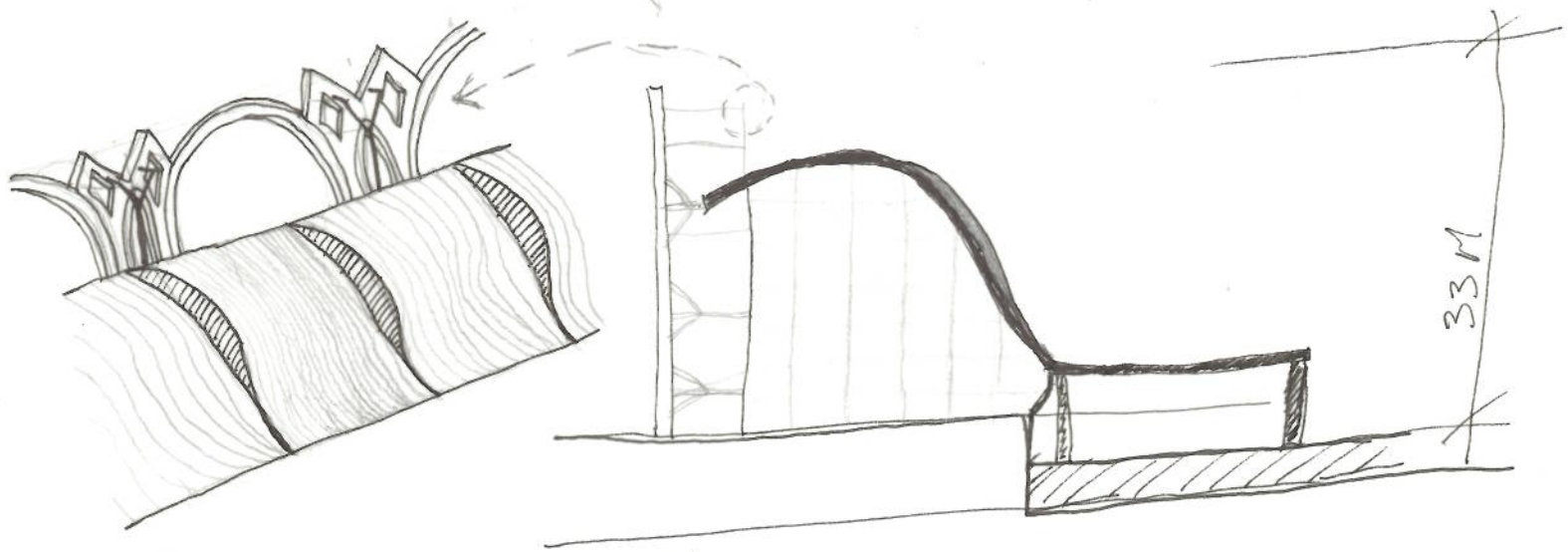




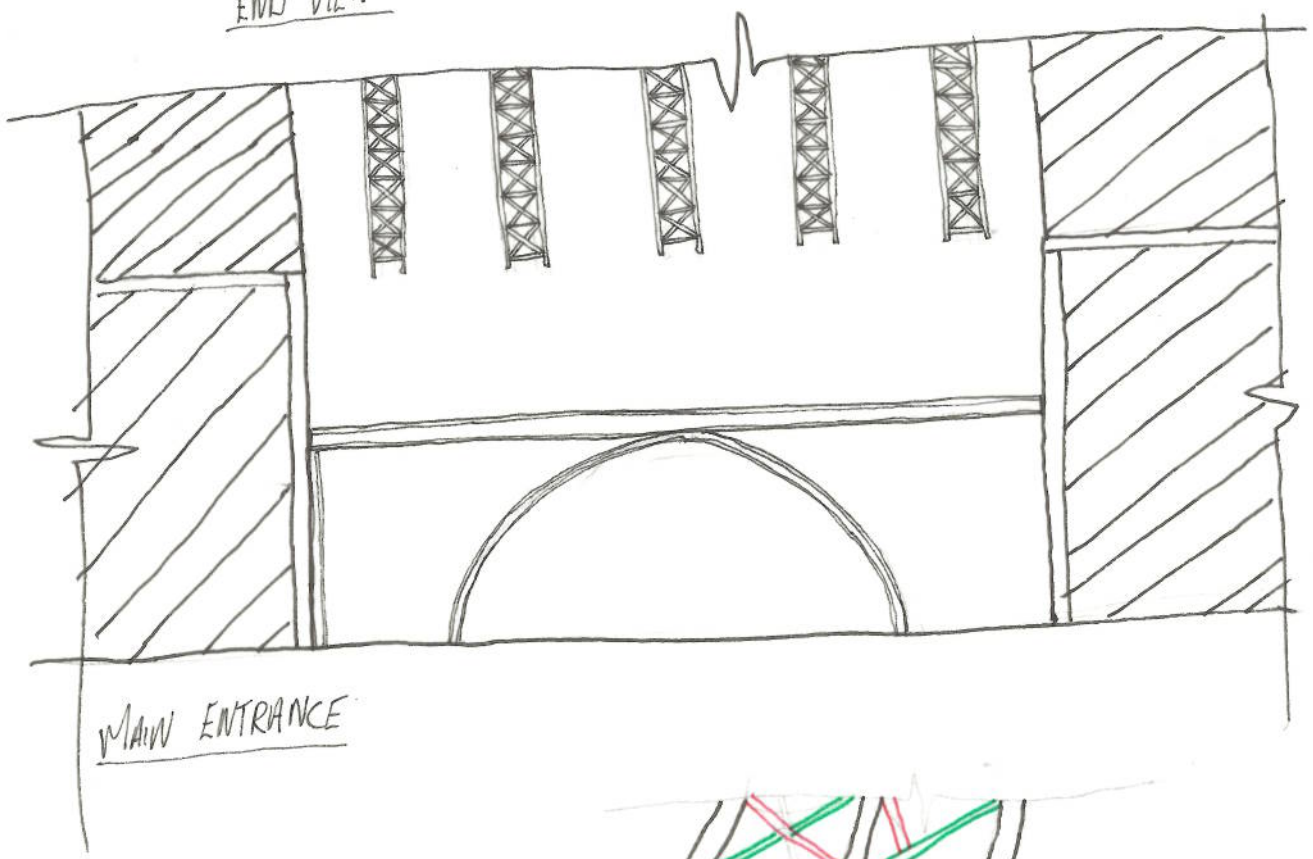
Rough Work



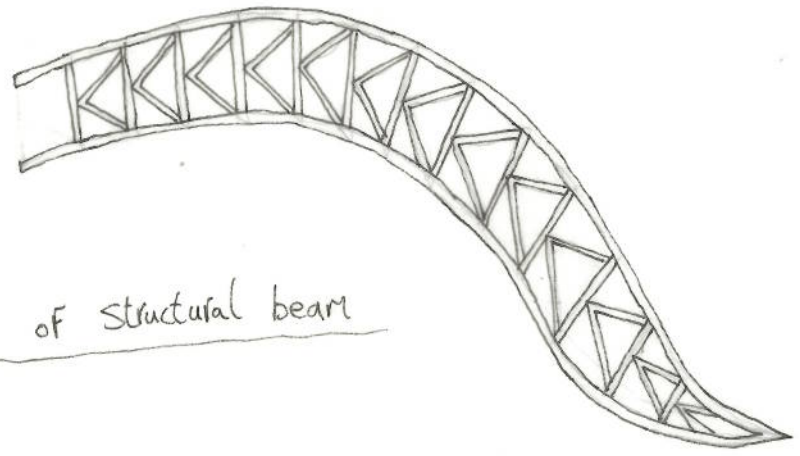
PLAN



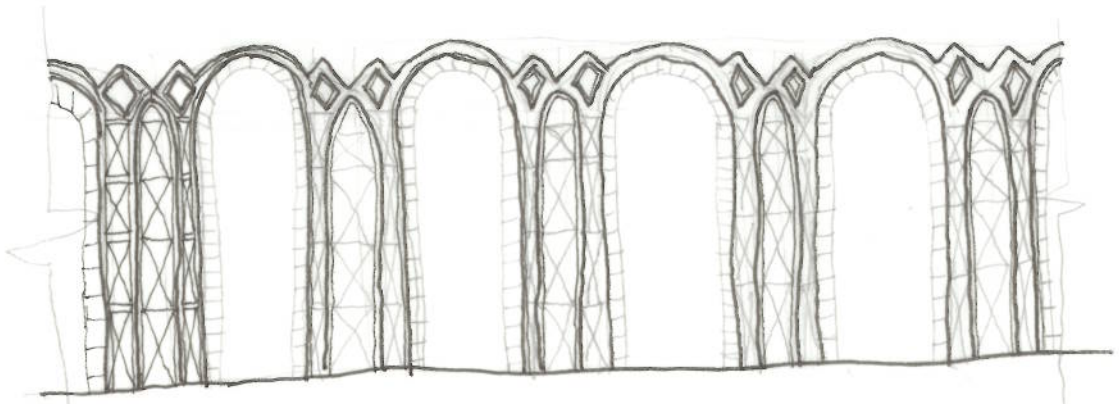
END VIEW



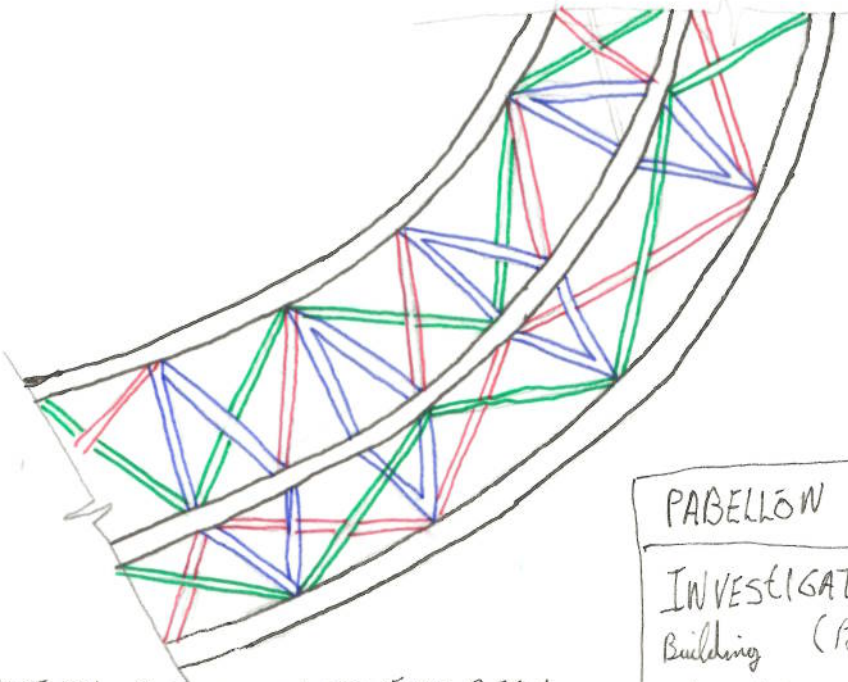
MAIN ENTRANCE



Section of structural beam



Front Facade

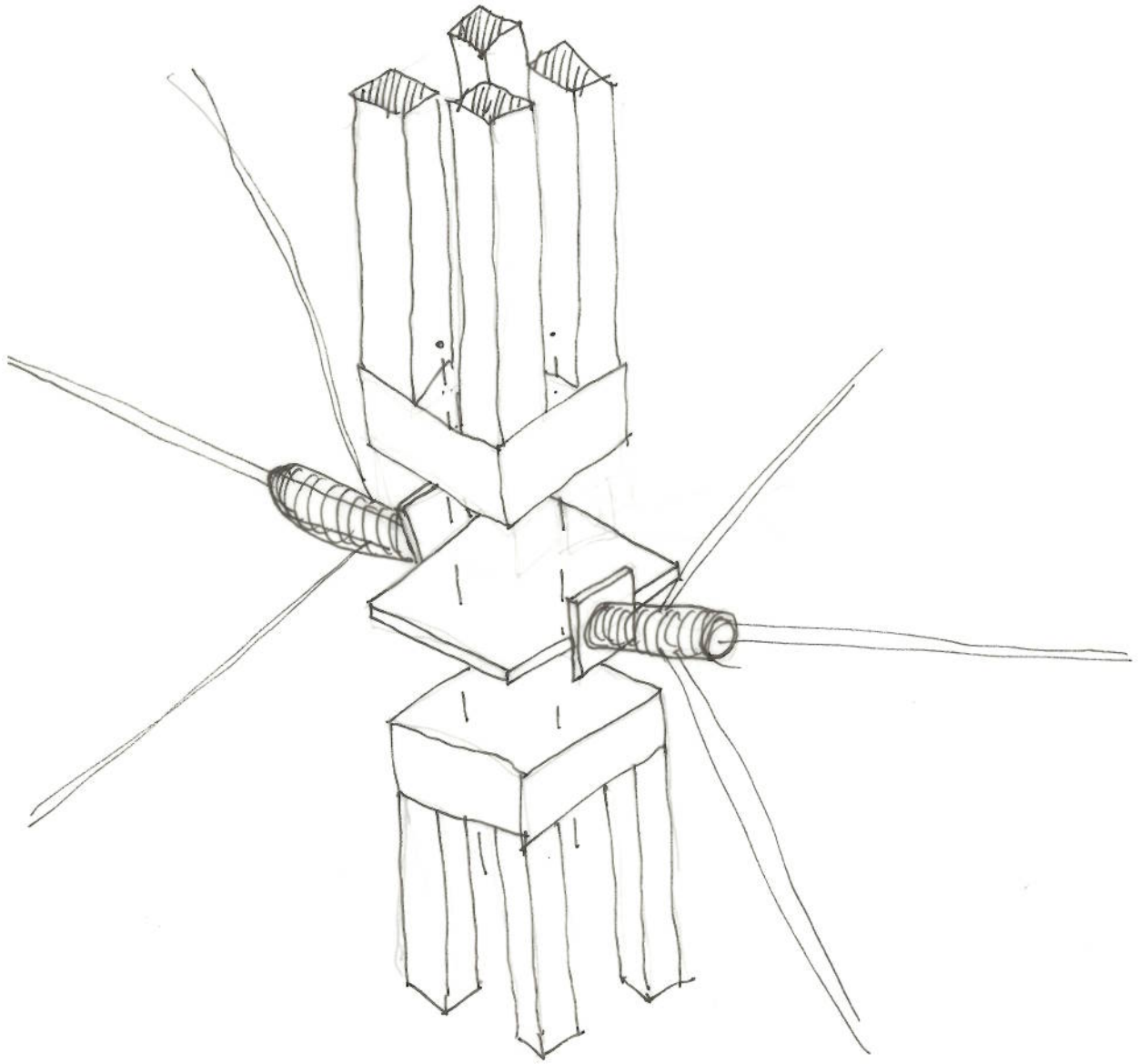


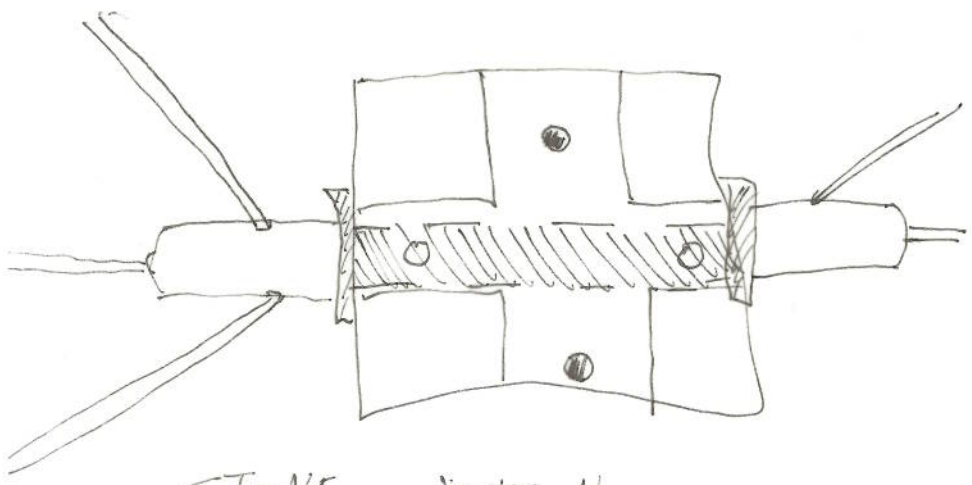
3D of structural forces on structural beam

PABELLON DEL FUTURO

INVESTIGATION OF Building (Page 1 of)

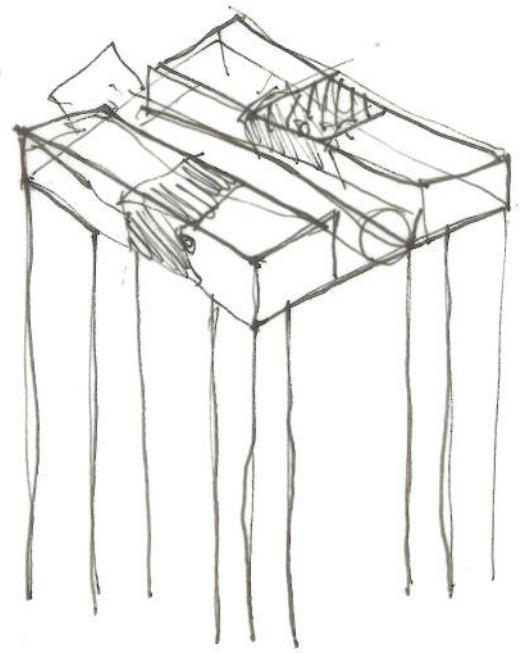
M. MALONE 17-9-13

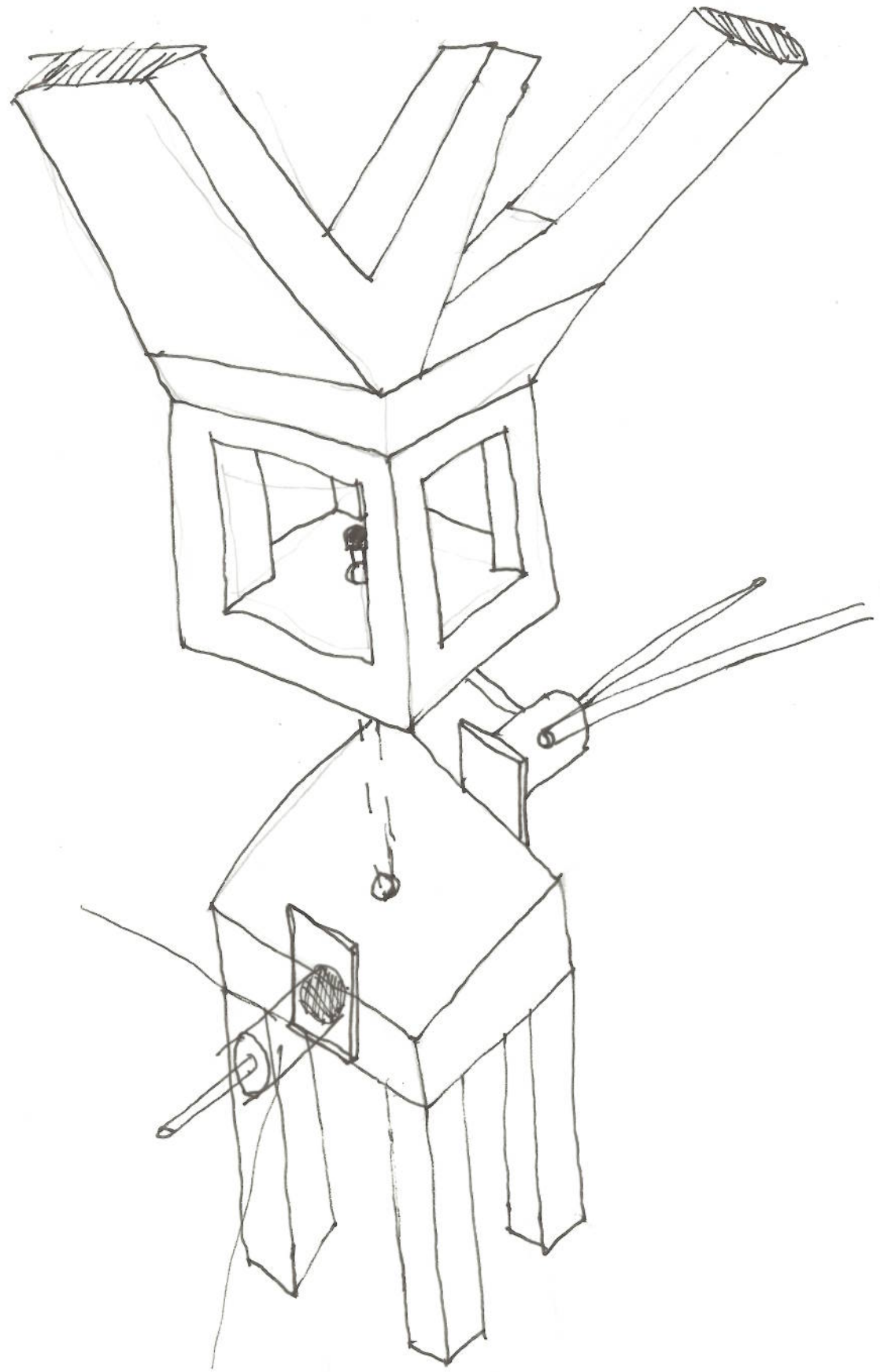




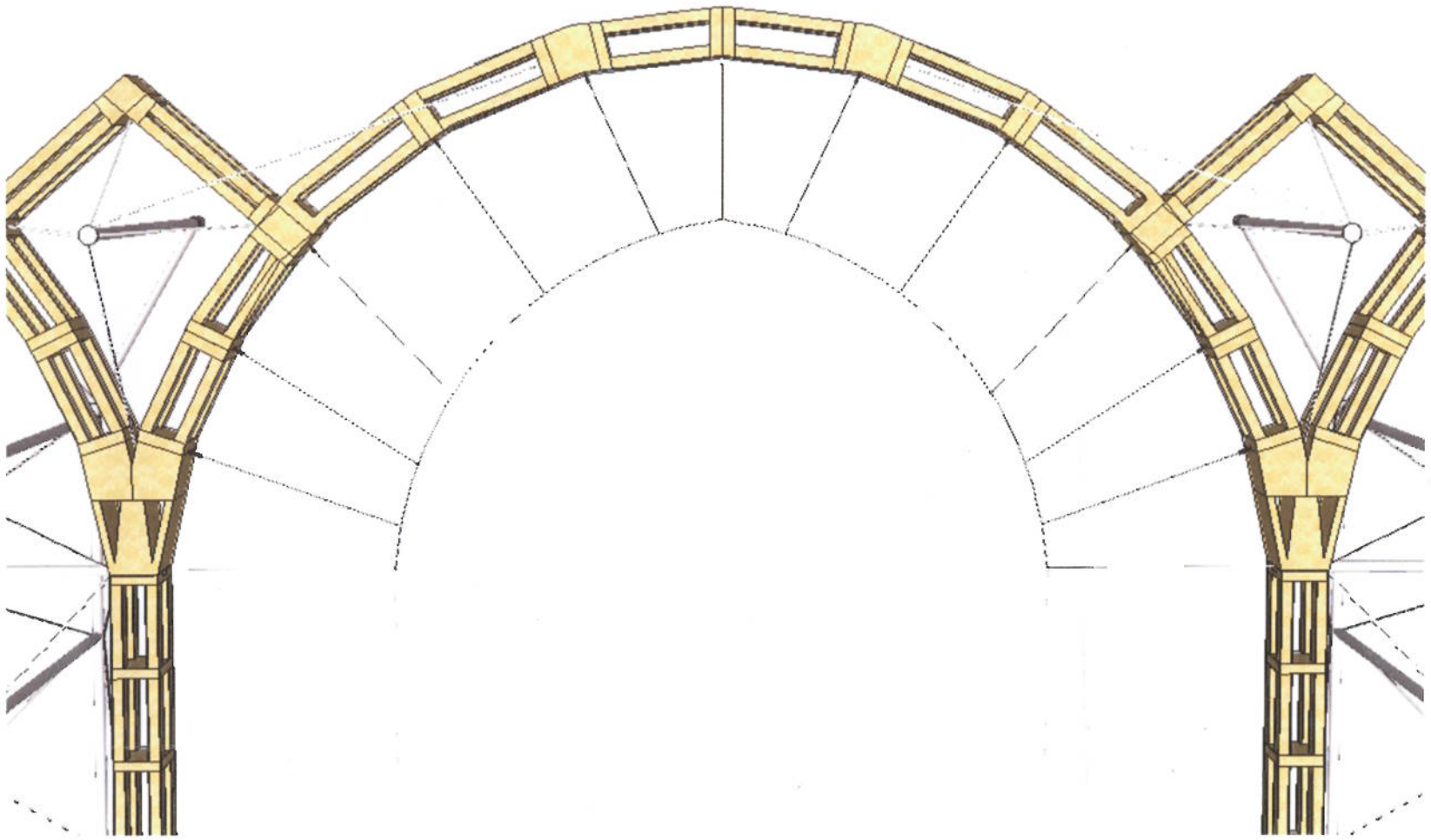
STONE JUNCTION

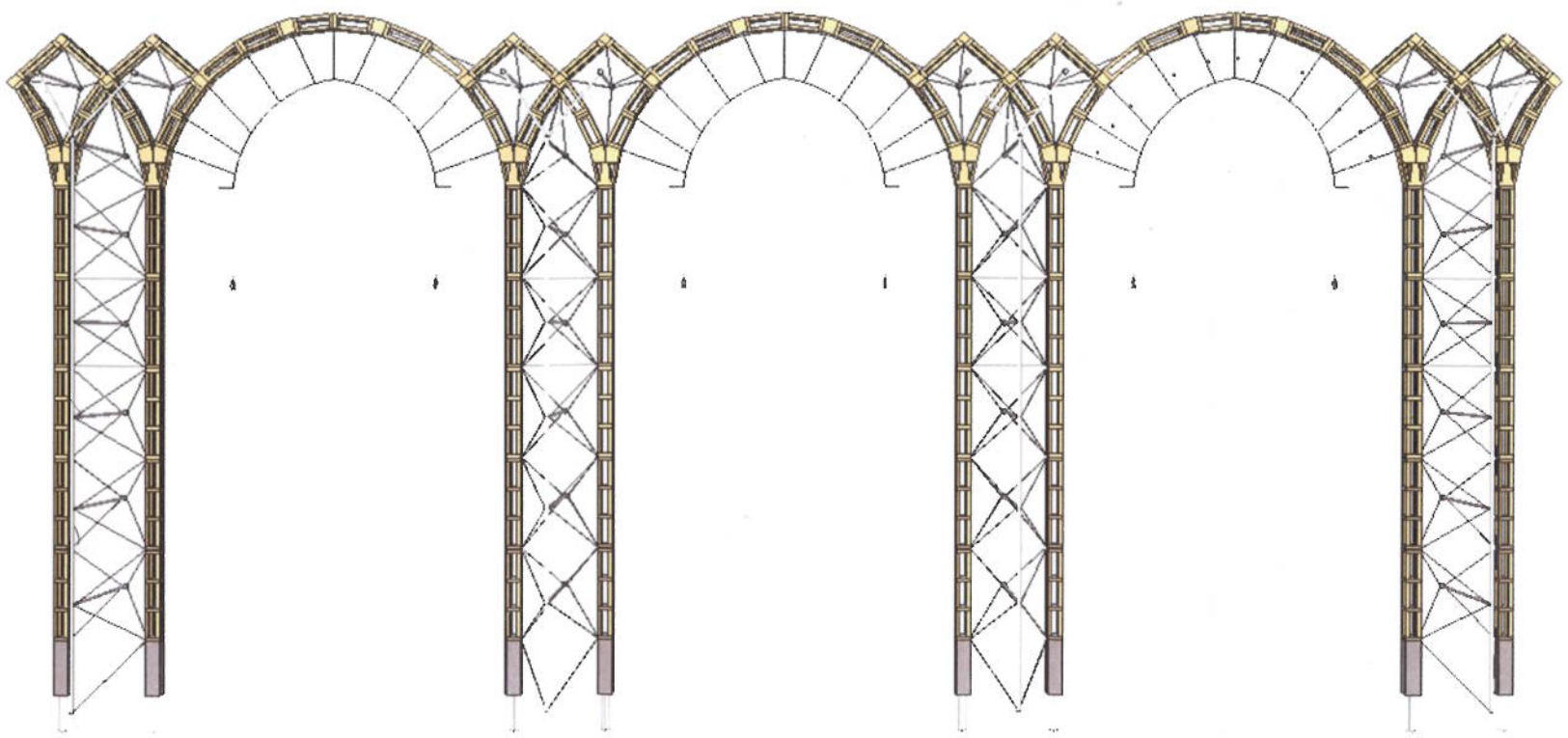
CONNECTING SLEET CABLES

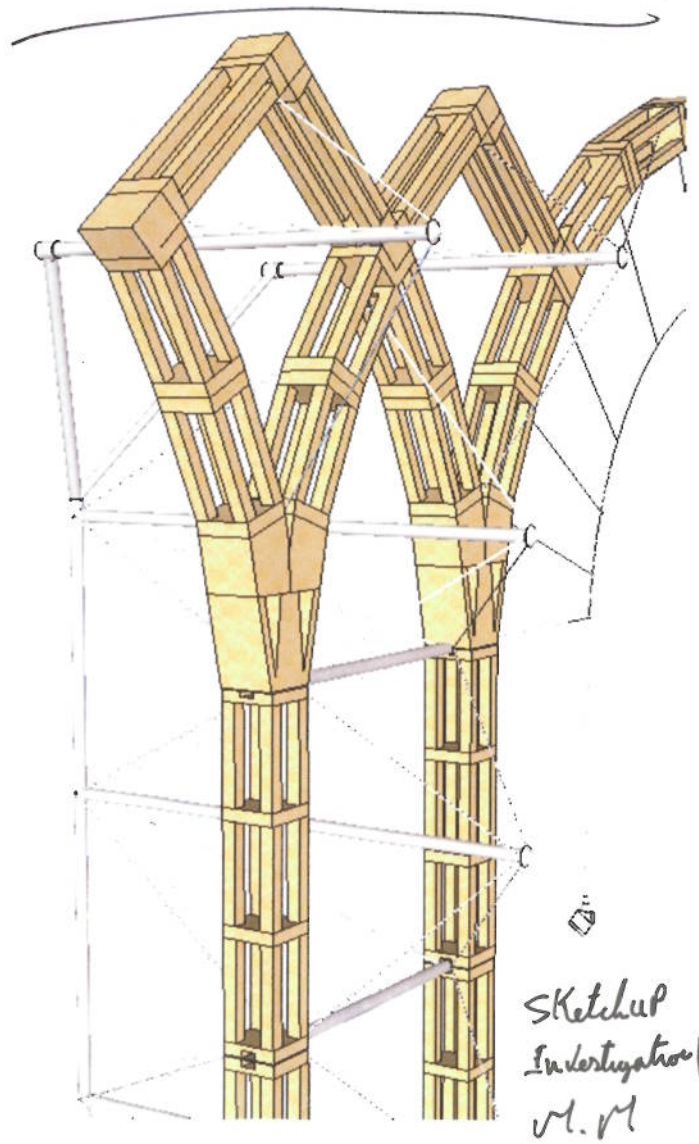


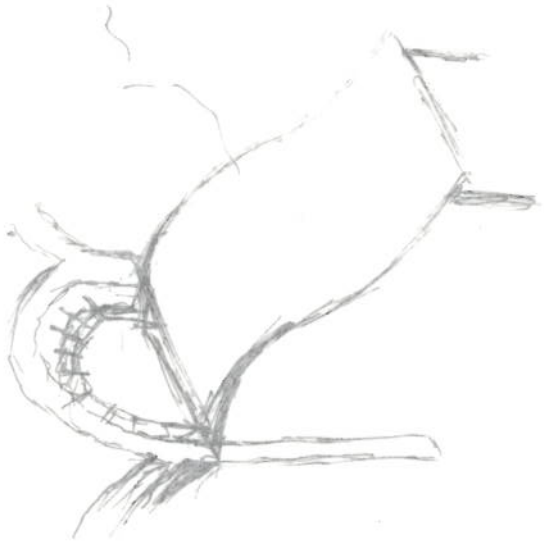


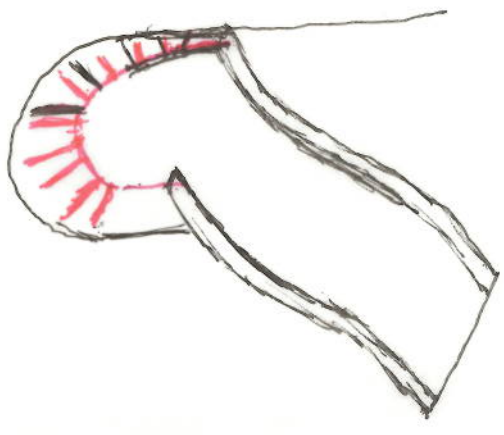
Rough work

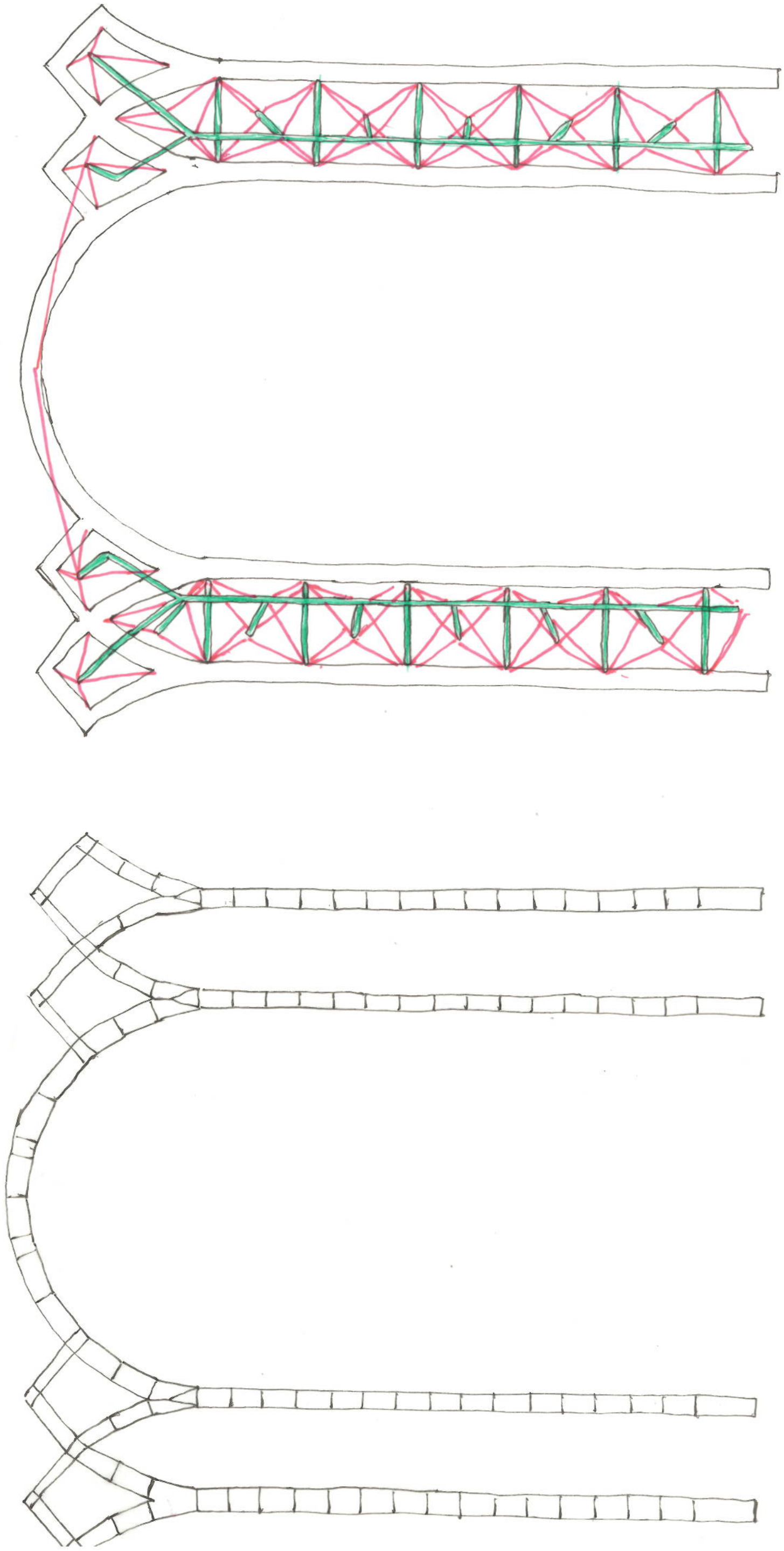


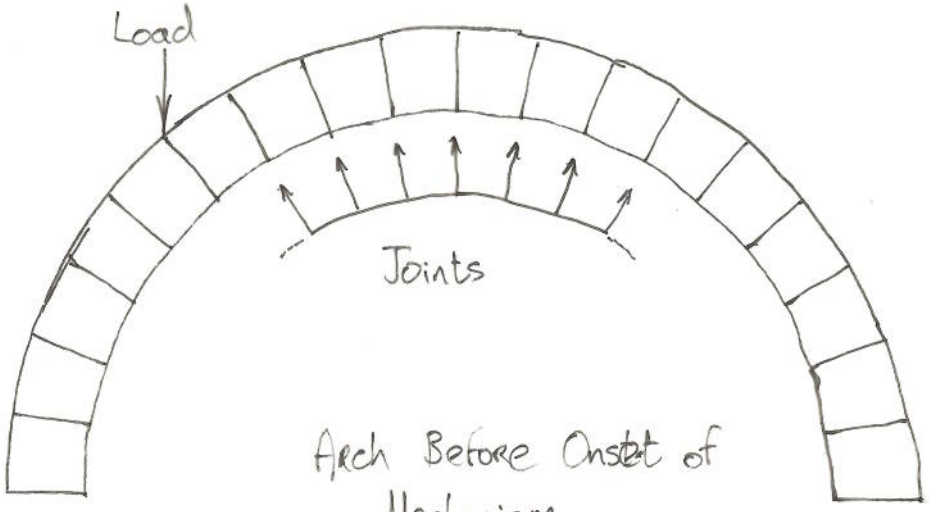



SKetchuP
Investigation
M. M

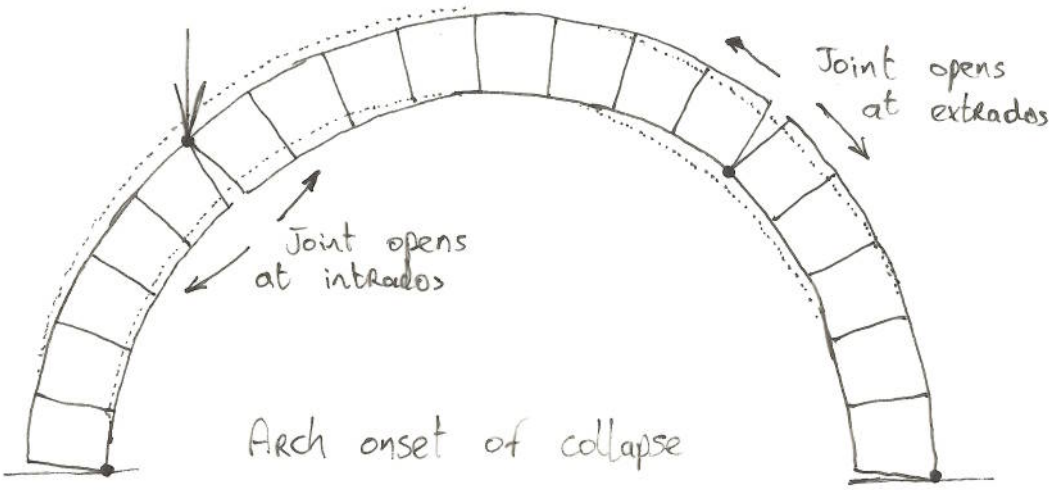








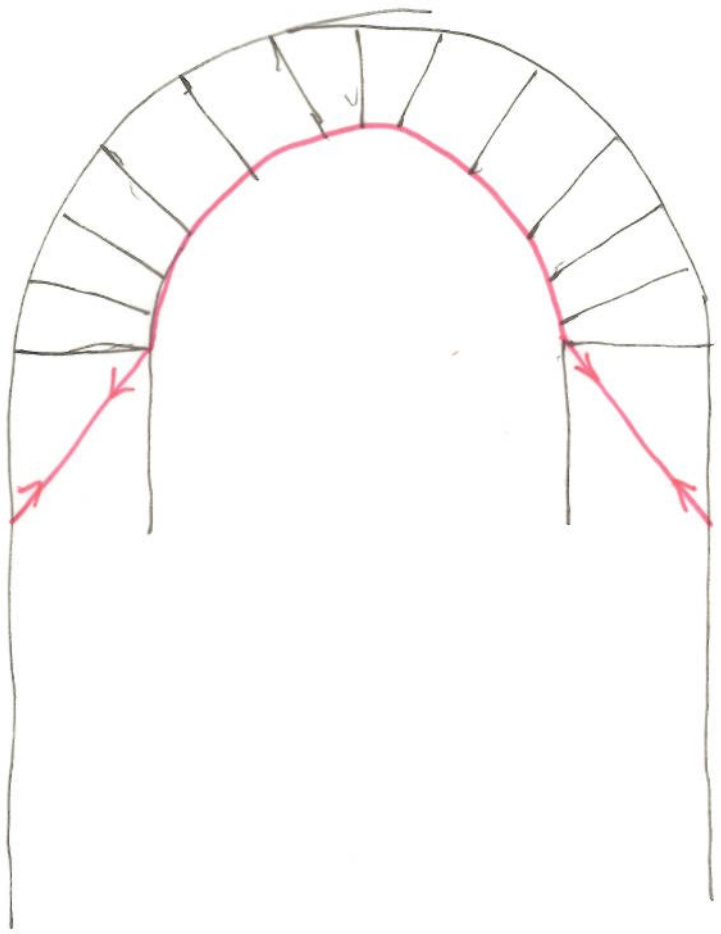
Arch Before Onset of Mechanism

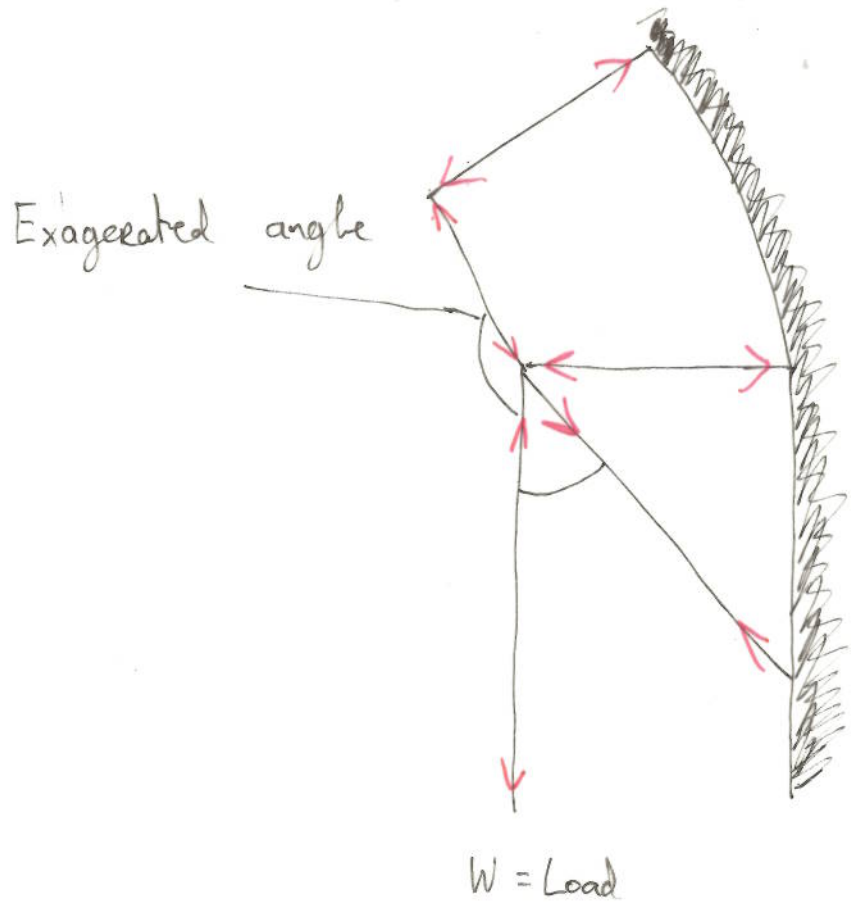


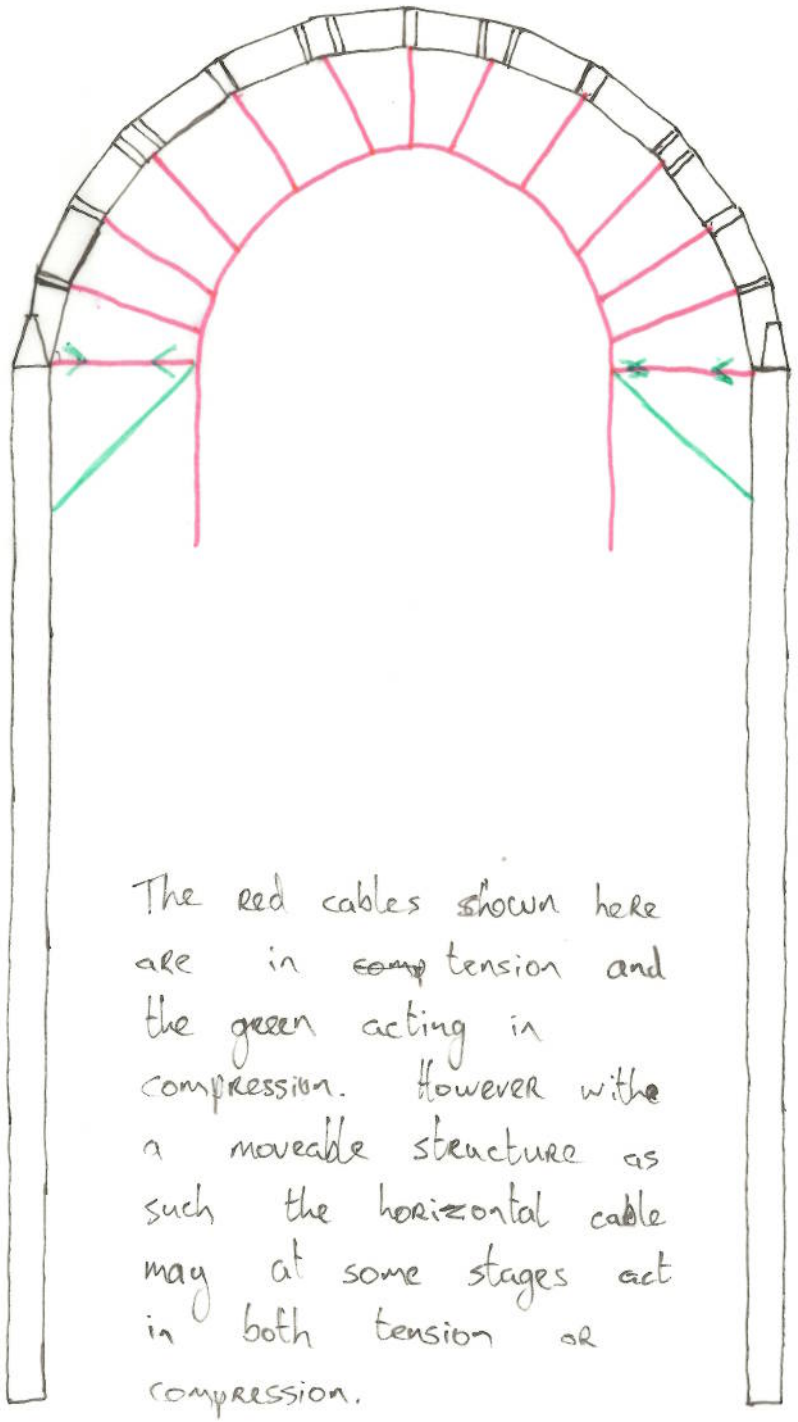
Arch onset of collapse

The top 3D image shows how the tension cables act with a downward force of wind, Rain or snow. Most of the cables are in tension with two bottom cables in compression.

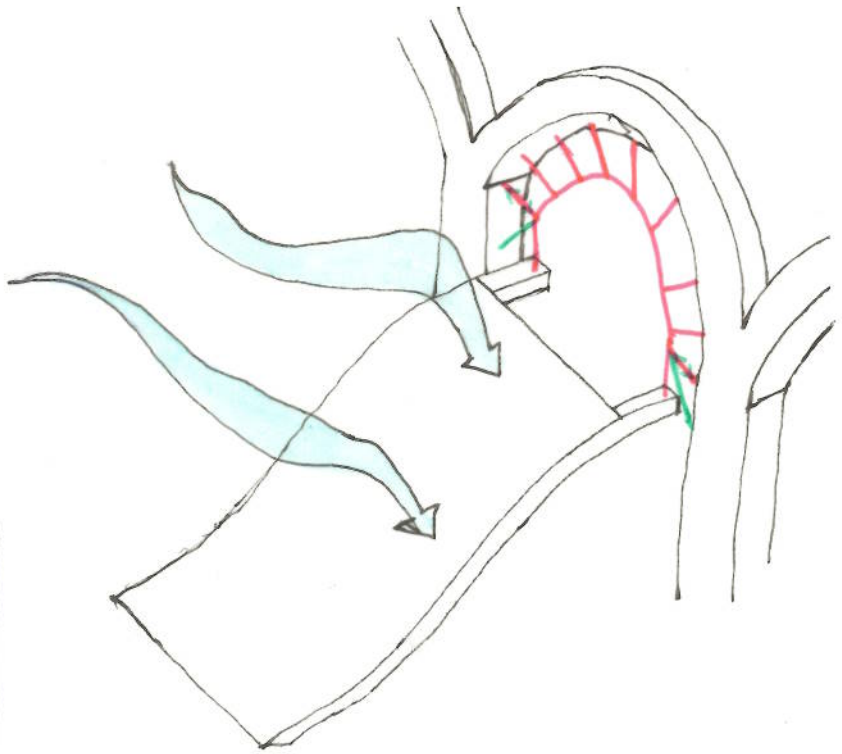
The bottom image shows the bottom cables along with the horizontals act as anchors to stop an upwind from ruining the structure.




Exaggerated angle
W = Load

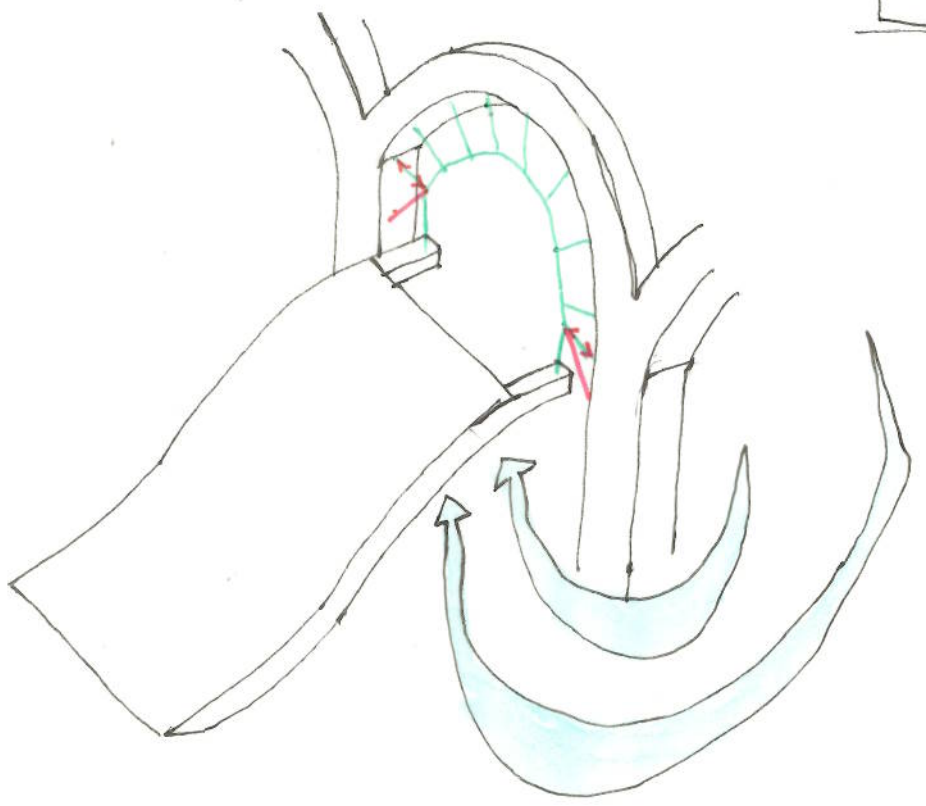


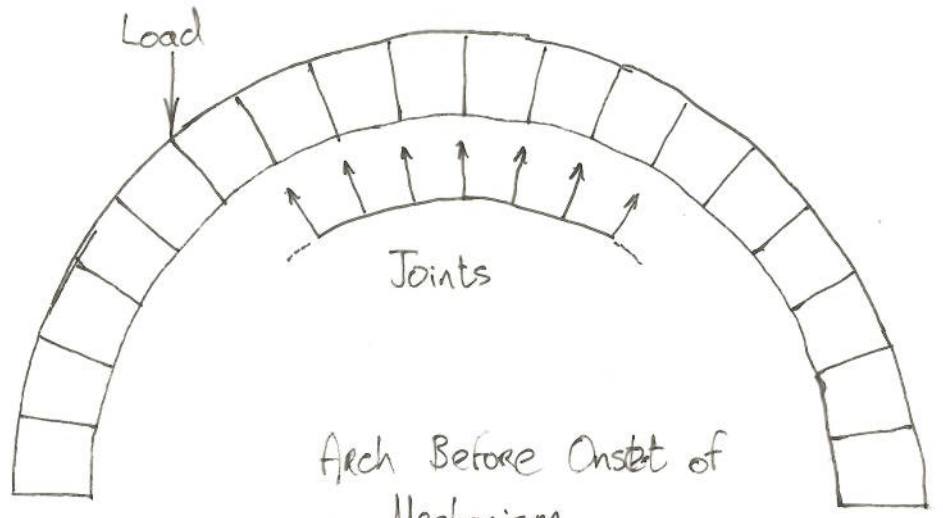
The red cables shown here are in ~~comp~~ tension and the green acting in compression. However with a moveable structure as such the horizontal cable may at some stages act in both tension or compression.



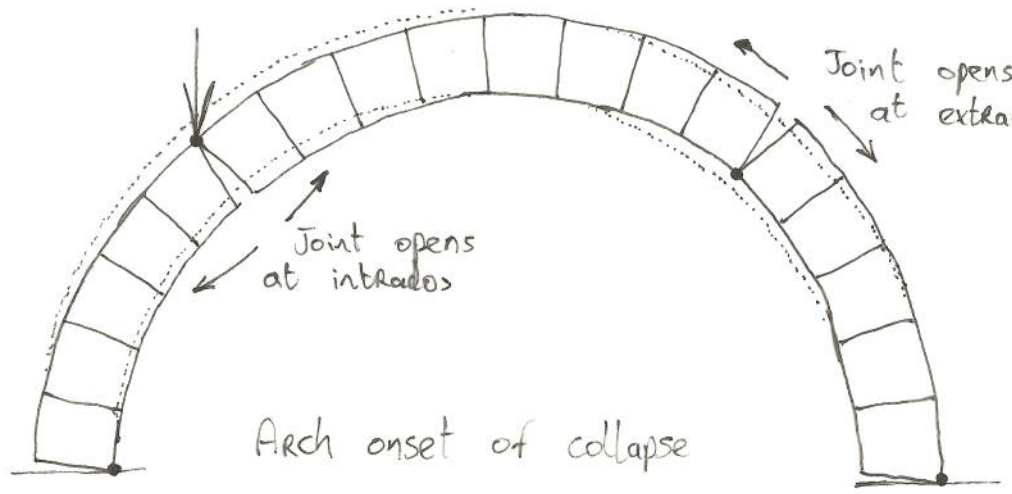
Wire in tension

Wire in Compression





Arch Before Onset of Mechanism



Arch onset of collapse

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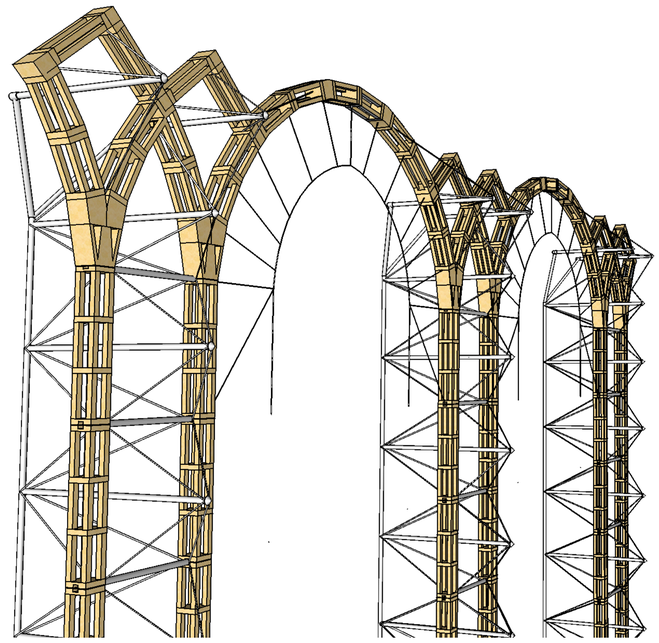
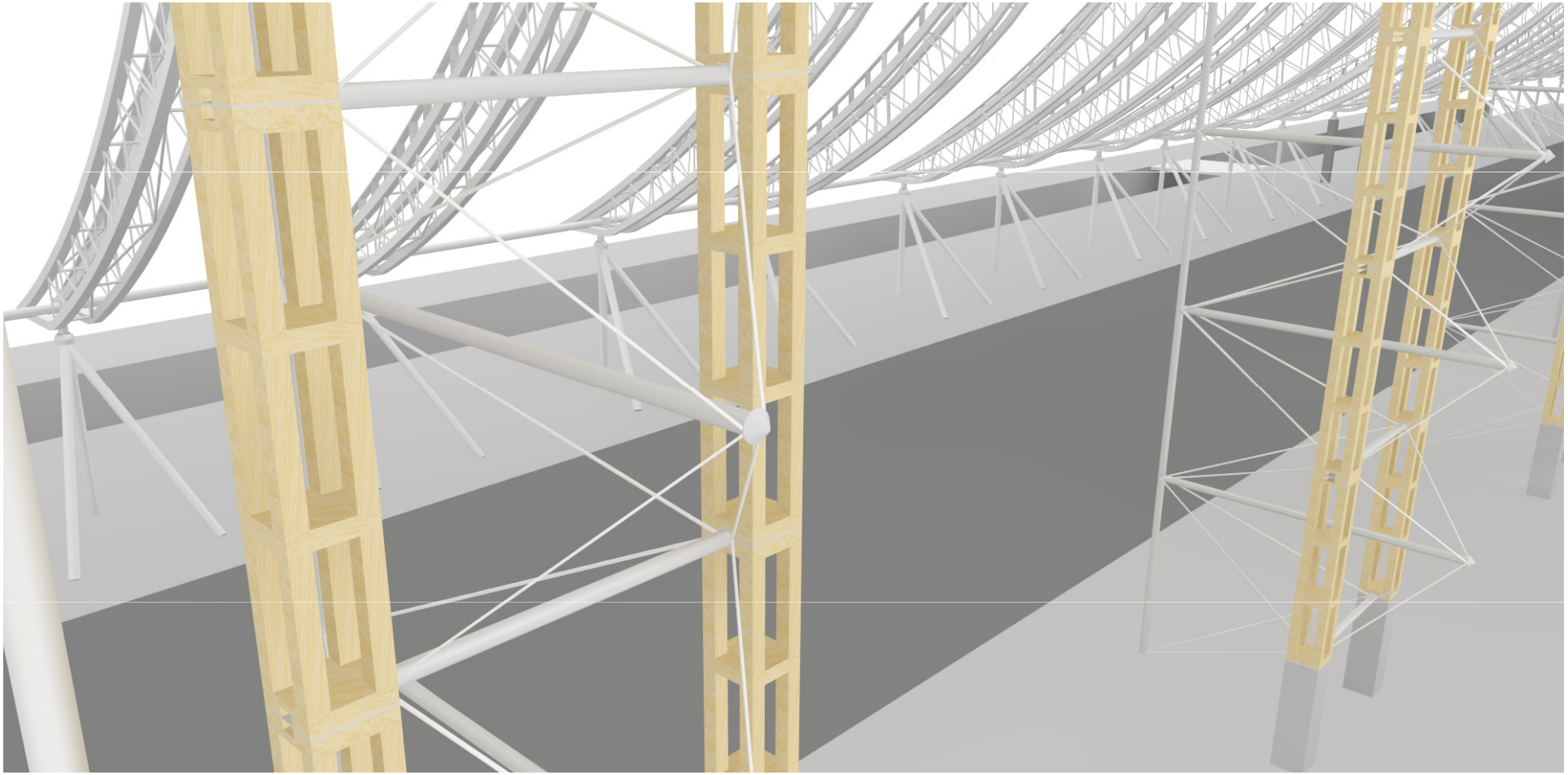
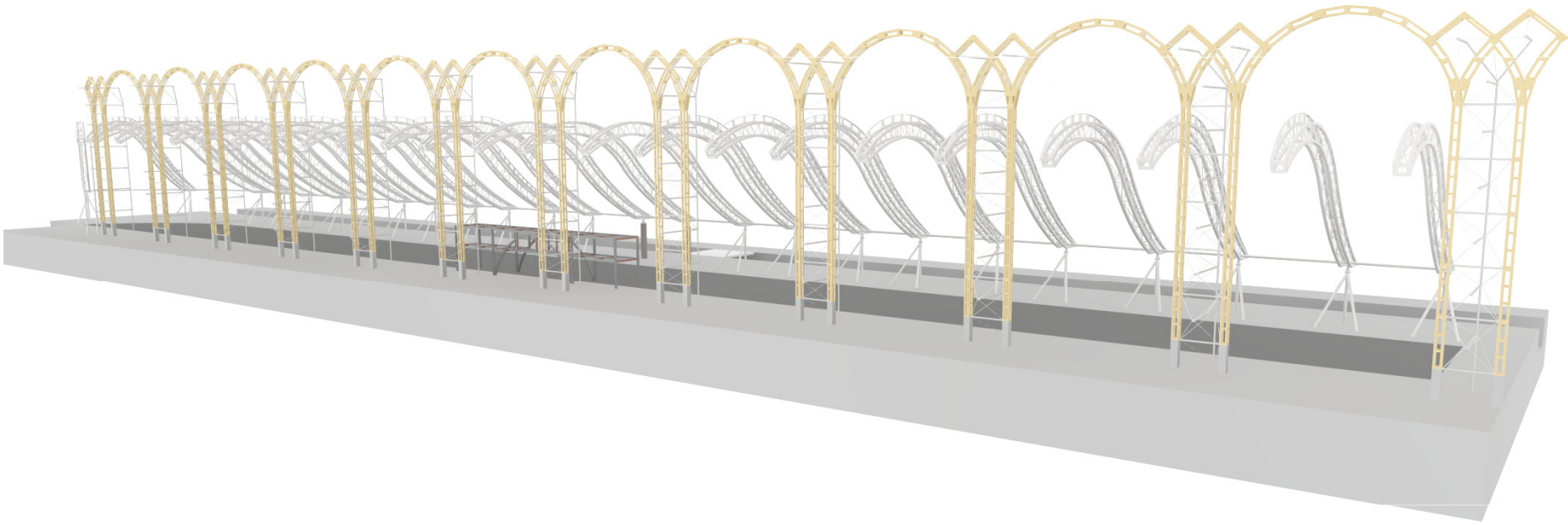
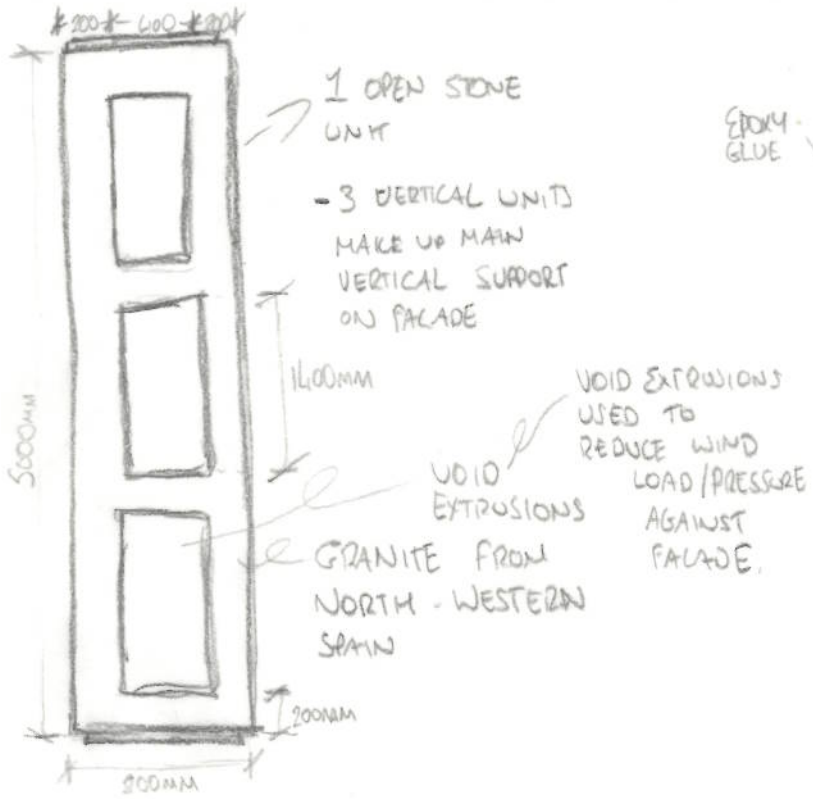
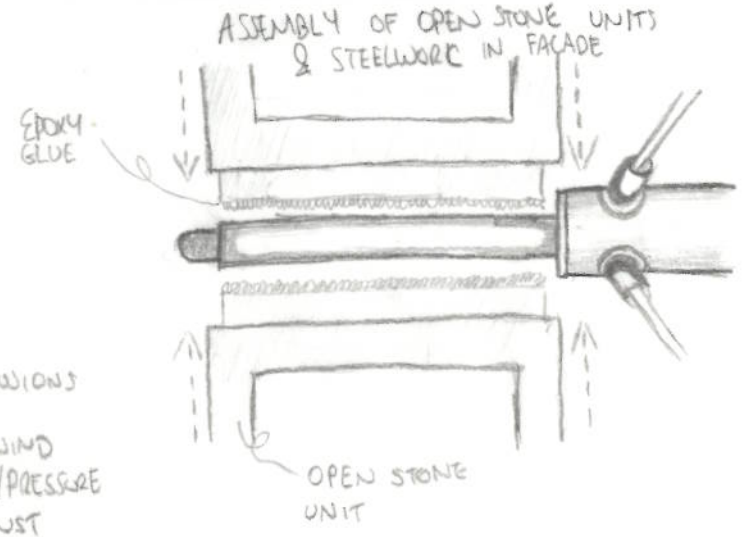
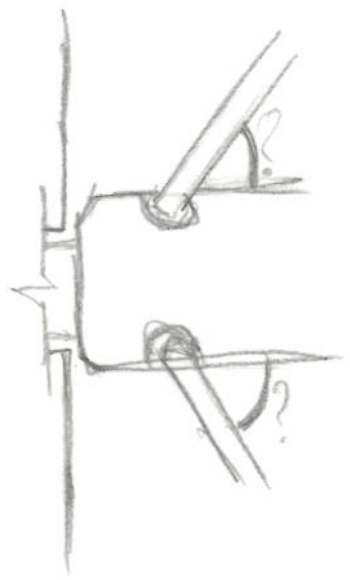


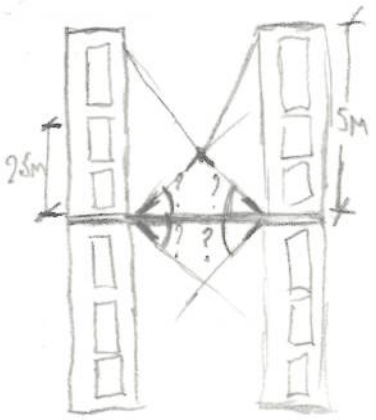


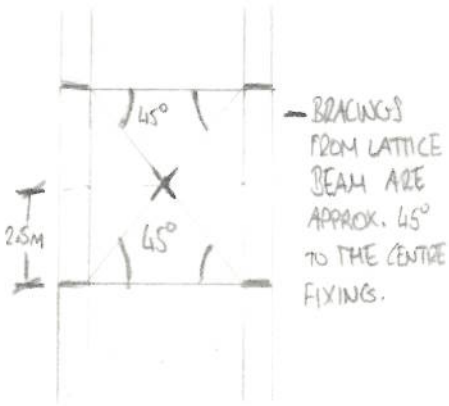


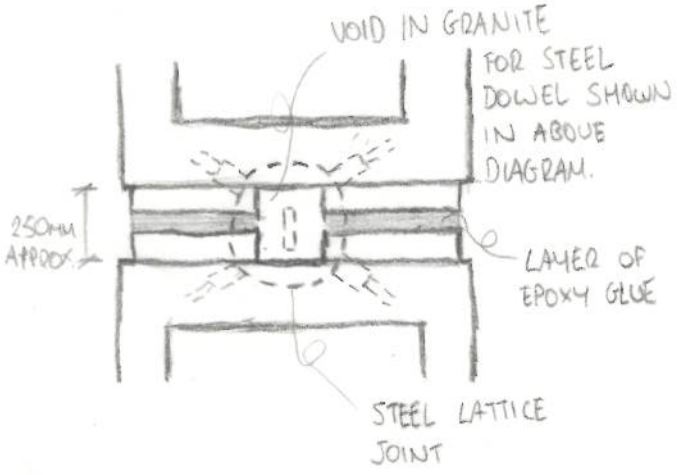

300
600
300
1 OPEN STONE UNIT
- 3 VERTICAL UNITS MAKE UP MAIN VERTICAL SUPPORT ON FACADE
1,600MM
5000MM
VOID EXTRUSIONS USED TO REDUCE WIND LOAD/PRESSURE AGAINST FACADE.
VOID EXTRUSIONS
GRANITE FROM NORTH-WESTERN SPAIN
300MM
900MM

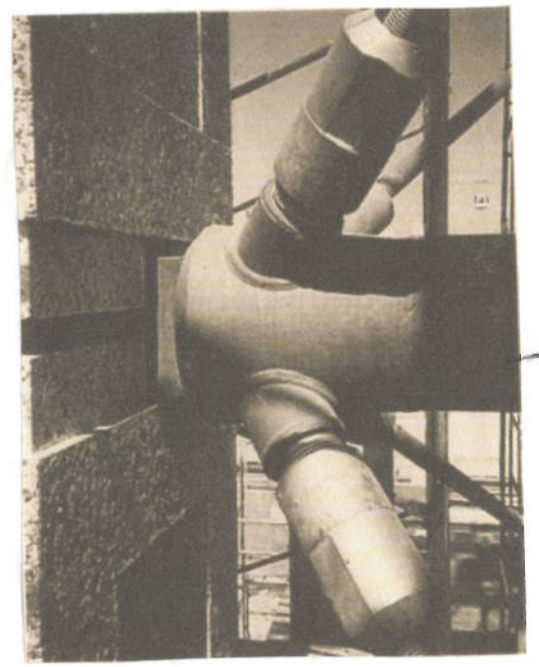

ASSEMBLY OF OPEN STONE UNITS & STEELWORK IN FACADE
EPOXY GLUE
OPEN STONE UNIT

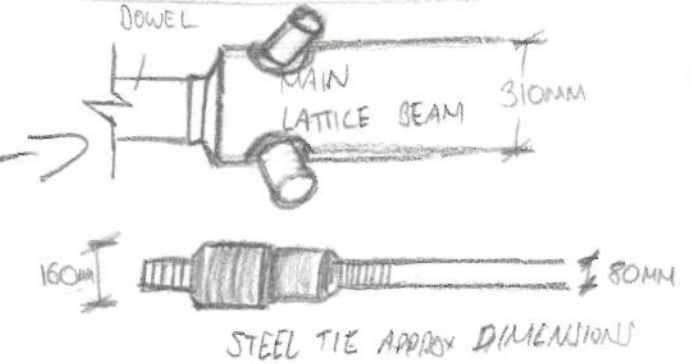


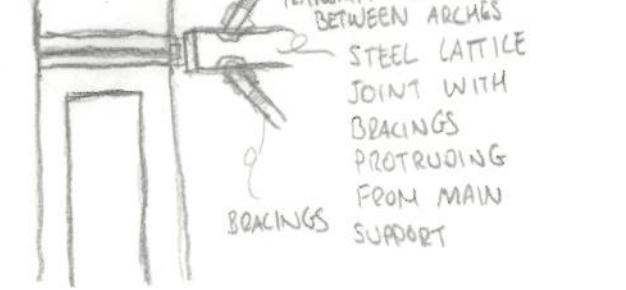

BRACING MEETS AT HALFWAY APPROX (NO EXACT FIG. FOUND)
- 5M HEIGHT OF OPEN STONEWORK
5M
2.5M

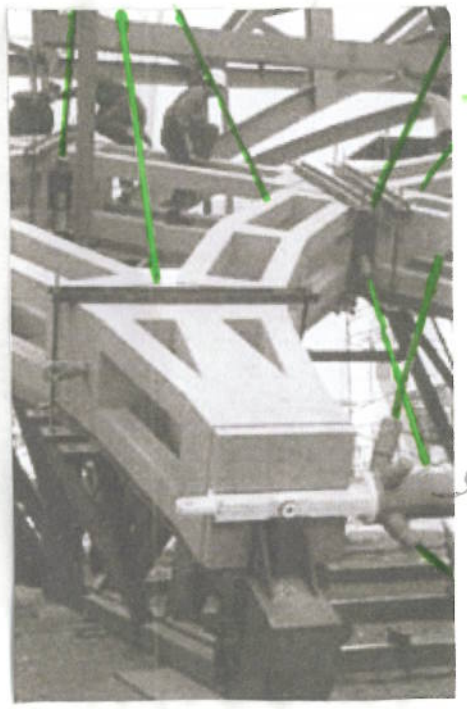

45°
45°
2.5M
- BRACINGS FROM LATTICE BEAM ARE APPROX. 45° TO THE CENTRE FIXINGS.


VOID IN GRANITE FOR STEEL DOWEL SHOWN IN ABOVE DIAGRAM.
250MM APPROX
LAYER OF EPOXY GLUE
STEEL LATTICE JOINT

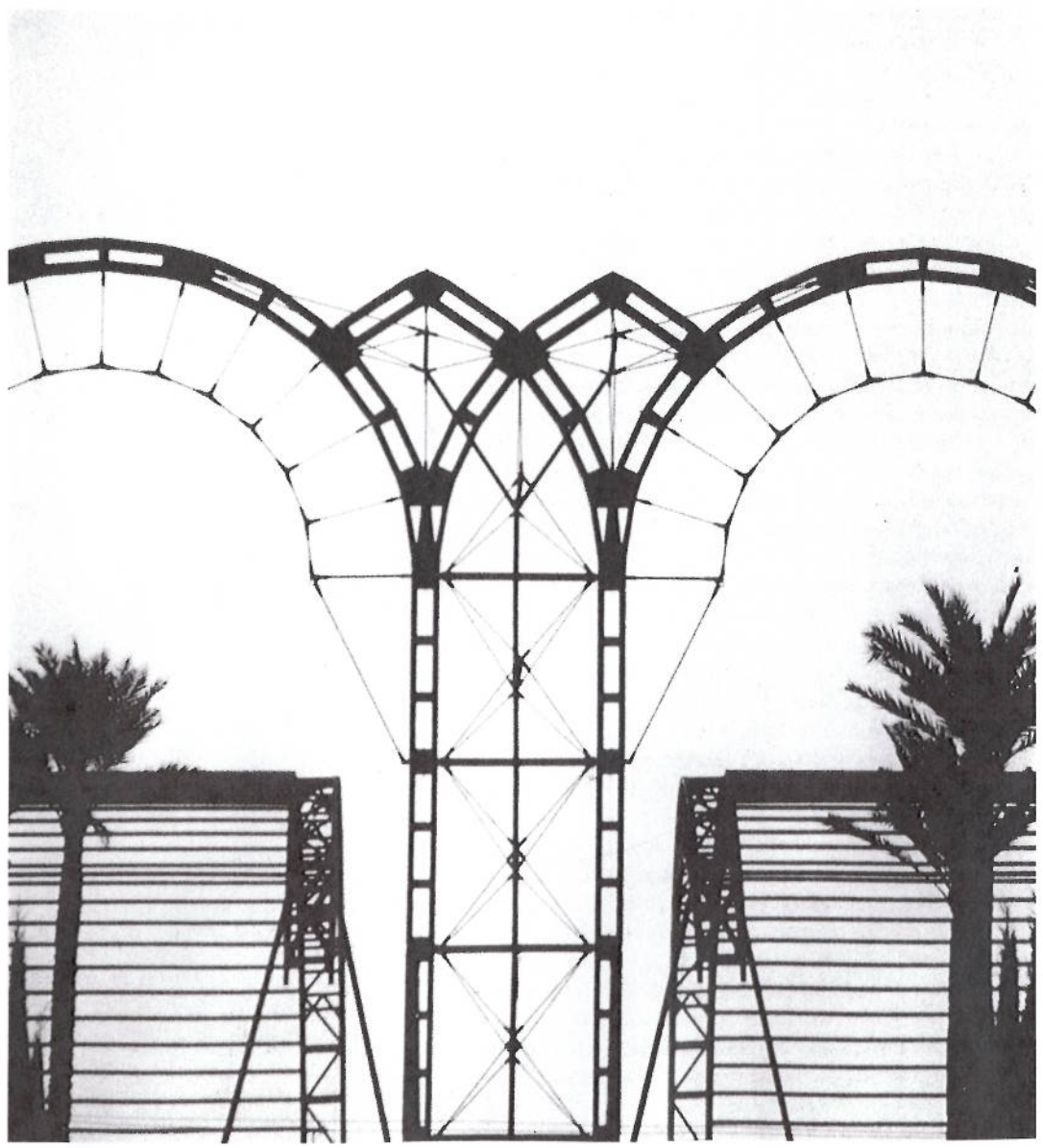



APPROXIMATE DIMENSIONS OF STEEL LATTICES & TIES
DOWEL
MAIN LATTICE BEAM
310MM
160MM
80MM
STEEL TIE APPROX DIMENSIONS


CONNECTION BETWEEN 2 UNITS:
- EPOXY GLUE & STEEL DOWELS
LATTICE JOINT
- STEEL DOWEL & SUPPORT BRACING
- EACH STEELWORK SUPPORT OCCURS AT EVERY CONNECTION POINT OF THE OPEN UNITS. (EVERY 5 METRES)


GREEN HIGHLIGHTER REPRESENTS THE STEEL BRACING. NOTE THAT THEY ARE FIXED ON TO STONE FACADE AND THEN CRANED AFTERWARDS.
IT IS VISIBLE IN THIS PICTURE TO SEE THE STAINLESS STEEL DOWEL USED TO SUPPORT THE LATERAL BEAM.

GRANITE UNIT TO CONNECT SINGLE VERTICAL UNIT TO PRODUCE ARCHWAY AND TO TRANSMIT VERTICAL LOADS BETWEEN ARCHES
STEEL LATTICE JOINT WITH BRACINGS PROTRUDING FROM MAIN SUPPORT
BRACINGS



Stone façade structure of the Pavilion of the Future during construction.

Stone: Pavilion of the Future, Seville

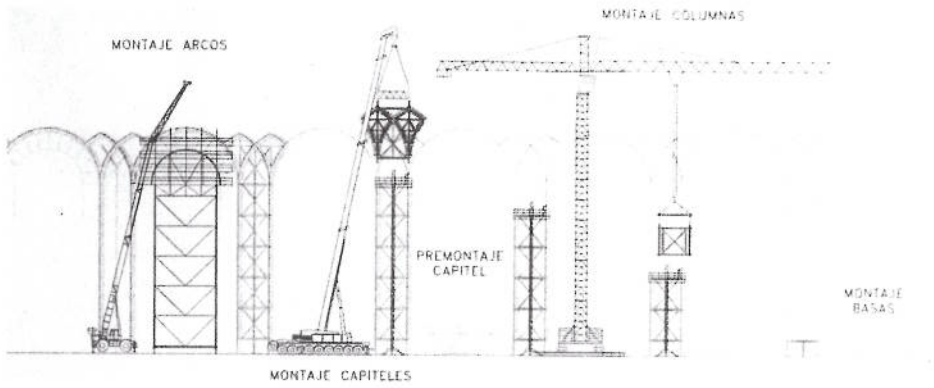
In 1988 I was asked by the Anglo-Spanish architect, David Mackay, a partner of Martorell Bohigas Mackay (MBM) in Barcelona, if I would participate with them in the design for the Pavilion of the Future. The site on the Isla de la Cartuja was 25 metres wide and 300 metres long, facing the old city across the Guadalquivir River, and alongside the gardens where many of Expo's night-time events would take place. The client, the Expo '92 Committee, specifically asked that the solution be spectacular.

I went to Barcelona to work with the architects and while I was there I remembered the Palacio da Ajuda in Lisbon, a building which I had seen the previous summer. This building, built around a quadrangle, had been left uncompleted on one side. Apparently Napoleon had attacked Lisbon while the building was under construction, and the work was stopped and never completed. A tall gaunt façade, complete with window openings but with no windows or building behind, was left to form one side of the quadrangle. I mused at the time that it was surprising that it stood up, but it was there, proof positive that it worked. It was not unlike the medieval ruins of churches, visible throughout Europe. Obviously such structures must be stable. I was very interested and thought one day I would build a structure like that. As I contemplated what to do for Seville, I remembered Lisbon and I proposed that we build a wall, a façade on to the park and separating the open space from the jumble of the international pavilions behind. The architect was interested, so we proceeded.

At first the idea took a form that derived from its inspiration. We thought to build an elaborate long façade as though there were a building behind. On examination that seemed complex to justify and very expensive. So we searched again. Then I remembered the experience of building the La Villette glass conservatories. We had postulated then that the same techniques might be used to build in stone. Stone and glass have similar physical characteristics, and we realized that the techniques developed for glass could also be developed to enable stone to be used structurally. Stone, like glass, is very strong in compression, but fragile and prone to cracking. If we could protect the stone from tension forces and from sudden loads then we could perhaps build the screen using stonework as a primary structural material, but in a more sophisticated way.

The possibility of working in stone led me to think of what else was being built in stone today. It was clear. The architects and

Palacio da Ajuda, Lisbon, Portugal. View of free-standing façade.



Contractor's drawing showing proposed construction sequence.

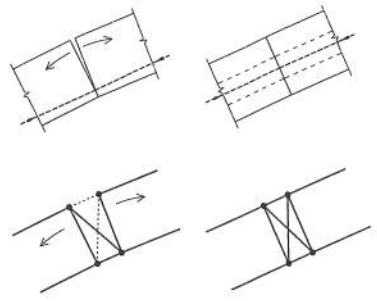
Inspecting stone unit at workshop.

Open arch unit after assembly at stone workshop.

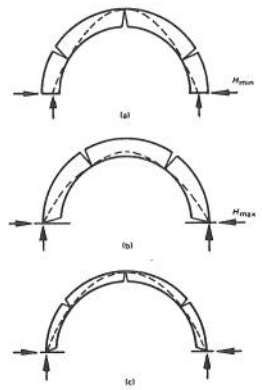
that any change in shape of the stone arches was followed by a corresponding change in shape in the support system. This would guarantee that the loading system would always remain funicular, or of the same form and shape as the stone under geometric change caused by wind or other non-symmetrical load parallel to the line of the arches.

The final stage in the design decisions was the assembly and the bracing system. The arch units were assembled as though they were precast concrete units with mortar joints. The pre-assembled units were then treated as single blocks of stone and the granite in the preformed units was analysed and checked to ensure that the 20 centimetre by 20 centimetre sub units were not overstressed during or after the assembly. The steel tie-bracing system for resisting out-of-plane loading (that is, the loading normal or at right angles to the plane of the façade) was designed to treat the stone columns as chord elements in a vertical cantilever, with the shear-resisting elements being the steel bracing system. The form and geometry of this vertical bracing system were chosen to make the least impact on the stone plane itself. By placing the bracing between the vertical stone columns but not in the vertical plane of the façade, we were able to avoid the feeling of a façade flat-braced in the vertical plane.

The last element in the story was the analysis method which was developed for the behaviour of the stone arches. We studied the theory of the way in which stone arch bridges worked, notably following the methods developed by Professor Jacques Heyman of Cambridge University. In his model the stone arch voussoirs, when subjected to tension at the joints, opened up on the tension side, as either the arch extrados or intrados. Normally in stone arch bridges, the large self-weight of the arch is sufficient to guarantee stability under different asymmetrical live loads, usually traffic loads. As our main joints between the pre-assembled sub-elements had no tension capacity either, and the principal loading or pre-load came from the applied load of the roof, the conditions were very similar to the arch bridges treated by Heyman. We therefore developed a computer modelling system which simulated the opening of the joint if it had to carry tension on either its extrados or intrados. This non-linear mechanical behaviour we called flip-flap and it can generate geometrical change within the arches' mechanical connectivity when the thrust line deviates substantially from the arch centre line. The arches were analysed under a full range of loading conditions, including wind and earthquake, using this programme.



Computer modelling of 'flip-flap' behaviour of joint within stone arch as used for Pavilion of the Future.



Diagrams from Professor Jacques Heyman's book *The Masonry Arch* showing occurrence of hinges in arch depending on the thrust-line position.

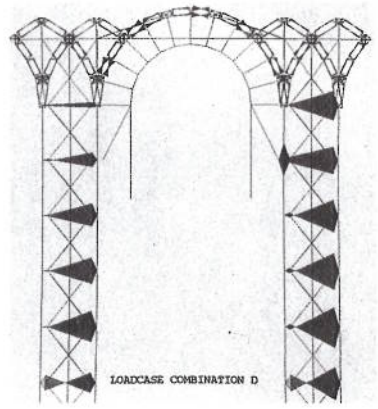
This method was a development of the special analytical system which had already been used extensively for other structures with non-linear behaviour, such as nets and tent structures. This programming system method, known as dynamic relaxation, as originally invented by Alistair Day, one of the team members, is a very powerful tool for examining the behaviour of non-linear, geometrically variable systems.

So, if we go back and examine this innovative façade and its use of stone, we find that at each stage the spur to proceed was created by something that already existed. Each step was prompted by something similar which could be used as a guide. Innovation here was the development of existing ideas and the belief that they were relevant and applicable in the structure we were exploring.

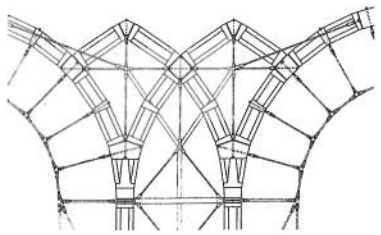
Perhaps the missing ingredient is courage. The courage you need is the courage to start. Once launched, then each step can be evolved naturally. Each step requires careful examination. The courage to start and an unshakeable belief in one's ability to solve the new problems which will arise in the development are essential. It is important to emphasize here that the team should have at least three or four members capable of contributing at every stage of the development. Every stage of the design should be subject to detailed scrutiny by engineers who feel themselves to be sharing in the responsibility. Nothing must be left to chance. Others not so closely involved must also be asked to review the project to question the assumptions and demand explanations. This is obviously easier when one has a large reservoir of skilled and talented engineers, as one finds in Arups. But they can be found even in smaller design groups, such as RFR in Paris. The presence of a competent, dedicated and sceptical checking authority is also very important in this respect.

The final stage in the story is the contractor. When working in a place where one is known, convincing the contractor of the viability of the design is not so difficult. But this was Spain, where I had not built before.

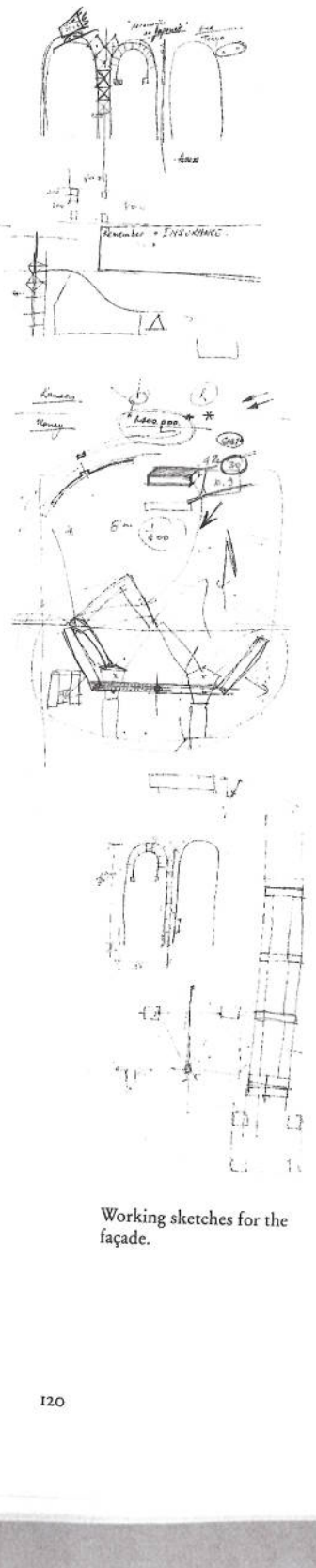
To convince the contractor and the client we made all our calculations available and then we produced a detailed erection method for the arch system. At first the contractor, backed by the client, said that our proposals for erection were far too complicated and would not work – a standard reaction. They proceeded with their



Graphic results of computer analysis of arch under unequal suspended loads producing bending in steel cross-bars of supporting towers.



Elevation detail of façade arches.



Working sketches for the façade.

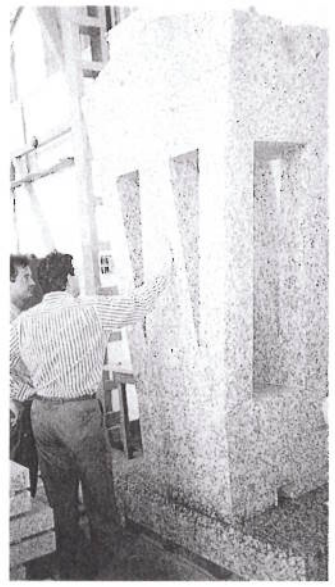
builders who built using stone cladding worked to very tight tolerances and very high levels of accuracy. If it were possible to harness the accurate stone-cutting which is necessary to obtain the large stone slabs visible on many post-modern façades, stone elements could then be used as blocks in a pre-cast concrete-type construction. We discussed this with some stone experts who normally worked on façade design and they corroborated our line of thinking. Yes, they said, one could expect to cut stone to tolerances of less than half a millimetre. Furthermore some of the best and most adaptable stone-cutters were international companies which were regularly making elements for complex façades. The component elements of a solution started to appear.

The next task was to choose a stone. The granite of northwestern Spain seemed an obvious choice. It has an interesting colour and is of very consistent quality. We had decided early on that granite was probably the best stone to use because, being igneous, it would offer constant properties which could be exploited to guarantee the quality of the assembly.

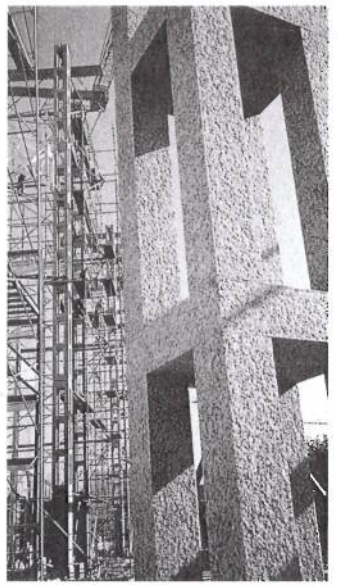
The search was then on for a form for the façade. From the beginning we had postulated that to justify the façade it should be used to support the roof of the Pavilion behind. At a philosophical level we theorized that the façade or screen should be like a modern ruin, like a fragment of a viaduct or the aqueduct that we had found in southern Spain. And the notion of the aqueduct gave us the idea about the form. A series of arches seemed a reasonable and logical form for the screen to take.

At around this time we were told that the standard product of the quarries was blocks of stone 20 centimetres by 20 centimetres by 1.4 metres high. We decided to make a prefabricated element out of these blocks. This would be made by epoxy jointing together the pieces, a technology also well known in the stone industry in northwest Spain. These fabricated elements were chosen to be 5 metres long by 80 centimetres by 80 centimetres in overall section and made up of the sub-units. These would then be treated like precast concrete units and assembled into the façade in a similar way as precast concrete elements might be.

The form and shape of the arches were derived from the best shape to support the roof load. By making the roof load tie-support system geometrically similar to the stone arch geometry, and by then attaching this to the stone arches by radial ties, we ensured

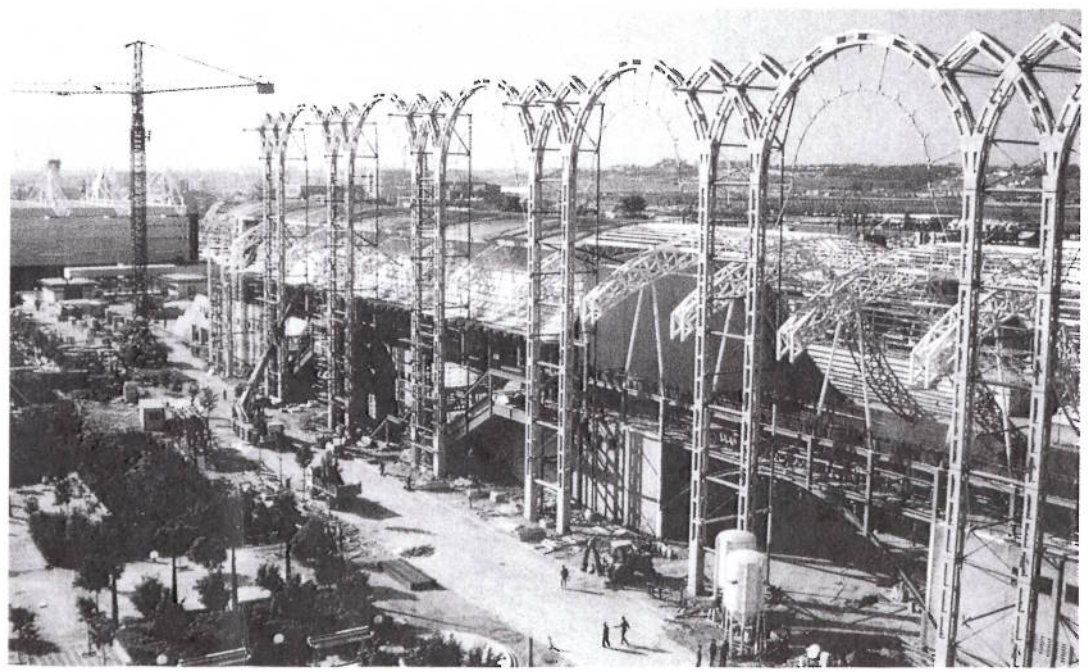


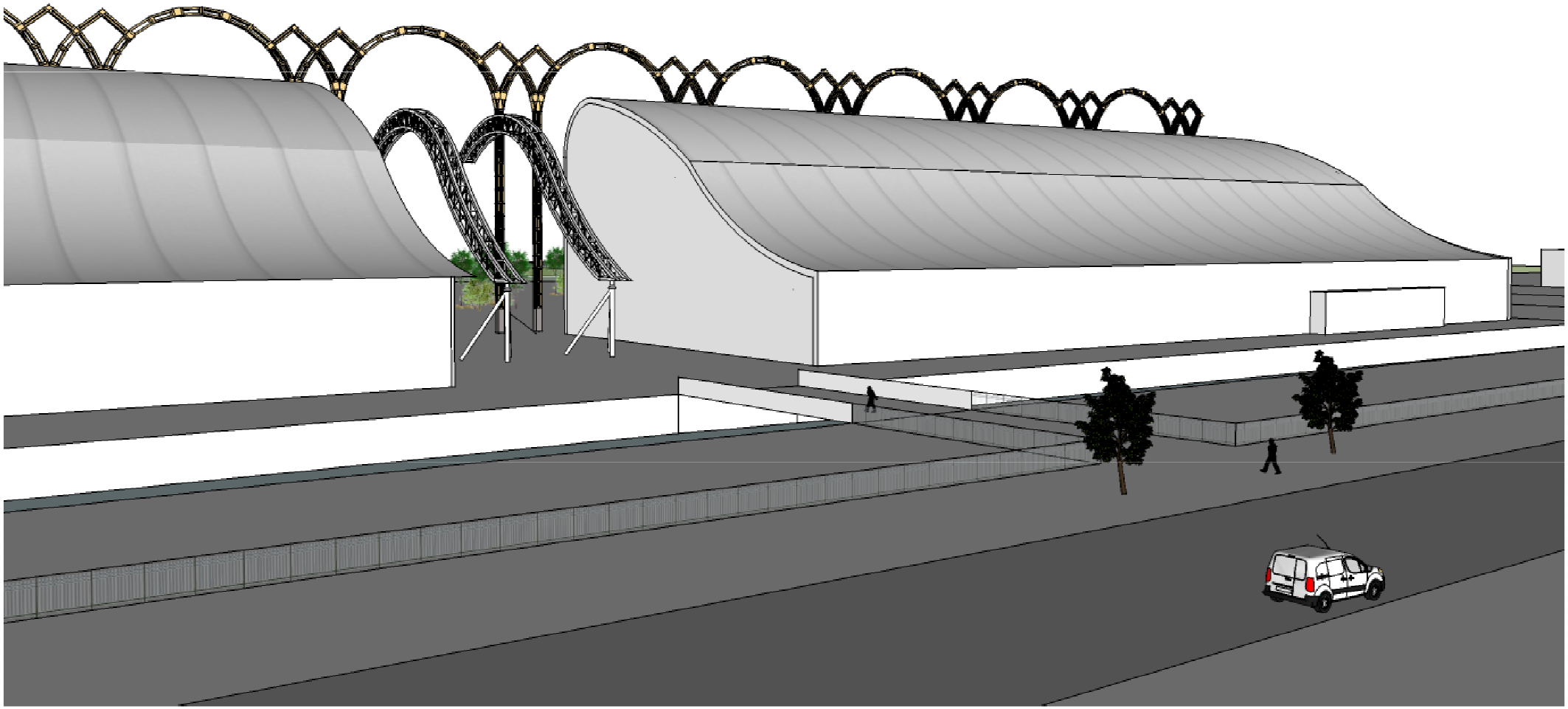
Peter Rice (back to camera) inspects prototype of stone unit at the stonemason's workshop near Vigo, Galicia, Spain.

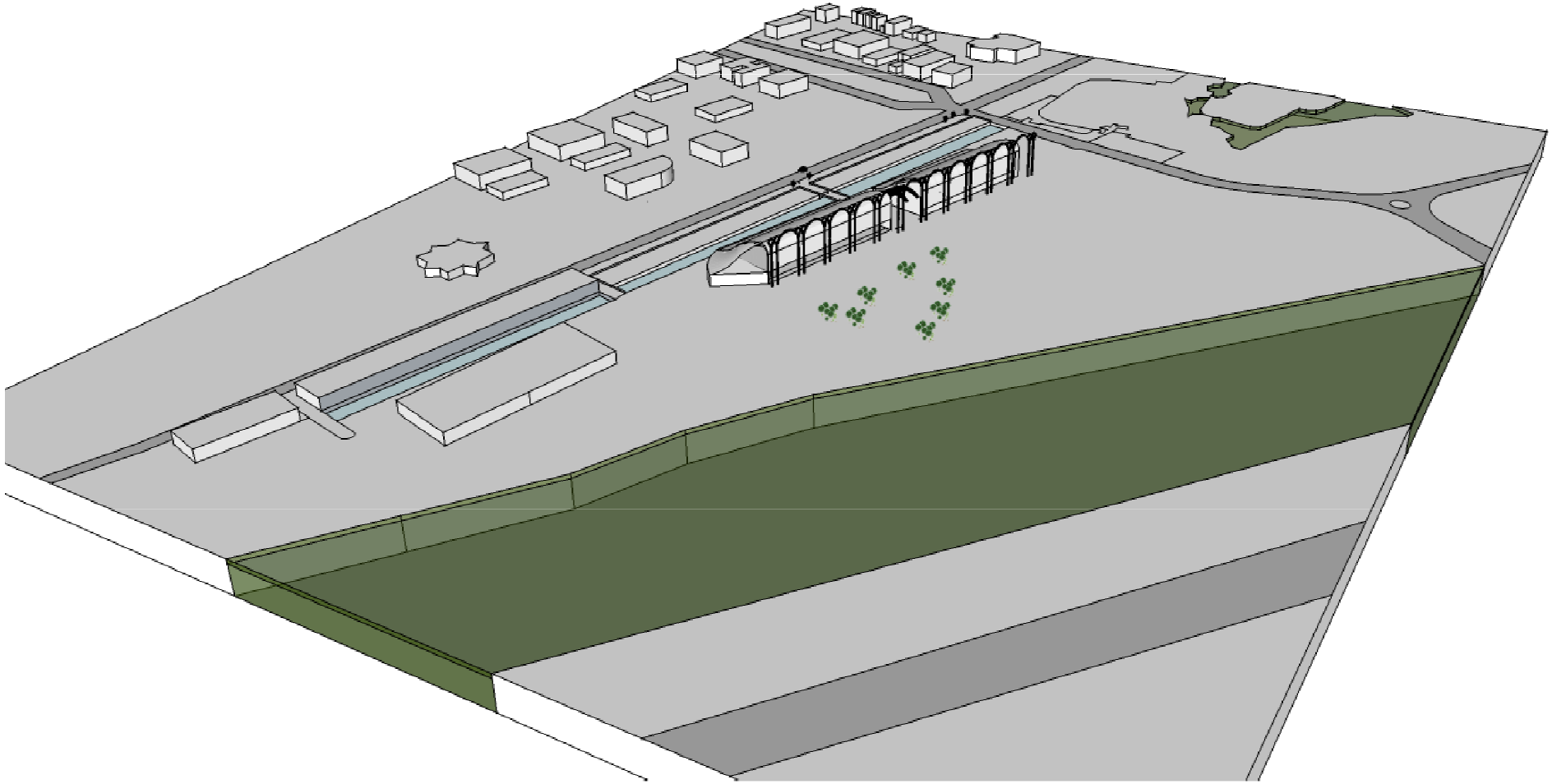


Open column unit in Rosa Porina granite.

View of façade looking south-west during construction.







http://www.sevilla5.com/city-map/cartuja.html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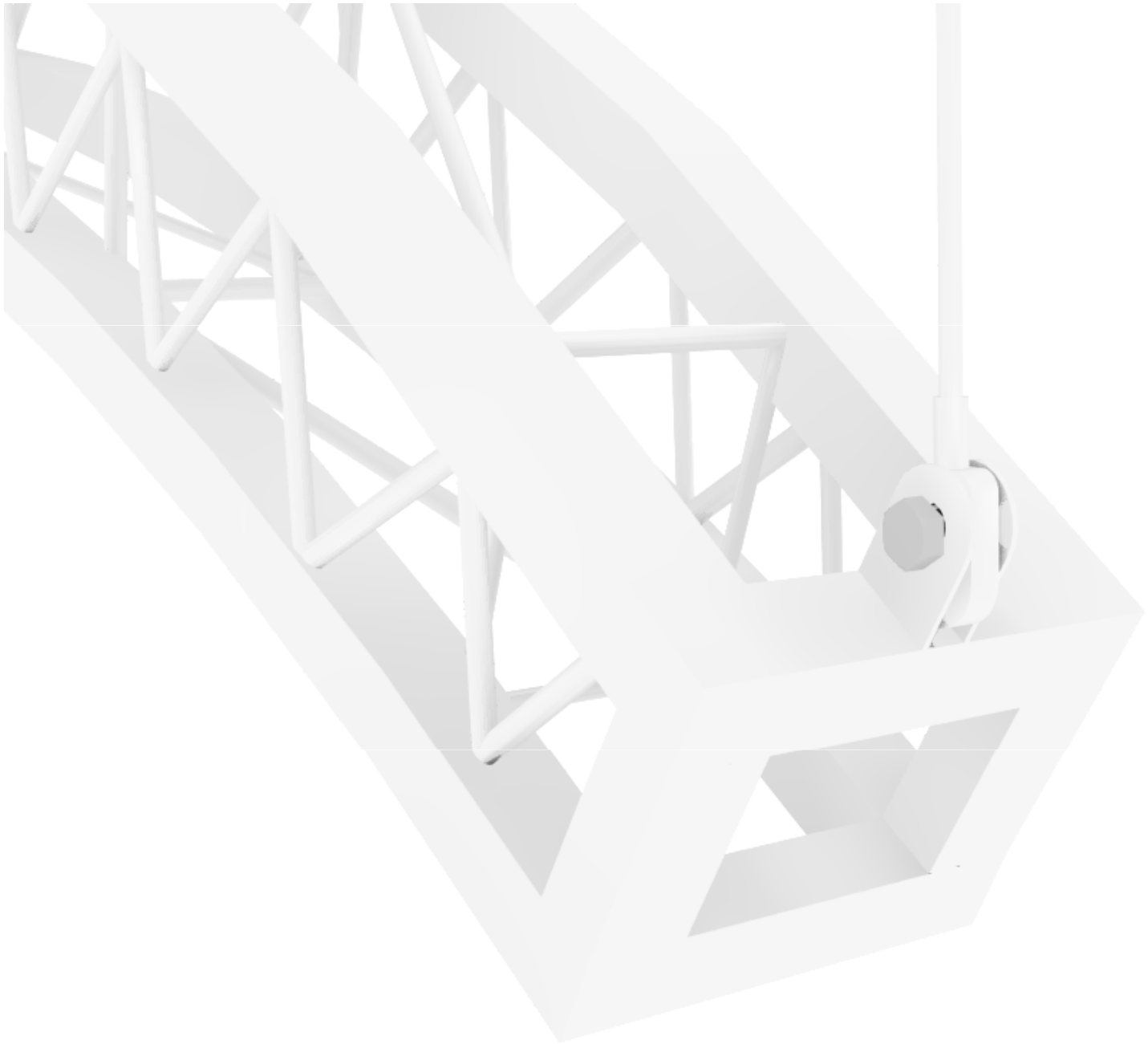
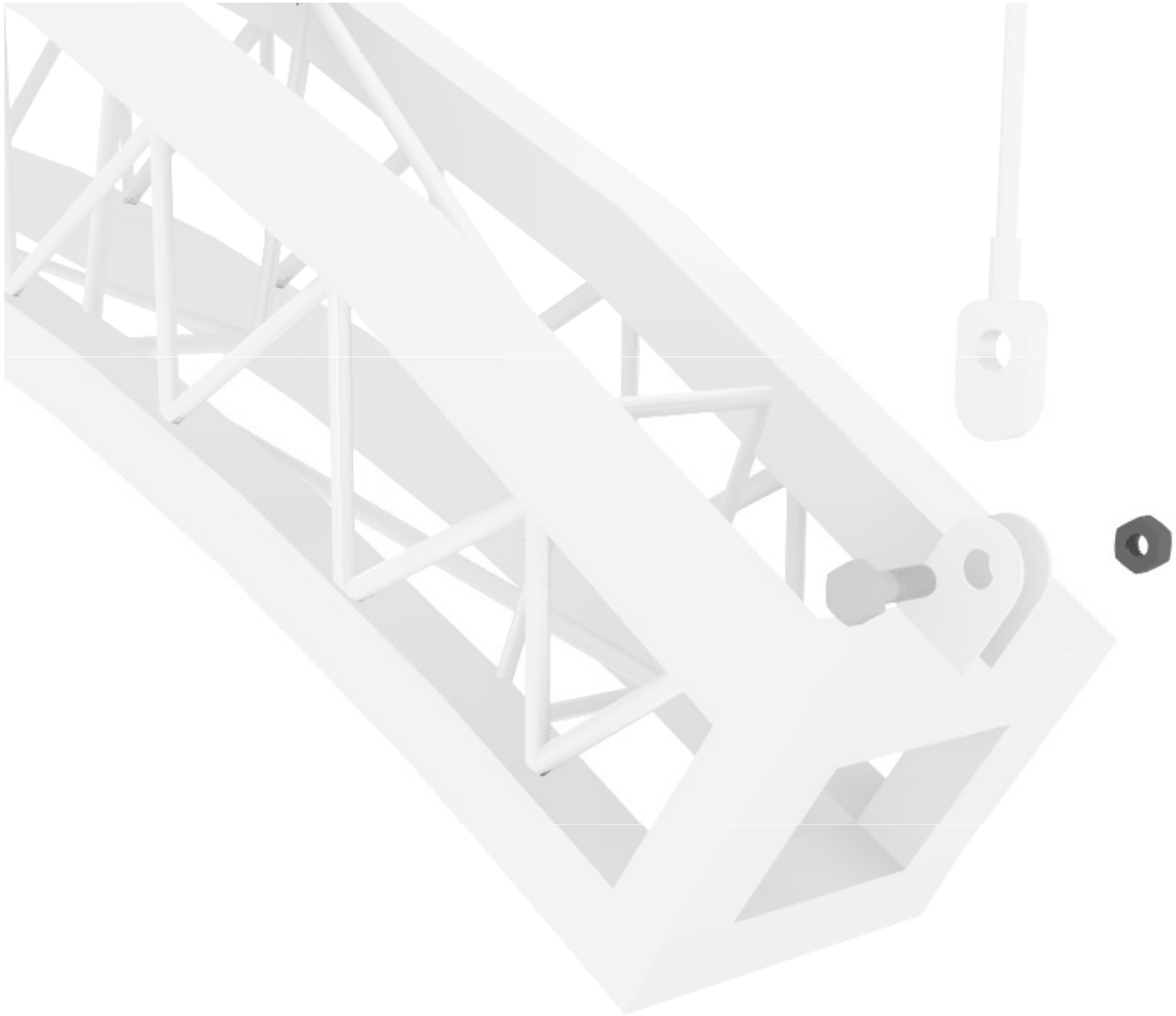
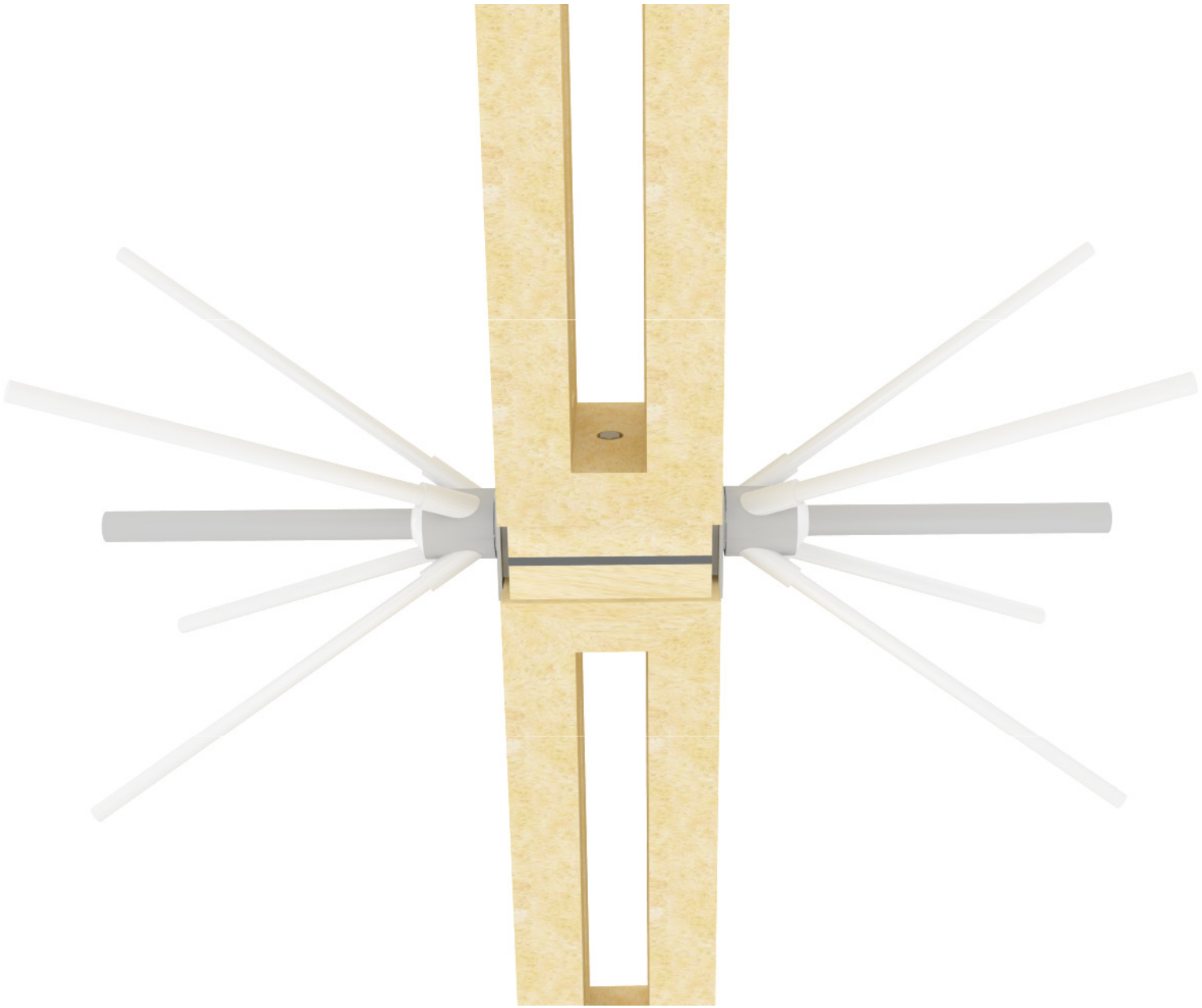
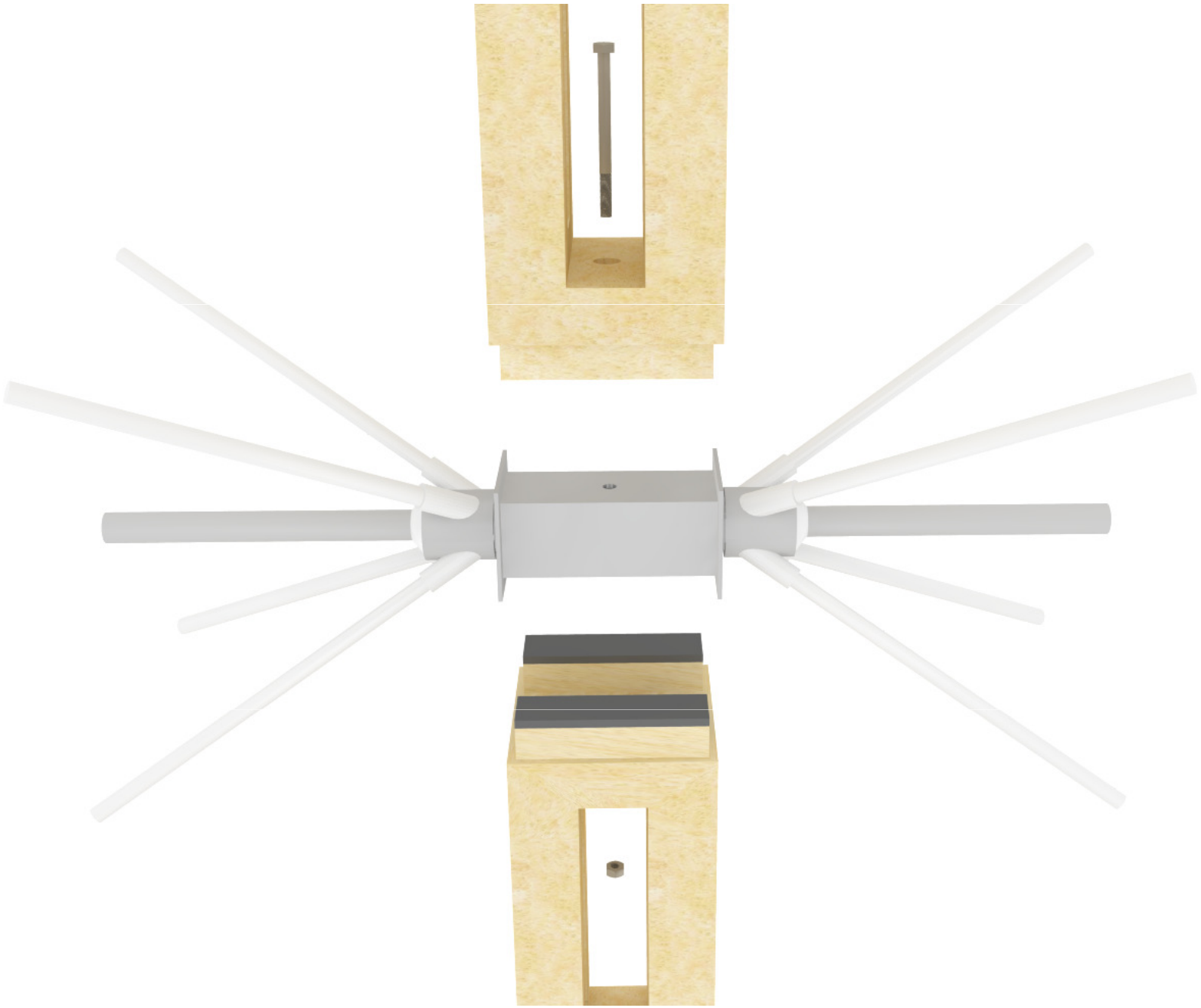
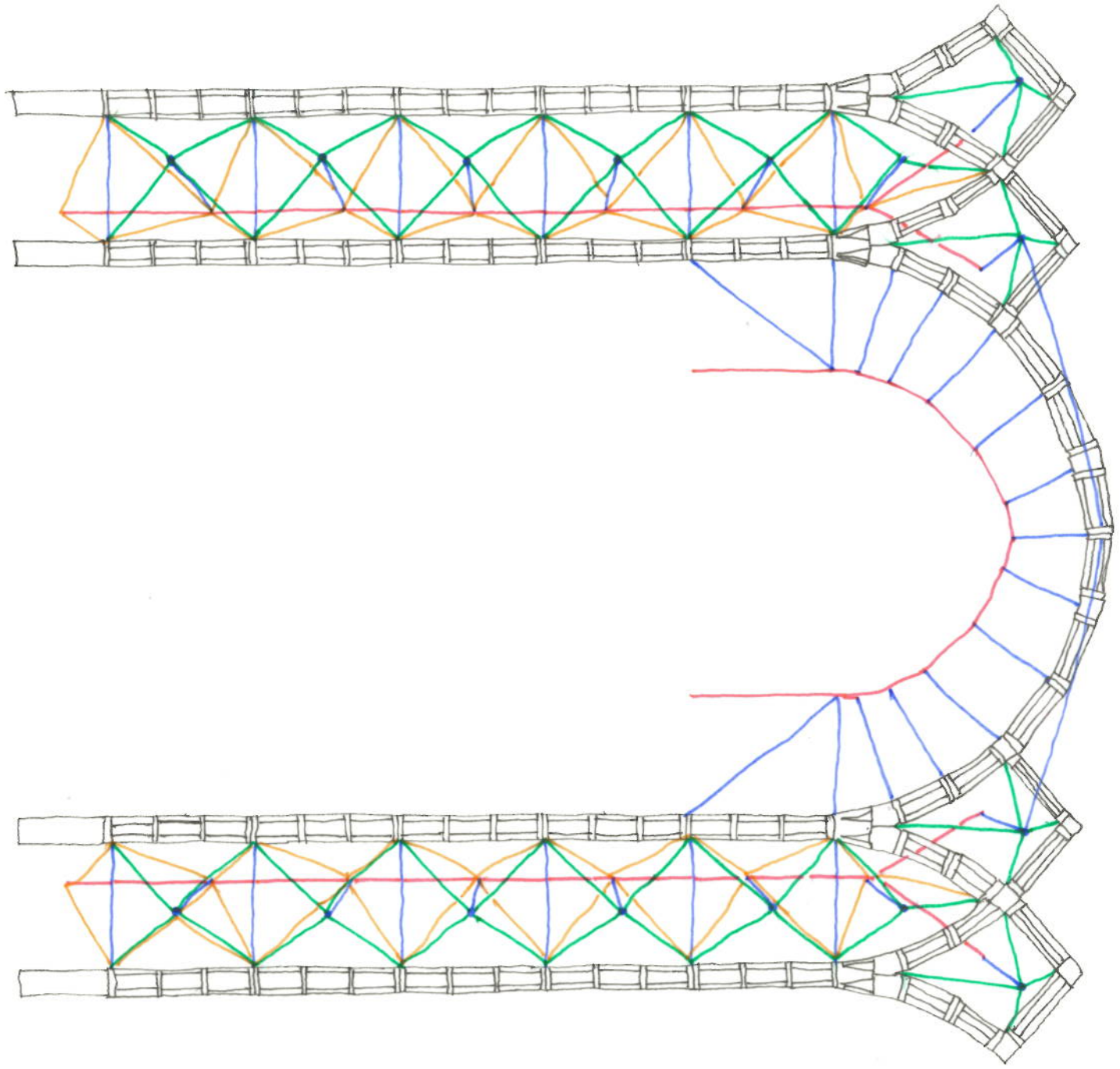
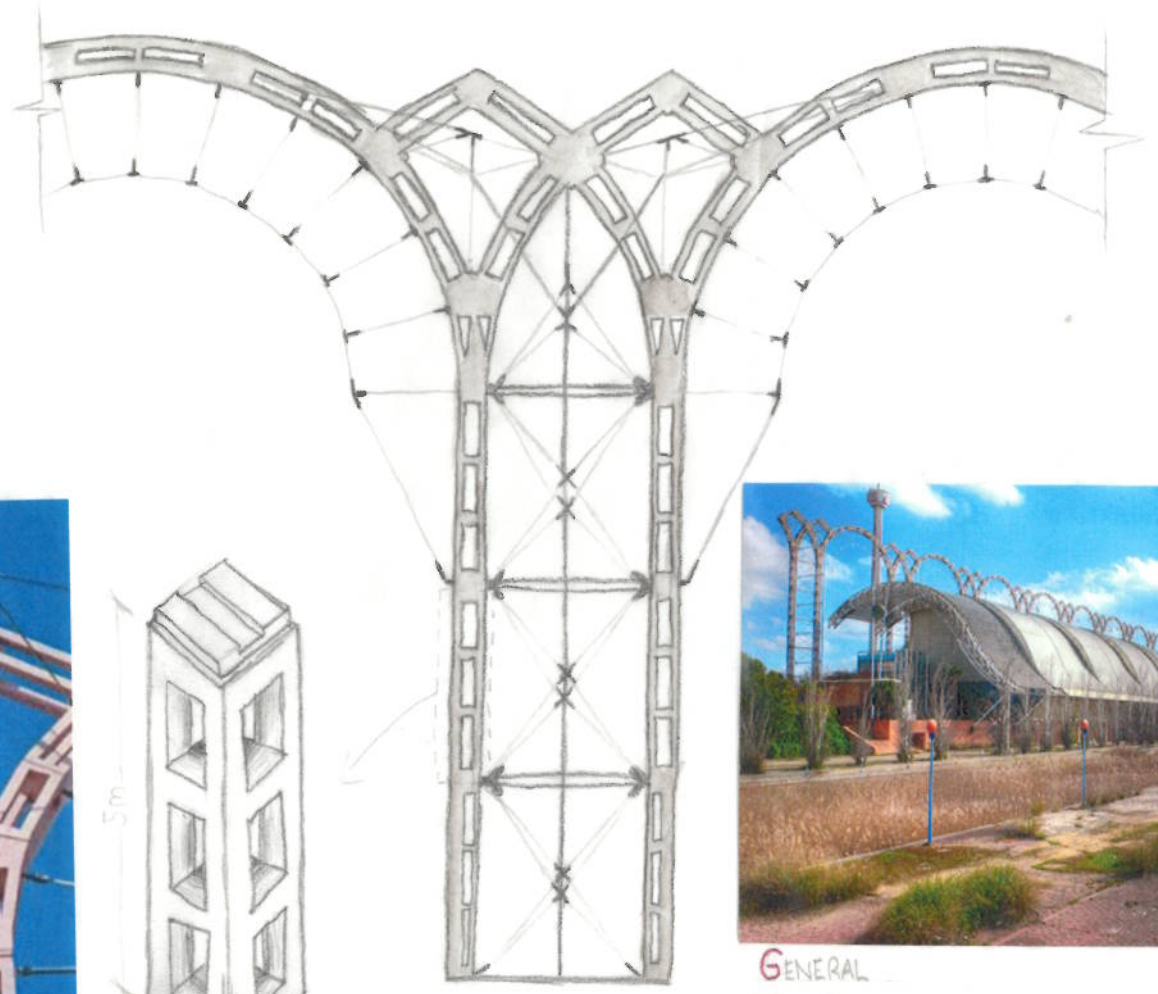


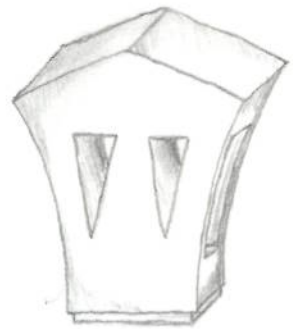






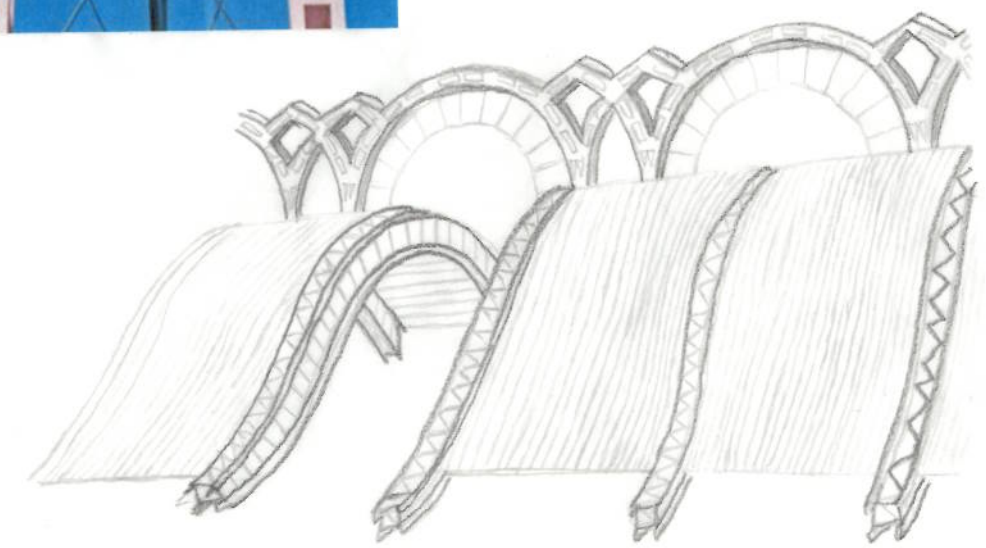






SITE

THE PABELLON DEL FUTURO OR THE PAVILION OF THE FUTURE IN SEVILLA, SPAIN ON THE ISLA DE LA CARTUJA. THIS IS SEEN MARKED IN THE ABOVE PICTURE IN RED. THE BUILDING FACES ONTO THE GUADALQUIVIR RIVER AND TO THE OLD CITY ACROSS THE RIVER ITSELF. IT IS A LARGE SITE AT 25 METRES WIDE BY 300 METRES IN LENGTH APPROXIMATELY.

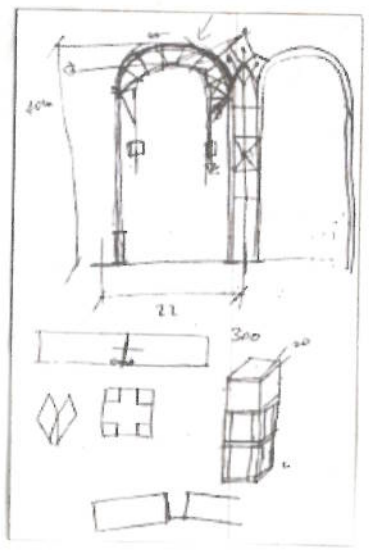


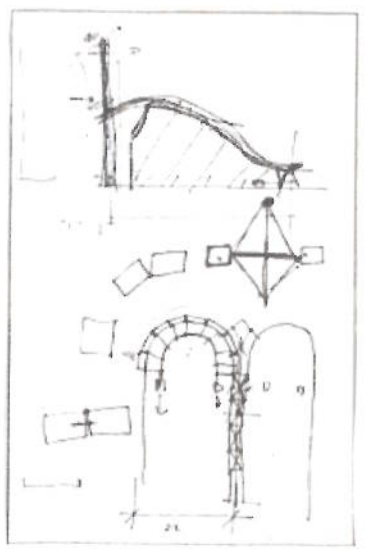
GENERAL

THE PLANNING STAGE OF THE PABELLON DEL FUTURO BEGUN IN 1988 WITH THE CONSTRUCTION BEGINNING IN 1989. THIS WAS ONE OF THE FINAL PROJECTS THAT PETER RICE PARTICIPATED IN BEFORE HIS DEATH IN 1992. THE IMAGE ABOVE SHOWS THE SOMEWHAT ABANDONED SURROUNDINGS OF THE PAVILION. IN A LOT OF CASES BUILDINGS THAT HAVE BEEN BUILT ESPECIALLY FOR EVENTS SUCH AS THE WORLD EXPO '92 BECOME USED LESS FREQUENT THE MORE YEARS THAT PASS. THIS COULD BE AN EXAMPLE.

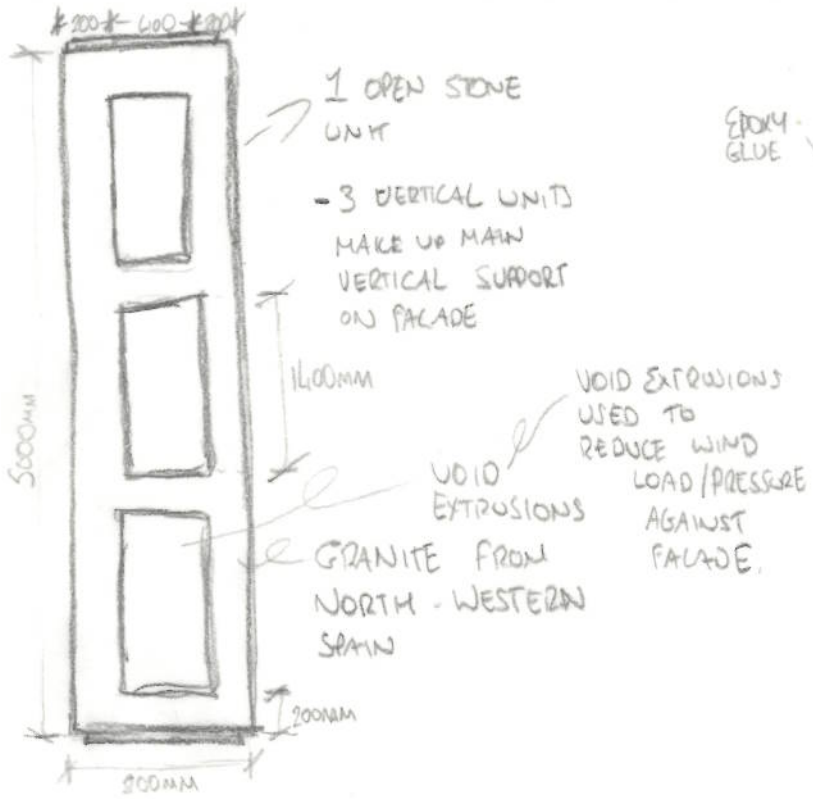
INSPIRATION

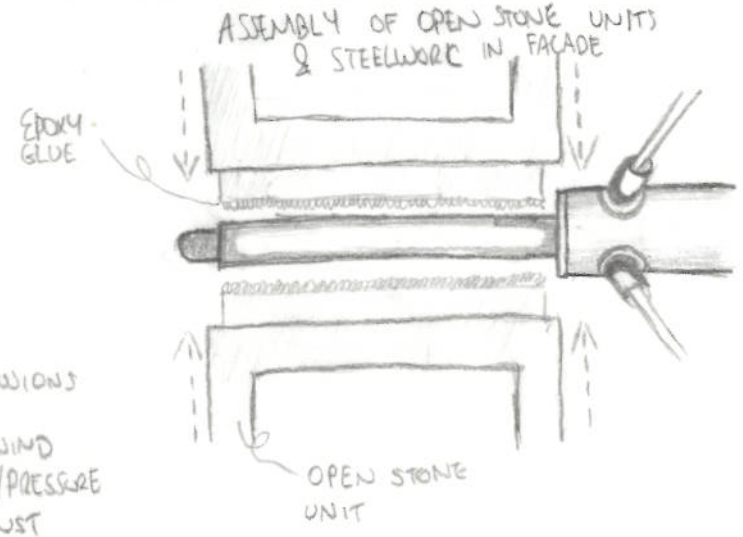
THE PALACIO DE AJUDA IS A BUILDING IN LISBON THAT PETER RICE GREW TREMENDOUS INSPIRATION FROM FOR A POSSIBLE IDEA FOR THE PABELLON DEL FUTURO. THE PALACIO DE AJUDA HAS A WHOLE FACADE UNFINISHED DUE TO THE ATTACK OF NAPOLLON WHILE THE BUILDING WAS BEING CONSTRUCTED. WORK ON IT CAME TO A HOLT DURING THE ATTACKS AND TO THIS DAY HAS NEVER BEEN COMPLETED. RICE WAS AMAZED THAT THIS FACADE SUPPORTED ITSELF FOR SO LONG SO HE DECIDED TO DESIGN A FACADE WITH THE SAME PRINCIPLES AS IN LISBON. RICE, WITH THE CHOSEN ARCHITECTS - MARTORELL BOHIGAS MACKAY EVENTUALLY DESIGNED THE VIADUCT LOOKING FACADE WITH ARCHWAYS AND STEEL CABLE SUPPORTS THROUGHOUT

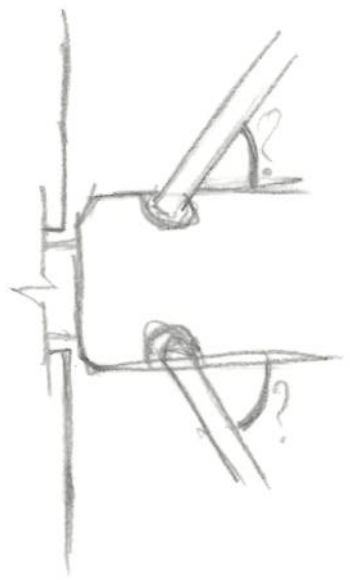


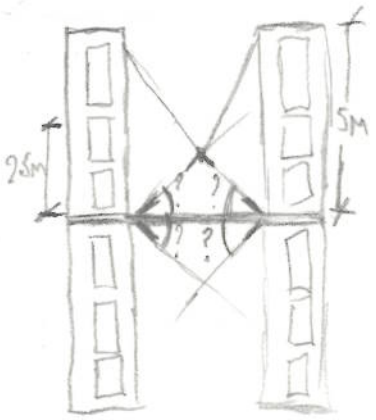


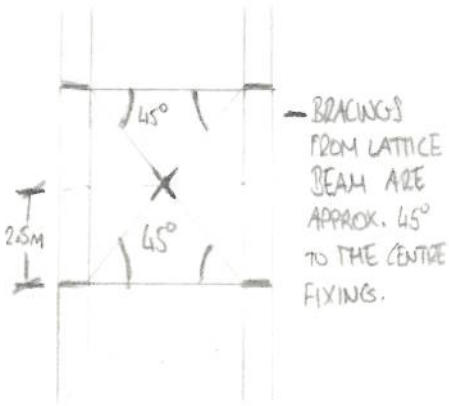
TO THE LEFT IS A SECTION OF THE PAVILION SHOWING THE GRANITE FACADE WITH STEEL BRACINGS AND THE STEEL WAVE-LIKE ROOF

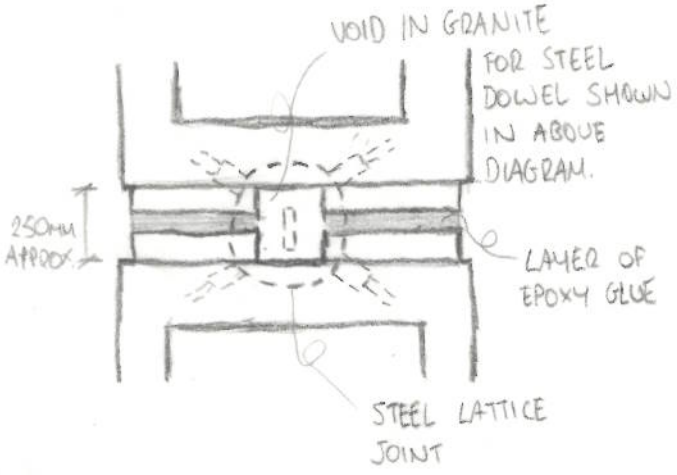

300
600
300
1 OPEN STONE UNIT
- 3 VERTICAL UNITS MAKE UP MAIN VERTICAL SUPPORT ON FACADE
1,600MM
5000MM
VOID EXTRUSIONS USED TO REDUCE WIND LOAD/PRESSURE AGAINST FACADE.
VOID EXTRUSIONS
GRANITE FROM NORTH-WESTERN SPAIN
300MM
900MM

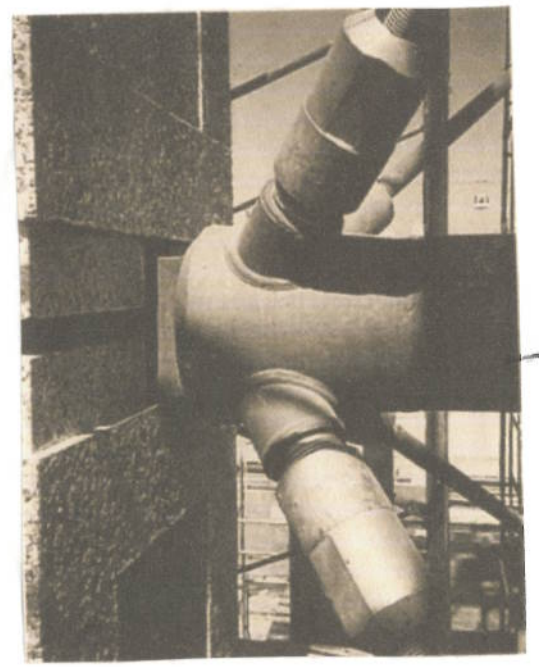

ASSEMBLY OF OPEN STONE UNITS & STEELWORK IN FACADE
EPOXY GLUE
OPEN STONE UNIT

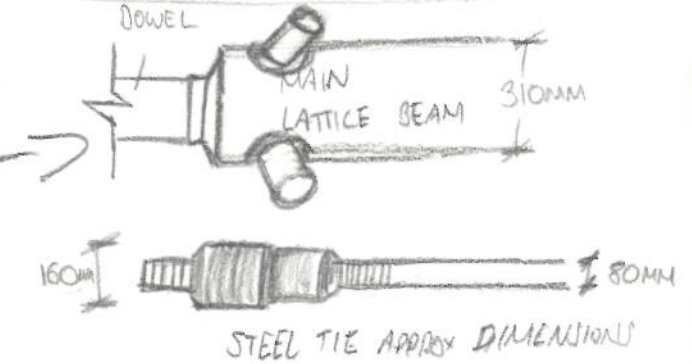


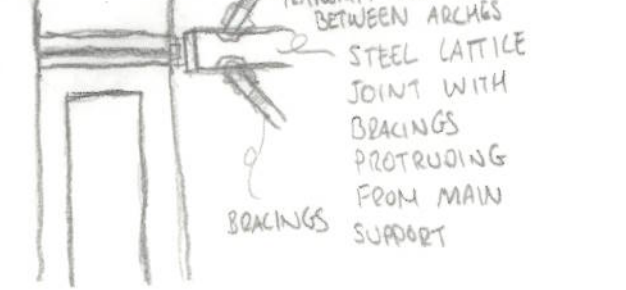

BRACING MEETS AT HALFWAY APPROX (NO EXACT FIG. FOUND)
- 5M HEIGHT OF OPEN STONEWORK
5M
2.5M

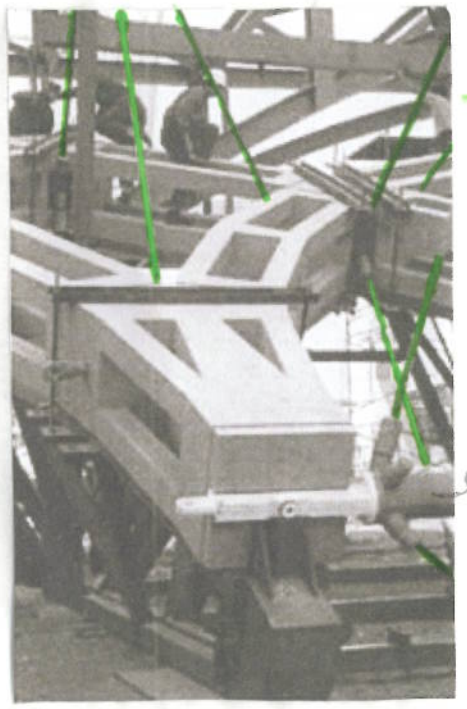

45°
45°
2.5M
- BRACINGS FROM LATTICE BEAM ARE APPROX. 45° TO THE CENTRE FIXINGS.


VOID IN GRANITE FOR STEEL DOWEL SHOWN IN ABOVE DIAGRAM.
250MM APPROX
LAYER OF EPOXY GLUE
STEEL LATTICE JOINT




APPROXIMATE DIMENSIONS OF STEEL LATTICES & TIES
DOWEL
MAIN LATTICE BEAM
310MM
160MM
80MM
STEEL TIE APPROX DIMENSIONS


CONNECTION BETWEEN 2 UNITS:
- EPOXY GLUE & STEEL DOWELS
LATTICE JOINT
- STEEL DOWEL & SUPPORT BRACING
- EACH STEELWORK SUPPORT OCCURS AT EVERY CONNECTION POINT OF THE OPEN UNITS. (EVERY 5 METRES)


GREEN HIGHLIGHTER REPRESENTS THE STEEL BRACING. NOTE THAT THEY ARE FIXED ON TO STONE FACADE AND THEN CRANED AFTERWARDS.
IT IS VISIBLE IN THIS PICTURE TO SEE THE STAINLESS STEEL DOWEL USED TO SUPPORT THE LATERAL BEAM.

GRANITE UNIT TO CONNECT SINGLE VERTICAL UNIT TO PRODUCE ARCHWAY AND TO TRANSMIT VERTICAL LOADS BETWEEN ARCHES
STEEL LATTICE JOINT WITH BRACINGS PROTRUDING FROM MAIN SUPPORT
BRACINGS