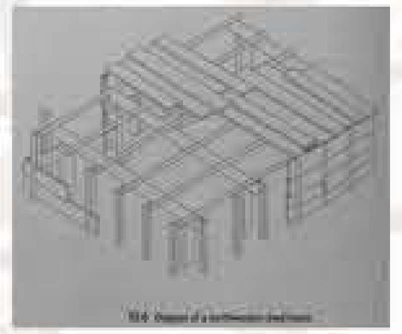
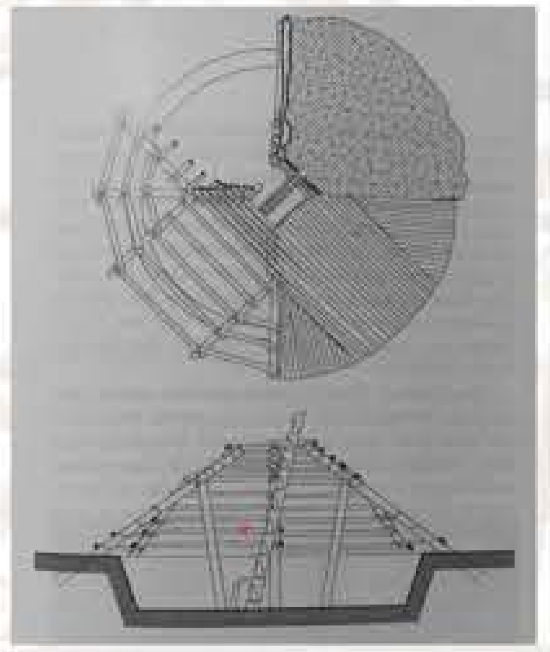
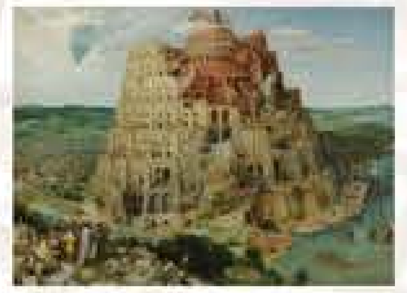
Long span structures have historically required expensive materials and expertise.

Indigenous Architecture in the Pre-Columbian Americas

I am studying this chapter on the history of early human structures in North America because I want to find out how isolated civilizations discovered structural spans using accessible resources to better understand how to simple tools can be used when exploring the prototyping phase of my thesis. Early civilizations discovered and built semi-complex structures using found resources and self-built tools. These structures are some of the first to utilize similar tubular members that I am studying to achieve relatively longer spans. This is the start of the historical timeline that lead me to research the evolution of the tubular structure into complex geometric forms.

Moffett, Marian, Fazio, Michael, Wodehouse, Lawrence. "Buildings Across Time: An Introduction to World Architecture, Chapter 10 Indigenous Architecture in the Pre-Columbian Americas" McGraw-Hill 2004.



"The basic problem of architecture, especially in the case of public buildings and public spaces, is the recognition of the forces that shape the solution." (Barelkowski 55)

"The structures of political and social, ultimately also cultural power are responsible for how architecture evolves and how it is designed, built, and used." (Barelkowski 37)

The Dark Side of Architecture. The Power over Space and the Control of Society

I am studying this paper on the link of architecture to power because I want to find out if power can control material selection in order to better understand if paper tubes can offer the same power and control over architecture in civilizations that do not have the same agendas. Advances in architecture and structure historically have come from wealthy civilizations "funding" the discoveries. Long spans and large structures in architecture still remain out of reach to many due to cost of construction and engineering requirements. Common materials can potentially allow these elements to be obtainable by all and not just in the form of temporary refugee shelters.

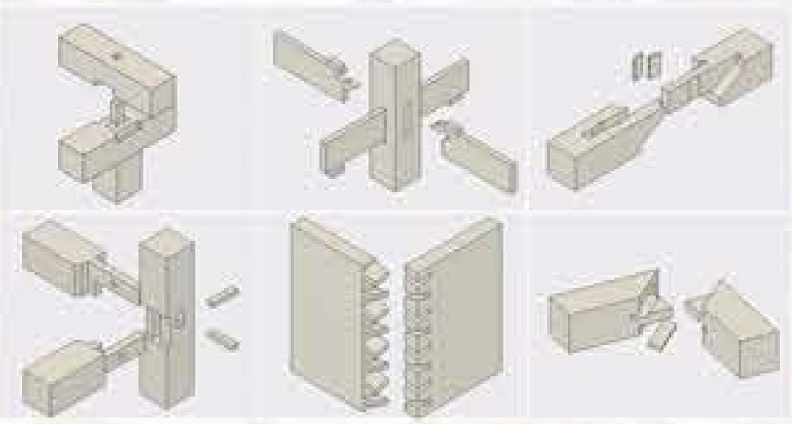
Barelkowski, Robert. (2019). "The Dark Side of Architecture. The Power over Space and the Control of Society. Space & Form.40. 33-74. 10. 21005/pif.2019.40.A-03.

"Tubular Building Materials"

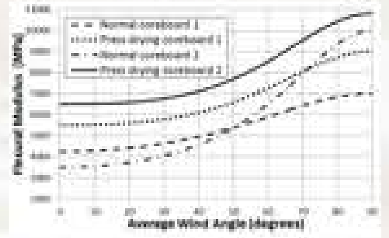
Research Statement

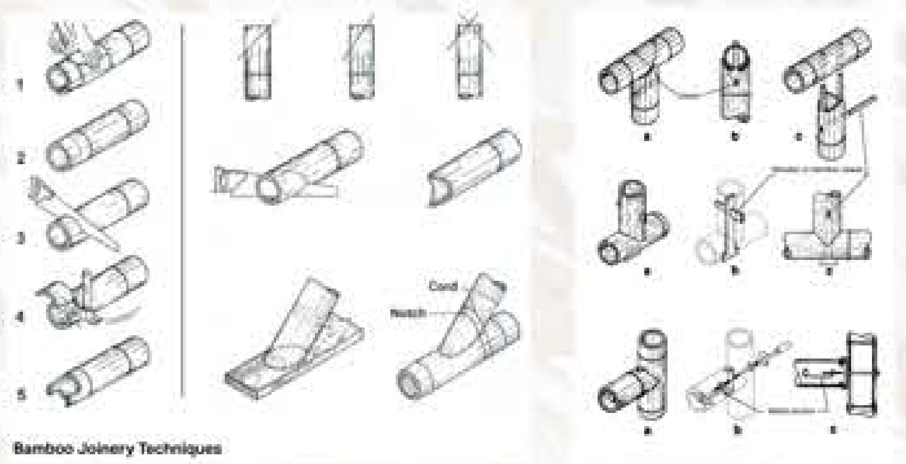
The element under consideration is hollow axial tube members that are easily accessible whether reclaimed or in abundance to be used as structural framing members. Paper tubes as a reclaimed material will be one tubular material under consideration for analysis, along with pvc pipe and rapidly renewable bamboo. These are not the only tubular materials but will be the focus case study material for the research moving forward. Through the use of prototyping and computer aided software these materials will undergo analysis of axial compression, bending and shear stresses. The materials will be compared to each other as well as to themselves in different spans and structural forms. Variables such as, but not limited to, weather and location will be considered when establishing durability of the tubular materials. The information gathered will determine the strengths and weaknesses of each material and will allow the determination of the most efficient methods used to build with each material, specifically when designing the joinery between members. The claim is that these materials can and will be used in complex geometric forms to make the design and construction of long span architecture accessible by the vast majority of the population by replacing more costly material such as steel and concrete that are more commonly used in these applications.


PVC Pipe



Japanese Joinery





Paper Tubes

The properties of structural paper tubes can vary by the manufacturer, but are measured for strength using a flat and radial crush tests. If this material is to be used in construction the biggest challenge beyond the physical strength, is moisture content. Increased moisture exponential decreases the structural properties of these paper tubes and therefore will need to be waterproofed. Paper tubes are recyclable and inexpensive which make them a "common material."

Bamboo

"Common materials" when associated with construction, are often documented as steel, concrete, wood, etc. Another instance of common material would be those that are rapidly renewable or low energy to manufacturer making them accessible. Bamboo is one of the fastest growing plants in the world that naturally grows in a tubular linear form making it ideal for construction. It is light-weight and has great tensile and bending strength allowing it to be formed into many more complex forms than just conventional construction utilizes.

A Timeline of Accessible Spans

The concept of the pit house actually dates back even further but with less common materials. The structure itself is essentially just a roof but it shows signs of early complexity in form using common accessible material and made from simple tools.

▼ ~2000 BC - Pit House

▲ ~1100 -200 BC - Chinese Bamboo Bridges

Chinese civilizations, while not as isolated as some of the indigenous from India and the Americas, have been using bamboo to achieve great spans for over a thousand years and have maintained bamboo bridges for hundreds of years.

The Yurt is a very early tent structure that was built with accessible materials and tools. Tents are not the main focus of this research, but in order to understand complex forms and a way to understand accessibility to complex forms, the "tent" is front and center.

▼ 600 BC - Yurt

▲ 1500 AD - Tipi

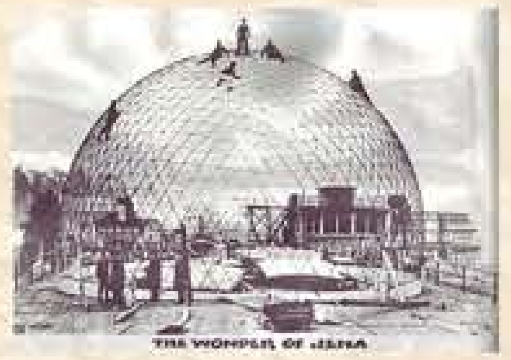
Like the Yurt, the Tipi is another tent structure built with accessible materials. It offers us rudimentary understanding of a tent system with interior supports in compression.

The Wigwam expresses experimentation and understanding in material properties. The indigenous people bent the saplings into arch shapes to form the dome-like structures.

▼ ~1600 AD - Wigwam

A Timeline of Contemporary Precedents

1600s - Scientific Revolution - Advances in Physics



▲ Zeiss-Planetarium Jena - 1926

This is the first geodesic dome and is still standing and functioning as it did nearly one hundred years ago.

The Montreal Biosphere offers a good understanding of complex space frame architecture. While it is a geodesic dome like others before it, or in this case a sphere, it inspired architects on all levels to explore more complex geometric shapes paving the way to the future of complex design.

▼ Montreal Biosphere - 1967

▲ Oguni Dome - 1989

This space frame is unique as it one of the few early long span space frames that used wood linear members with steel nodes. It is a double layer barrel vault making it more modern and complex for the time.

"We cannot clearly be aware of what we possess till we have the means of knowing what others possess before us" (Kurrer)

Kurrer, Karl-Eugen. The History of the Theory of Structures: Searching for Equilibrium. Wilhelm Ernst & Sohn 2018.

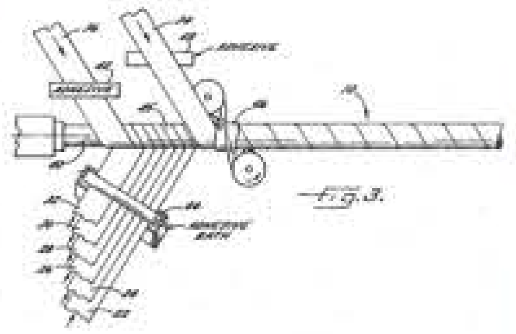
"History of Tubular Structures"

Research Statement

The element under consideration is tubular structures through history and the means and methods implemented by indigenous civilizations in the construction of these structures. To establish a comparison, these civilizations were making discoveries while other civilizations of power were using greater resources to create even larger scale architecture. The exact means of analysis will be how the indigenous built these structures and with what tools were used. The tools and technology were limited and often times the tools had to be made first with the resources they had, example being animal bones used for carving. Long spans that were achieved will be analyzed for their complexity of construction. The level of complexity of the spans will be compared and cross referenced to advances in scientific research. Knowing the limitations of simple tools will allow an establishment of precedence and goals for the level of difficulty for the type of structures that this research project aims to surpass. This will also help with a precedent for prototyping and using these simple tools and methods. The claim is that implementing state of the art technologies to analyze and improve simple methods of construction from historical contexts will allow longer spans to be achieved with the same or even simpler methods of construction.

Gerhardt, Rhodes, Johnson, Wang, McCarthy. Performance of Paper Tubes, 1999 Session 2 https://shareok.org/bitstream/handle/11244/321806/oksd_icwh_1999_gerhardt1.pdf?sequence=1





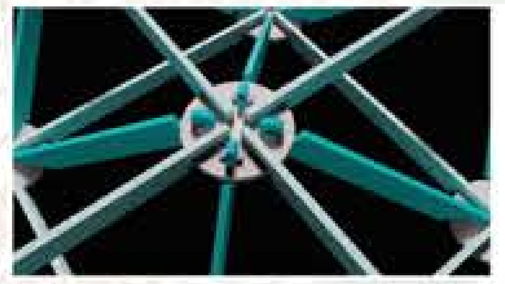
"Paper strength is significantly reduced when it is exposed to elevated humidity environments, so the use of large paperboard tubes in load–bearing architectural structures is uncommon." (Bank and Gerhardt 4)

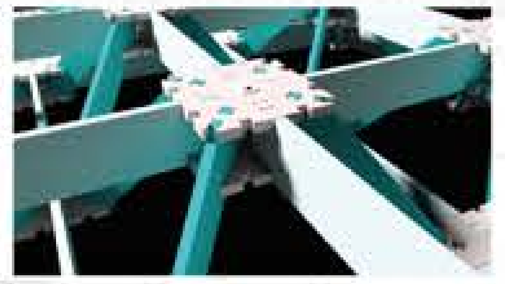
Paperboard Tubes in Architecture and Structural Engineering: A Review

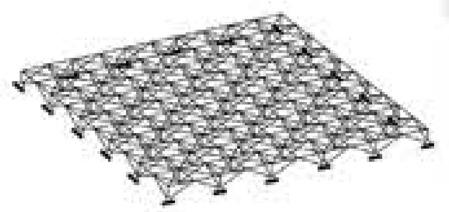
I am studying this review of paper tubes because I want to find out how paper tubes are manufactured in order to better understand the variables that the manufacturing process has on the structural integrity of the paper tubes. The government does not directly regulate the use of structural paper tubes meaning the designer and structural engineer must exercise caution in the selection of paper tubes. Understanding what makes paper tubes potentially stronger, will give me a baseline as to where the paper tubes I acquire for prototyping compare. This will ultimately help with achieving the spans and appropriate joinery to avoid premature material failure.

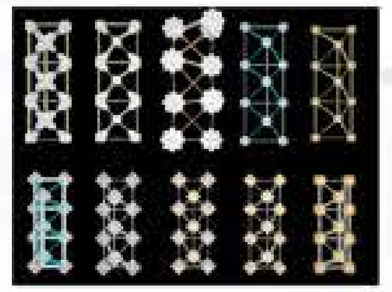
Bank, Lawrence, Gerhardt, Terry. "PAPERBOARD TUBES IN ARCHITECTURE AND STRUCTURAL ENGINEERING : A REVIEW" Conference: NOCMAT 16 At: Winnipeg, Manitoba, CANADA Volume: 1 Published 2015 https://www.researchgate.net/publication/298064617_PAPERBOARD_TUBES_IN_ARCHITECTURE_AND_STRUCTURAL_ENGINEERING_A_REVIEW

Bhonde, Nagarnaik, Parbat, Waghe. Physical and Mechanical Properties of Bamboo. International Journal of Scientific & Engineering Research, Volume 5, Issue 1 2014.





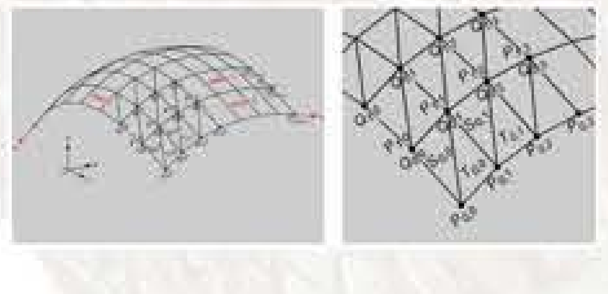
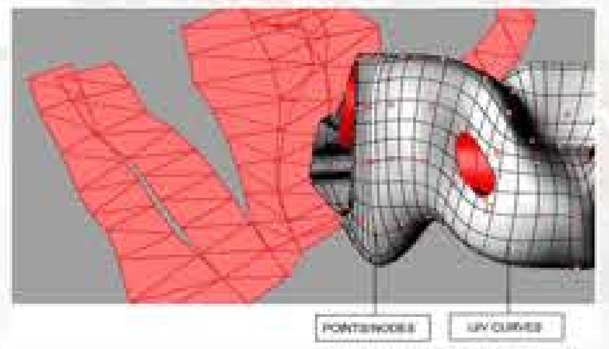


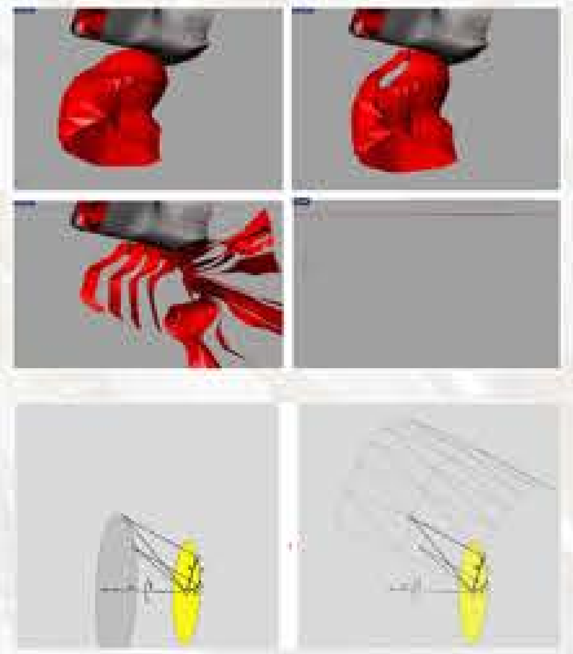


Experiments in Timber Space Frame Design: Fabrication, Construction and Structural Performance

I am studying this case study of an experimental wood space frame structure because I want to find out how they used computer aided manufacturing in order to better understand how these simulations helped achieve the long horizontal spans. The aim of the study was to utilize CNC routing technologies to create joinery that would allow the wood to be assembled into a 3D structural matrix that will ultimately be lighter and more economical than equivalent spans with comparable conventional materials. Over complexity can be an issue for real world implementation but it is a step in the right direction for structural long span research.

Finch, Gerard, Gjerde, Morten, Marriage, Guy, Pelosi, Anthony. Experiments in Timber Space Frame Design: Fabrication, Construction and Structural Performance, 2019. https://www.researchgate.net/publication/332567655.



SpaceCustomizer: Scripting Based Methods in Architectural Design

I am studying this paper about the relationship between mathematics, programming, 3D modeling in the context of designing with NURBS surfaces because I want to see how the software can be used to create controlled organic forms in order to better understand the process of analyzing my future generated forms and connections. The unrolled forms that the scripts generate become a way to analyze the behaviors of the nodes or points of the UV-Curve as well as the entire system. These unrolled forms can also be studied to develop programmed space by understanding the methods in which it is constructed.

Bier, Henriette, Schmehl, Roland 2006. SpaceCustomizer: Scripting Based Methods in Architectural Design. https://www.researchgate.net/publication/260592302

https://www.archdaily.com/796918/these-mesmerizing-gifs-illustrate-the-art-of-traditional-japanese-wood-joinery

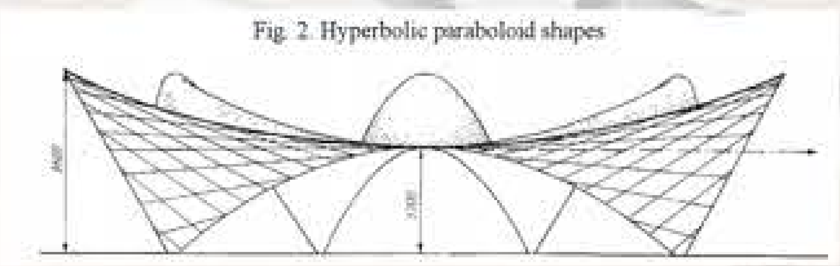
Simple tools can be used to errect complex forms.

Paraboloid geometric shapes can acheive longs spans with less material.

"Paraboloid Geometric Shapes"

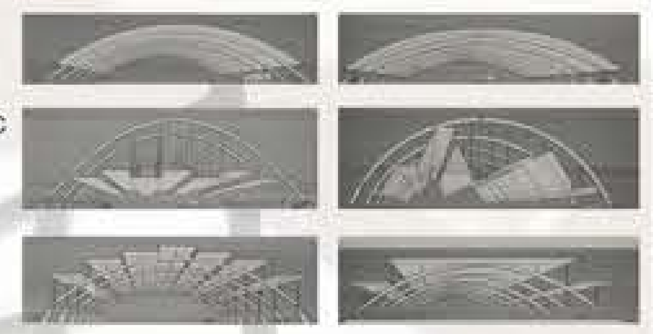
Research Statement

The element under consideration is Paraboloid Geometric shapes or three dimensional parabolic shapes used in structural long spans. Study of known equations and past knowledge of these forms is essential. It is important to note that the research intent is not to create a new form or to discover a new quadratic equation but to better establish the connection between the complex and the simple. These forms will be heavily analyzed and generated in computer modeling software in order to establish design strategies. Research of software to best achieve this will become a part of the research prior to the analysis of the forms themselves. These shapes will be paired with the complex structural systems of space frames, space frame arches, geodesic domes, and grid shells to determine the most efficient forms for the spans and simple methods of construction to be used. The claim is that these complex geometric shapes can be paired with the most modest of materials and simple tools to achieve great lengths of structural spans. This is the present and future of tubular construction and it is paramount that this become one of the main focuses of research and will be the main driver of all prototyping.

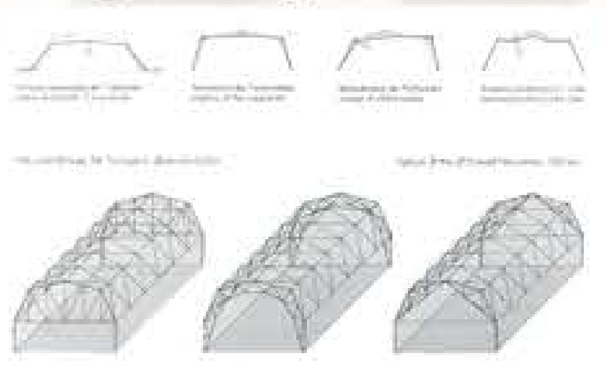


Structure Systems

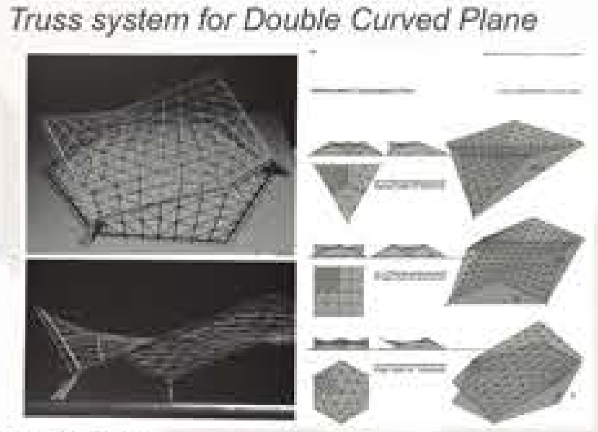
Long Span Arches



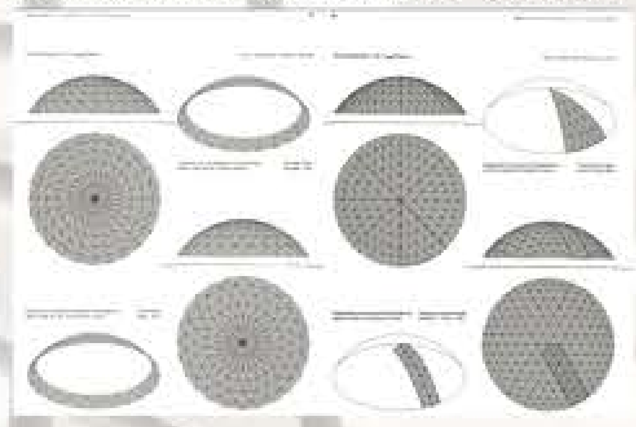
Truss system for Single Curved Plane



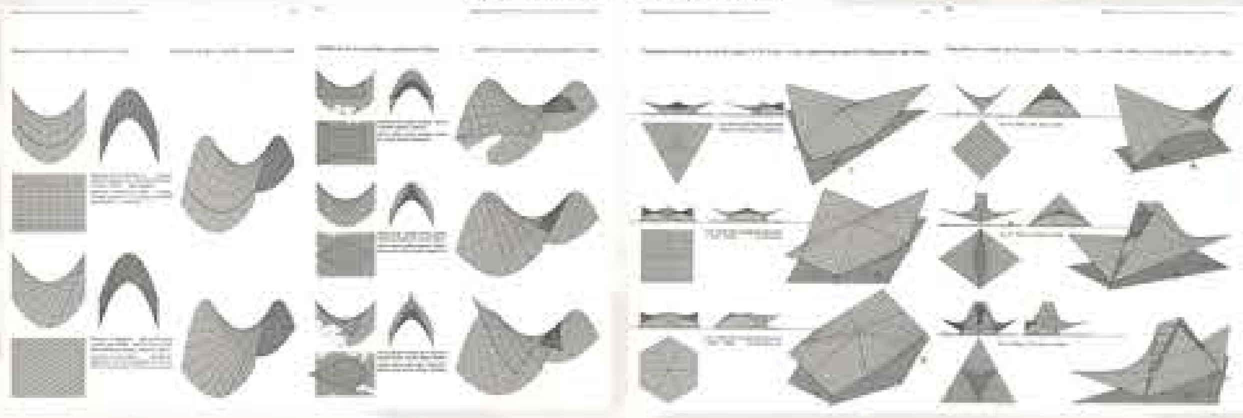
Truss system for Double Curved Plane



Truss system for Spherical Plane- Synclastic

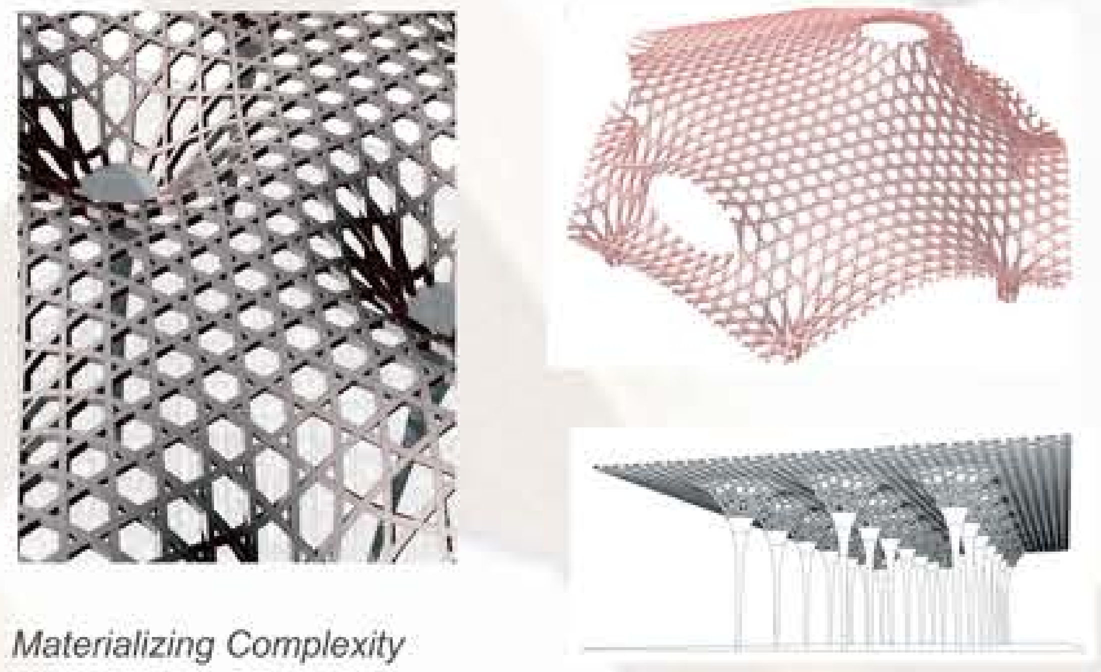


Anticlastic Shell Systems



Short linear members are only capable of transfering normal stresses, but when assembled together in common shapes like triangles and hexagons and arranged in certain patterns with the appropriate joinery, they can transfer loads in great distances without support.

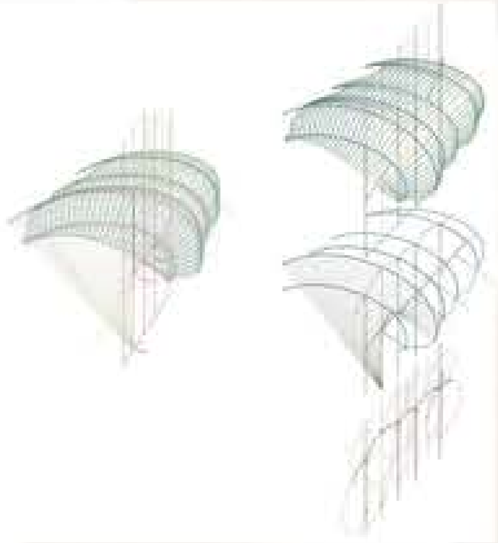
Heino, Engel. Structural Systems. New York Praeger 1968.



Materializing Complexity

I am studying this article on the emergence of complex forms over the past few decades because I want to find out how they were generated to better understand how to document, simulate, and analyze complex geometric forms. The document notes the transitional period in which architecture when from regular to irregular and references Zaha Hadid for her famous complex geometric shapes and their expensive price tag. Software has made these shapes more feasible but still not readily obtainable by all because of the cost for certain building materials to take on these complex geometries can still be costly even with less material.

Scheurer, Fabian. Materialising Complexity. Architectural Design July/August Vol 80, No 4, pp. 86-93.



"...structural engineering has to be a creative contribution to the design process." (Mangelsdorf 45)

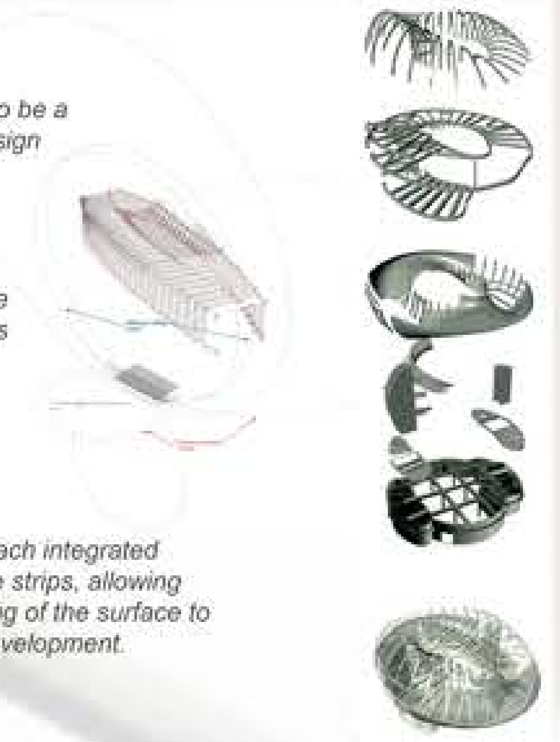
"Allows a high degree of freedom in the development of the form, but integrates concepts based on physics, form description and fabrication. (Mangelsdorf 41)"

"...a parametric modelling approach integrated with the structural analysis of the strips, allowing he aesthetics and the engineering of the surface to be investigated in an iterative development. (Mangelsdorf 44)

Structural Strategies For Complex Geometries

I am studying this article outlining methods of approach for designing complex structures because I want to find out these forms have been used in large scale architecture to better understand how to design and implement similar approaches with reclaimed modest materials. The article gives case studies that implemented physical prototyping to help determine initial geometry and behavior of the material. The initial shapes were then further simulated and developed using computer models. Another case study was able to reach long spans column-free by designing a series of interlocking ridges and valleys. These methods are a good starting point for research development.

Mangelsdorf, Wolf. "Structuring Strategies for Complex Geometries." Architectural Design July/August Vol 80, No 4, pp. 40-45.



Built for an expo, Shigeru Ban used paper tubes in a grid-shell to span great distances. Additional materials were used to support the roof and tension cabling was added for additional support, but this was still a huge advancement and a major precedent to any structure pursuant of paper tubes as the primary building material.

▼ *2000 Japan Pavilion*

The Rural studio was able to create this arched structure by spanning conventional lumber accessible from any lumber yard without any additional mid-span supports by implementing a more complex framing strategy that allows members to transfer more than just basic loads.

▼ *2006 Hale County Animal Shelter*

This pavilion combines old bamboo techniques of weaving the structure for added stability with modern understanding of complex forms.

▼ *2018 Bamboo Pavilion*

This is one of the largest wooden grid shell buildings in Europe and is really showcasing the precision of computer aided technologies to complex forms.

▼ *2019 Swatch Omega*

▲ *1982 IBM Pavilion*

This structure uses repeating modular processes to make it very easy to assemble and disassemble as a temporary exhibit. The modular pieces are also very unique. These arches were constructed of polycarbonate pyramids connected to timber arches at the three points of their cross sectional triangle.

▲ *2001 Zeri Bamboo Pavilion Bridge*

This bridge offers a more modern understanding of the span capabilities of bamboo.

▲ *2010 Centre Pompidou-Metz*

The complexity of the roof of this structure and the integration of the vertical supports lifts previous speculations as to the limitations of flat linear wood framing members. Shigeru Ban once again is able to push the properties of materials as well as modify connection details as he did here.

▲ *2019 Luum Temple*

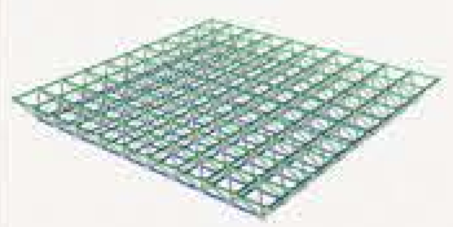
This structure utilizes bamboo techniques of weaving to create an anticlastic shell system much like Felix Candela's concrete forms.

▲ *2021 The Arc at Green School*

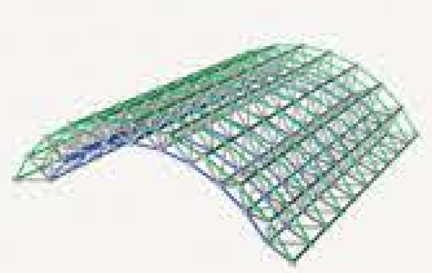
This is great example of tubular members bundled to achieve stronger members for spanning. This structure utilizes old techniques of bending bamboo into arches to create a relatively complex form. This type of structure may have had cranes on site to erect the large arches, but the methods of construction were relatively simple.

Flat Double Layer Grids Square on Square Offset

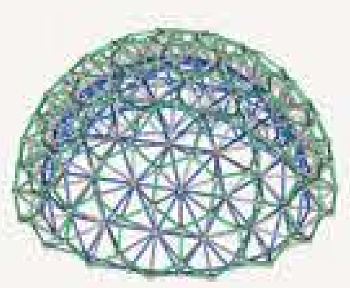
Double Layer Braced Barrel Vault



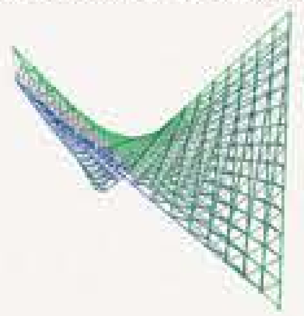
Double Layer Braced Dome



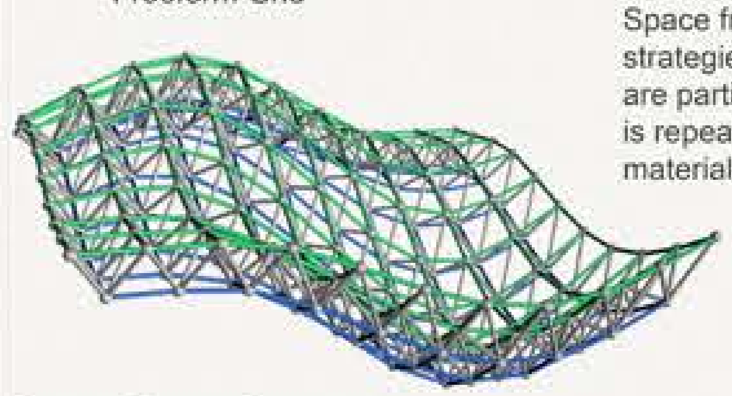
Double Layer Hyperbolic-Paraboloid



Double Layer Freeform Grid



Space frames are a cost effective strategy of long spanning that implement many of the strategies for the construction of common materials needed to be successful. The details are particularly minimal once the complexity is solved. The node, or structural connector, is repeated as infinitely as needed and becomes the mechanism for small length tubular materials to transfer loads great distances.



Space Frame Structures

I am studying this article on the concepts of space frame structures because I want to find out advantages of space frames to better understand the strategies and implemented when designing a space frame structure. This article simplifies the approach to establishing a geometric form and then breaks the space frame structures into modules. These details can be applied to different tubular materials and analyzed specifically based on the weight of the material to establish the appropriate geometry and layers. It continues with a more complex analysis of structure, but lists and explains several types of tubular structural space frame typologies, including possibly the most complex yet most versatile, the hyperbolic paraboloid.

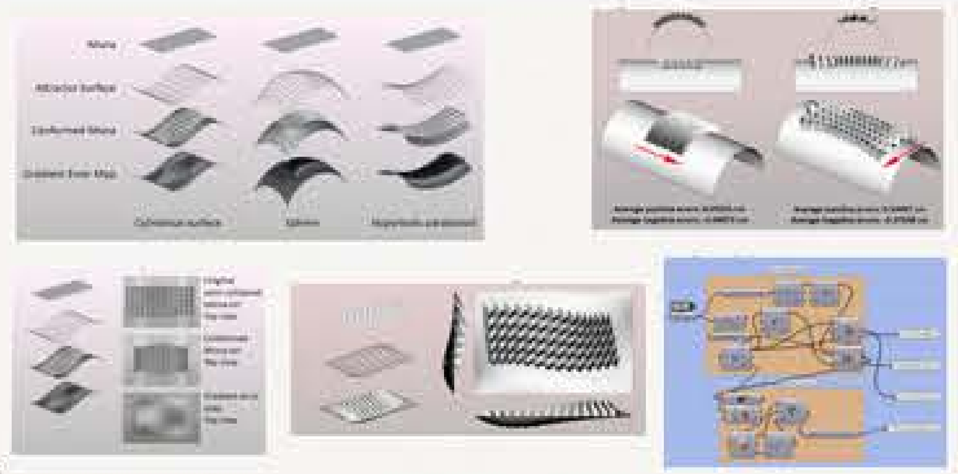
Lan, T.T. "Space Frame Structures" Structural Engineering Handbook Ed. Chen Wai-Fah Boca Raton: CRC Press LLC, 1999

"Spatial (space) Structures" Structure and Form Analysis System (SAFAS) https://www.setareh.arch.vt.edu/safas/009_introduction_01_ss.html

Conformation of a flexible Miura Pattern on a double Curvature Surface

I am studying this article about a case study and analysis of a parametric double curvature surface because I need to know the tools in order to better understand how to generate these parametric models. Designing with complex curved surfaces have become much more common in recent years, but a lot of the industry software hinder and limit these designs. In order to create and analyze space frames in anticlastic forms that can vary based on the existing context, mathematical algorithms will be required and grasshopper will perform. No two forms will necessarily be the same but the process is streamlined with math and the planning becomes less complex and adaptable, which is one of the primary goals of this thesis. It is noted that this not an analysis of tubular materials but the principal findings of the article are still very relevant.

Foschi, Riccardo. "Conformation of a Flexible Miura Pattern on a Double Curvature Surface" University of Bologna 2017

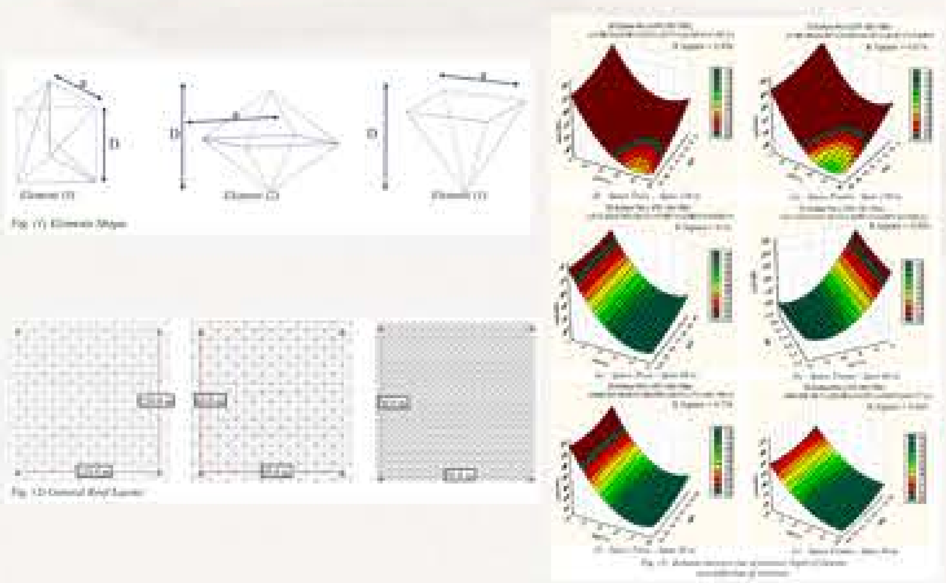


Optimization of Space Frame Design

I am studying this paper about the relationship between the size and depth of elements of a space frame because I want to be able to establish parameters in order to better understand how to design node connections. The analysis is using steel as a material, therefore the numbers will be different based on material choice, but with use of structural analysis software it is possible to establish variables that affect the design of a space frame and at what percentage of influence each have. The variables are Span, Element shape, Size, and Depth with depth having a heavy impact of the efficiency of the space frame span. This knowledge will help determine the effective angles of the connections regardless of material.

Sulayfani, Bayar Jafar Al. "Optimization of Space Frame Design" https://www.researchgate.net/publication/283734100

"Architect Shigeru Ban - A master of material"



Wood

"Shigeru Ban has developed both a new architectural language and radical engineering technique through his use of large tubes made of recycled paper..." (Wahab 5)

Paper

Shigeru Ban has used his knowledge of recycled paper tubes to design and build several temporary refugee shelters, schools, and cathedrals in response to natural disasters.

Research Statement

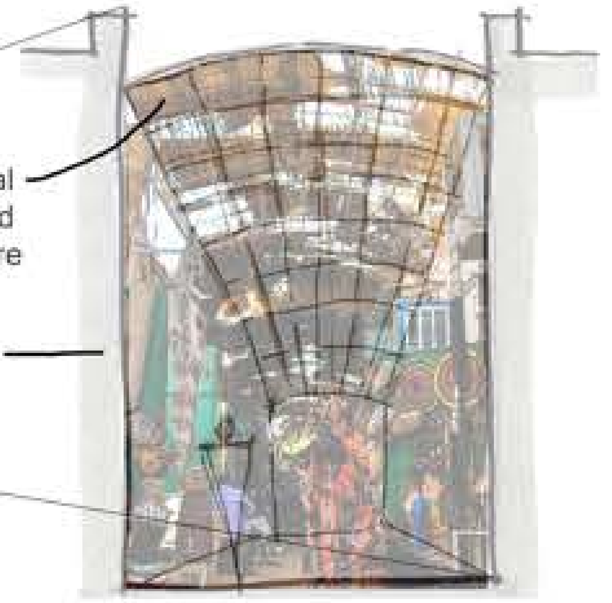
The element under consideration is the work of the Japanese Architect Shigeru Ban. Ban primarily works with tubular materials of the paper variety for disaster recovery projects. He also has achieved some of the longest and most complex spans using the extremely modest material. The analysis will be of the material and forms that he used in his designs as well as the drivers behind the projects. The methods and technology used to construct his project will be under close analysis. While his projects have been primarily in support of environmental and sustainability practices, some of the more complex longer span projects have been world showcase projects and that may blur the lines of simple and complex means of construction. The evidence will show how modest material long spans have been achieved in the past. Shigeru Ban has pushed the material of paper tubes far beyond many could have expected. He even has been able to water and fire proof the material as well as created "temporary structures" to last 50 years. The claim is that this material and these spans can be simplified further and become more accessible to a greater population due in part to a constantly improving technology.

Abdul-Wahab M. A. El-Kadi. "Paper Tube Application (A Paper Tube Shelter)". The International Conference on Civil and Architecture Engineering, 8, 8th International Conference on Civil and Architecture Engineering, 2010. 1-13. doi: 10.21608/iccae.2010.44436

Souza, Eduardo. "Cardboard: From Industrial Workhouse to Shigeru Ban's Master Material" (2019) https://www.archdaily.com/913567/cardboard-from-industrial-workhouse-to-shigeru-bans-master-material

Long Spans are obtainable with common materials

Accessibility of less invasive structural long spans are linked to socioeconomics.



Tactics:
1. Utilizes existing architecture to support sheltering system
2. Uses sheltering elements to maintain the pedestrian scale at the market spaces
3. Uses common materials and resources

Success/Failures:
The structure is very contextual and maintains the cultural values of Omdurman and does not impose itself.
The structure is at times too simple and not maintained. It still offers shelter from the sun but so does the alley itself most of the daylight hours.

Takeaways:
The spans are not overbearing but utilizing more complex forms to span over the top of the structure will offer more opportunity to expose more of the architecture that is hidden by the spanning shelter without sacrificing the pedestrian scale. This will also allow greater uses for available resources.

Tactics:
1. Utilizes existing architecture to support sheltering system
2. Uses sheltering elements to create a more interior space experience for pedestrians.
3. Uses less common materials and resources to create a more perminant roof over alleys

Success/Failures:
The structure is integrated well and does not impose itself preserving the pedestrian scale.
The structure itself is simple and completely shelters the occupants in some areas taking away from the open air cultural market experience.
Integrating some common materials helps preserve the context.

Takeaways:
Rethinking the materials and design of the sheltering element could help expose more of the existing architecture and preserve the cultural context.

"Invasive Long Span"

New structure removes the "individual" from the store.

Cultural Context: Communal market place creates the pedestrian space and shelter.

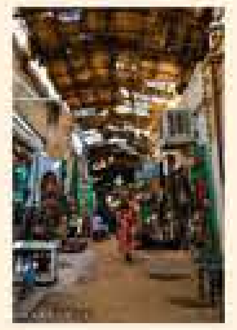
Tactics:
1. Utilizes large scale structure to reconfigure market and city function.
2. Uses large open spaces to create a grand communal shopping experience.
3. Redirects traffic to separate pedestrian and vehicular traffic entirely.

Success/Failures:
The structure completely imposes itself and steals from surrounding and removed cultural context.
Treats the pedestrian as "flow" vs the "individual experience."
Itemizes infrastructure and destroys the human scale.

Takeaways:
The design does not take into account the people. Scale of the architecture is critical in underdeveloped areas to avoid isolating or separating surrounding communities from one another.

Imposition
Positives and Negatives

Analysis of Context



Omdurman Market is a large local market in one of the most populated cities in Sudan. The Market spans through the streets and alleys and is full of the culture of the local population.

The Souks of Marrakech are a series of winding streets and alleys that house many shops and have have been the center of trading for the area for many centuries.

Kejetia is one of the largest markets in Africa consisting of over 10,000 stores. In 2015 it was impacted by the construction of a nearly 2 million squarefoot shopping structure.

▼ ***Omdurman Market, Sudan***

▼ ***Souks of Marrakech***

▼ ***Kejetia Market Kumasi, Ghana***

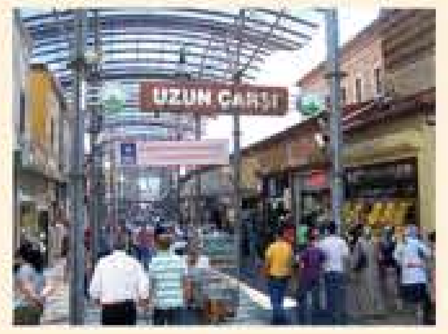
Relationships
Types of Space

▲ ***MOMA Paper Arch, New York***

The Paper Arch was a temporary exhibit piece by Shigeru Ban for the Museum of Modern Art in New York. It was made out of paper tubes and spanned over 80 feet.

▲ ***Uzun Carsi, Turkey***

The Uzun Carsi is a traditional Bazaar that is located on the streets of Bursa, Turkey. The open air street is sheltered by a free standing steel and glass structure.



▲ ***Mercat Encants, Barcelona Spain***

The Mercat Encants was built over an existing site that is the home a famous anual market that has been reoccuring for over a century.

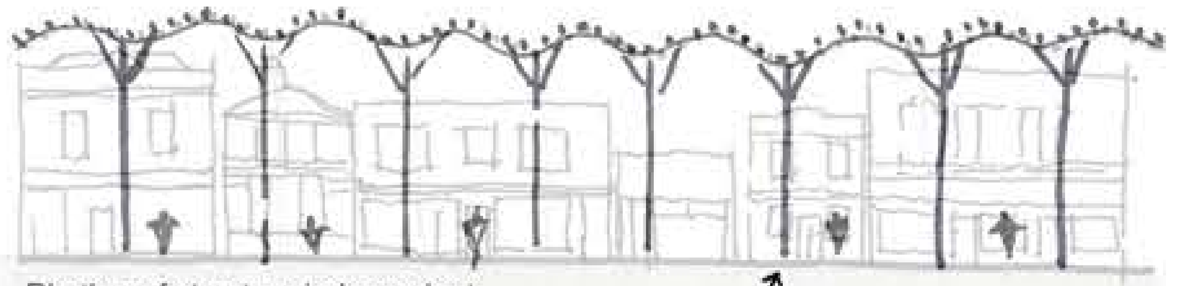
COMMUNAL - "GARDEN"

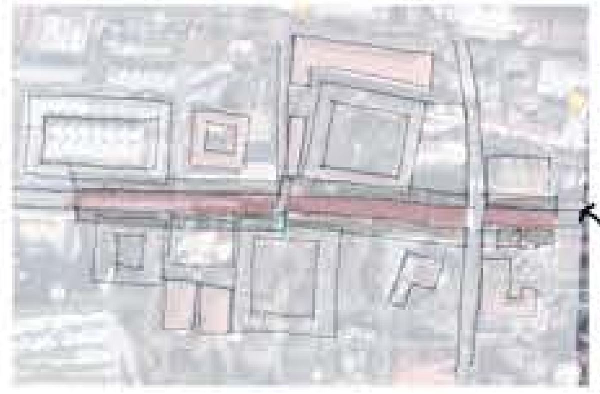
Tactics:
1. Uses simple materials in a more complex grid structure to define outdoor space.
2. Adds a human scale to an open air recreational urban green space.
3. Uses common materials and resources

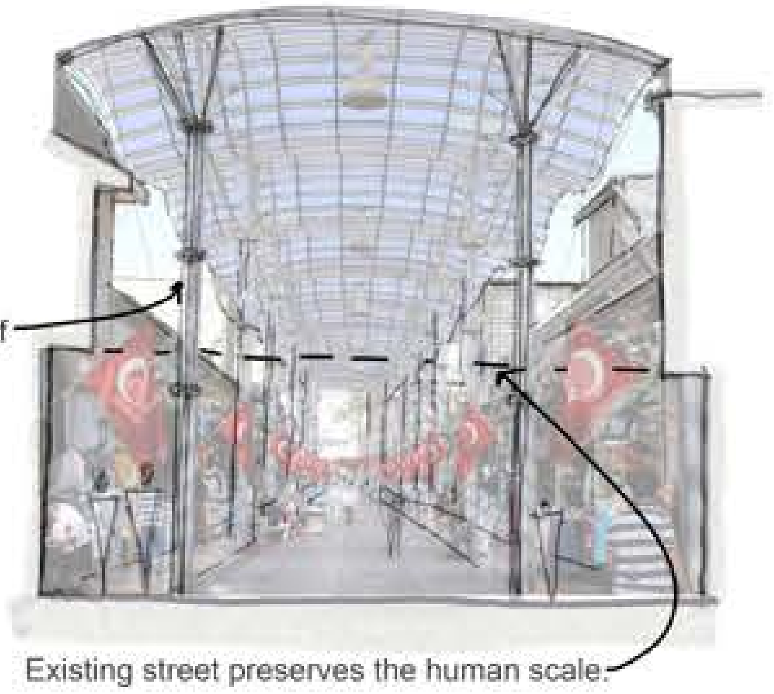
Success/Failures:
Feels light and does not steal from the experience of the outdoor environment.
Does not provide shelter, but is more scultural definition of space.
An exhibit of long span using a "common" material.

Takeaways:
Depending on the program of space, a sheathing material can add function and opportunity to the communal space below.

COMMUNAL MARKET - "STREET"





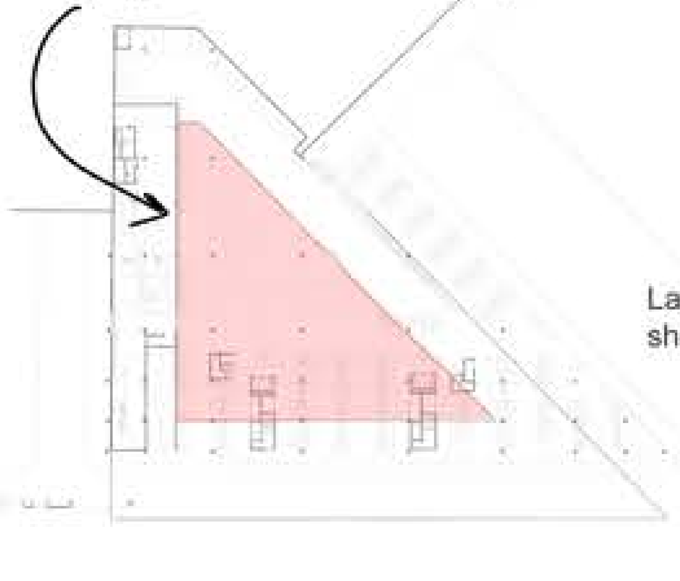


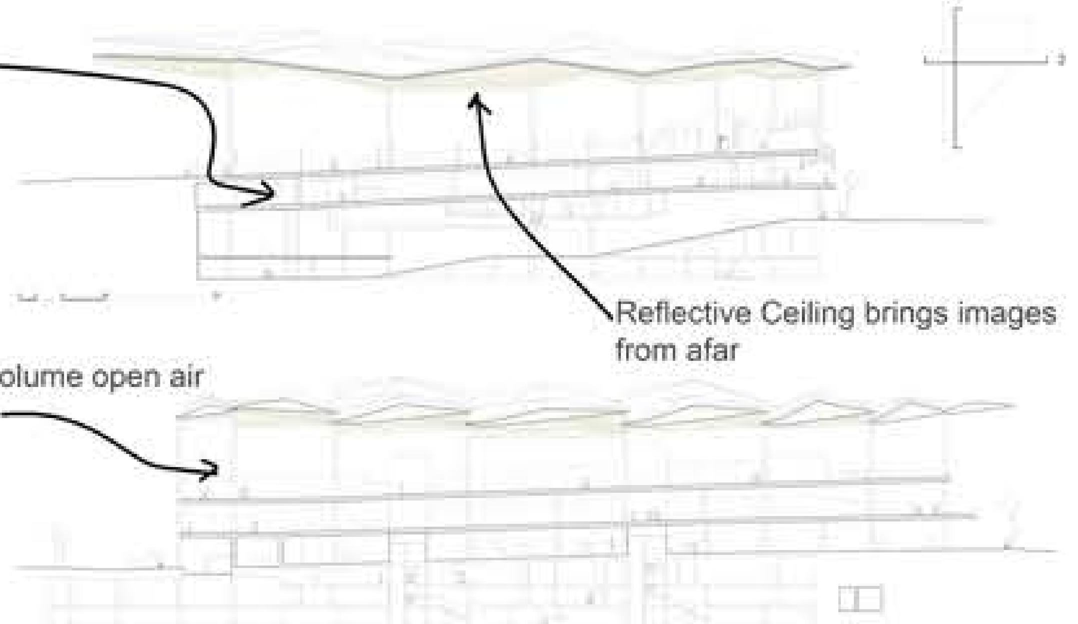
Tactics:
1. Structure functions entirely independent of existing architecture and ignores the cultural style.
2. Uses transparency to express and preserve the feel of an open air street
3. Uses a more complex form to limit the invasive columns in a congested area.

Success/Failures:
The contemporary form still integrates by not screening or stealing features from the existing architecture.
Structure defines the street as a pedestrian street.
Structure integrate well and have minimal impact on the existing architecture.

Takeaways:
The sheltering form can integrate more with the existing architecture. The rhythm of columns seem to ignore the street facade below.
The shelter could extend over the roofs below to shelter individual shop fronts from the elements.

COMMUNAL MARKET - "PLAZA"





Tactics:
1. Uses large scale space and open air volume to emphasize exterior space.
2. Uses winding sloped planes to give the feel of pedestrian roadways around the central plaza.
3. Reflective materials bring images of the city into the market space.

Success/Failures:
Feels like an outdoor space
New structure, but preserves the ideals of a traditional market.
Modern materials help preserve the history of the annual market.
The large scale roof canapies steal from the pedestrian scale of the market.

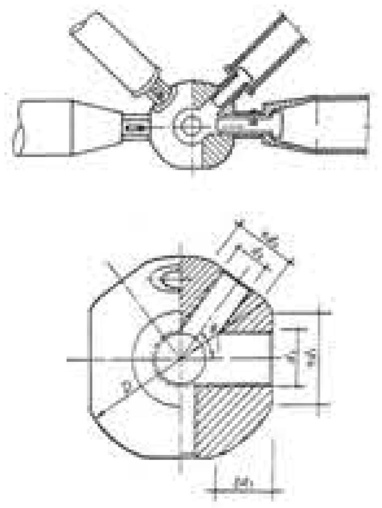
Takeaways:
Additional lower canopies can help preserve the pedestrian scale. Using architectural elements from the surrounding context can help connect historical context.

Less invasive structures can provide shelter over large communal spaces.

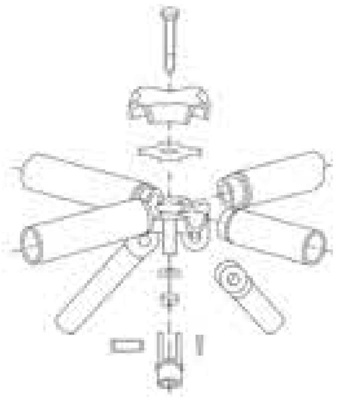
Types of Connections
With Node

1. Tuball Node.

Made of tubular members with threaded ends that thread into a sphere node. The sphere can be engineered with up to 18 threaded holes at different angles.



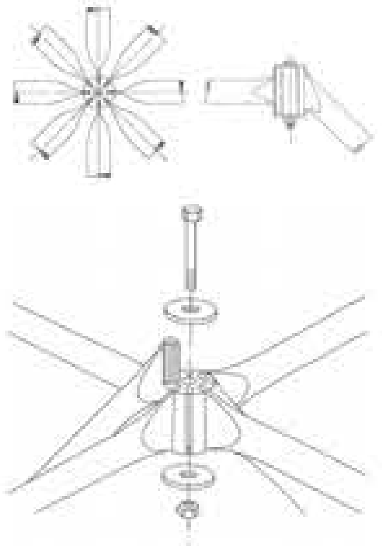
2. Nodus



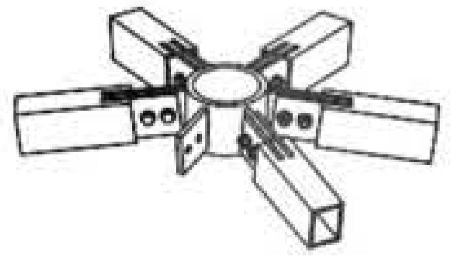
The body of this node connection is two pieces that is held together with a friction bolt.

3. Triodetic.

Central extruded hub with keyways to receive tubular members.



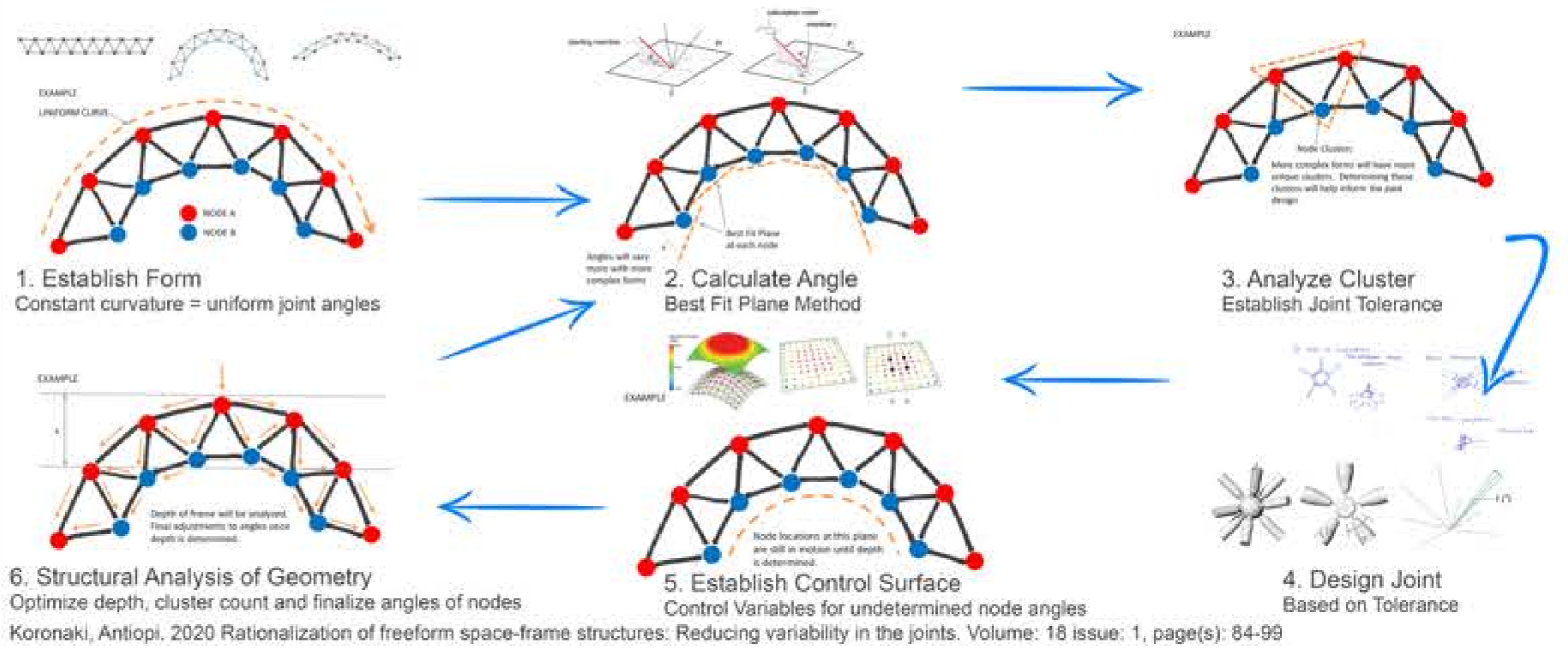
4. Hemispherical Dome



Used for geodesic domes and longer spans. This requires the ends of the tubular members to be slotted or modified to fit the tabs of the connector.

This speculation is comparing the different complexities of the connections of a space frame with a focus on only types with nodes. Node connections require less to no assembly to the connection itself creating a greater ease of installation. This will help establish and understand the limitations of each in terms of form finding and material compatibility. As the spans and form become known, certain types of connections will not be adequate but will potentially still offer insight during the prototyping portion of the architectural exploration.

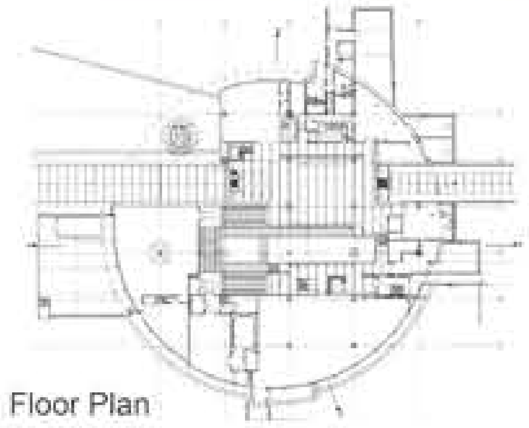
Influences on a connection - How to Design a Space Frame



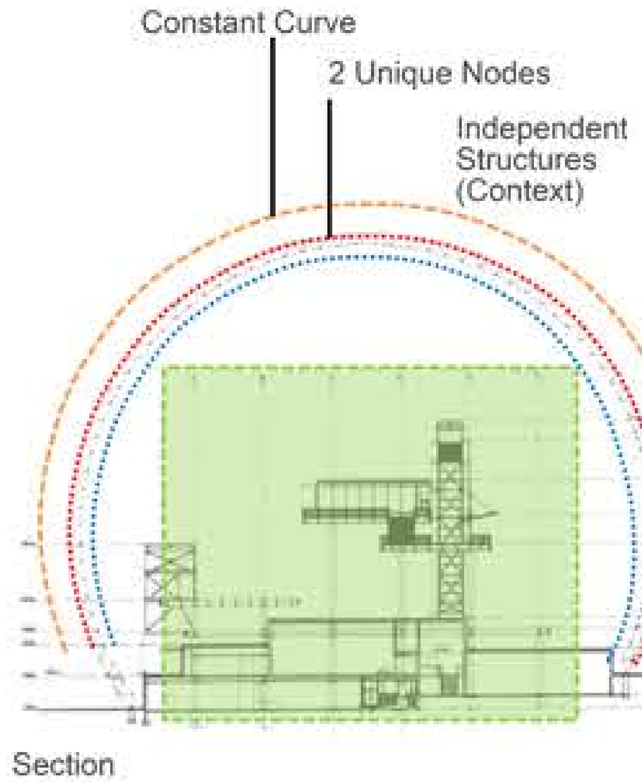
Koronaki, Antiopi. 2020 Rationalization of freeform space-frame structures: Reducing variability in the joints. Volume: 18 issue: 1, page(s): 84-99

This speculation breaks down the design of a space frame and how different forms and angles effect the node connections. Machine nodes can be built to a tolerance of 1/100th of a degree but the nodes can withstand a tolerance greater than that depending on the material properties of the members and the node connections. Optimizing geometry and depth of the space frame have a direct correlation to the node connection, the number of node connections, and the different types of node connections. The design and fabrication of a space frame is cumbersome but the spans are efficient and the method of installation can be easy as long as the installer can work with the selected material.

Analysis of Precedent

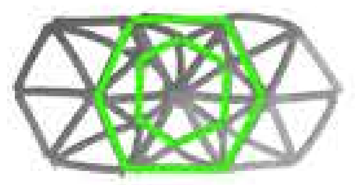


Floor Plan



Section

While simplistic in form and minimal in flexibility the hemispherical dome connector is able to span great distances over and around context (existing or new). The simplicity reduces human error.

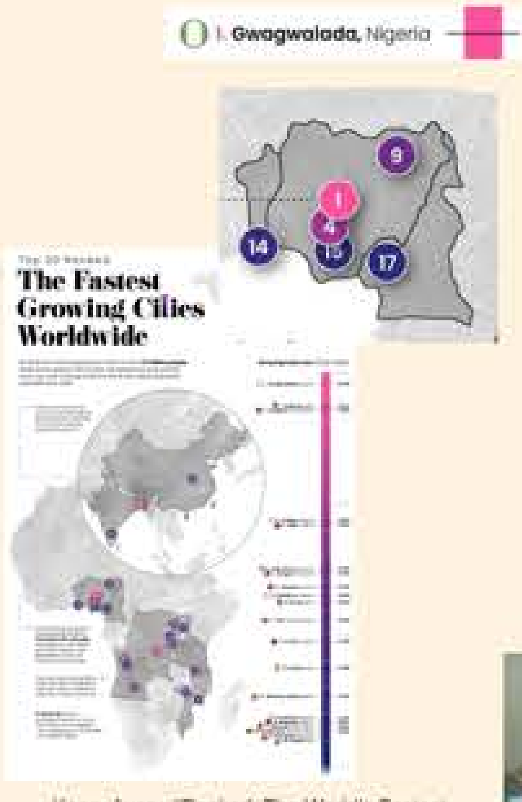


Double Layer Hexagon Geodesic Dome

Node Detail - Hemispherical Dome Connector

This speculation is a reverse engineering of the Montreal Biosphere. This will help to better understand the design process of a space frame and its nodes. Because of its constant curving form the details, while complex, are minimal in type. This may not ultimately become the form of the architectural investigation but it is a form that can encapsulate existing context and form new spaces around existing program spaces. It is also an early example of a space frame structure that predates the methods of scripting to create even more complex forms.

Control & Site Context



Koop, Avery. "Ranked: The World's Fastest Growing Cities" Visual Capitalist 2021. https://www.visualcapitalist.com/ranked-the-worlds-fastest-growing-cities/

Nigeria is rapidly growing in population and has one of the strongest economies in Africa. The population relies heavily on basic imports from food due to its petroleum based economy. This increases the need for trade within the urban environments of the country and gathering areas to support this trade. Markets are a primary programming need within this developing country. Nigeria also produces their own papercores ranging up to 51" in length and 3" in diameter. They also aquire them from abroad from in-direct means. Paper cores are used in rolling tarps, formica, foreign cloth materials and once unwound the paper cores are sold to the paper dealers and distributed.

Gwagwalada Main Market

1. "Umbrella"

2. "Wall"

3. "Street"

4. "Plaza"

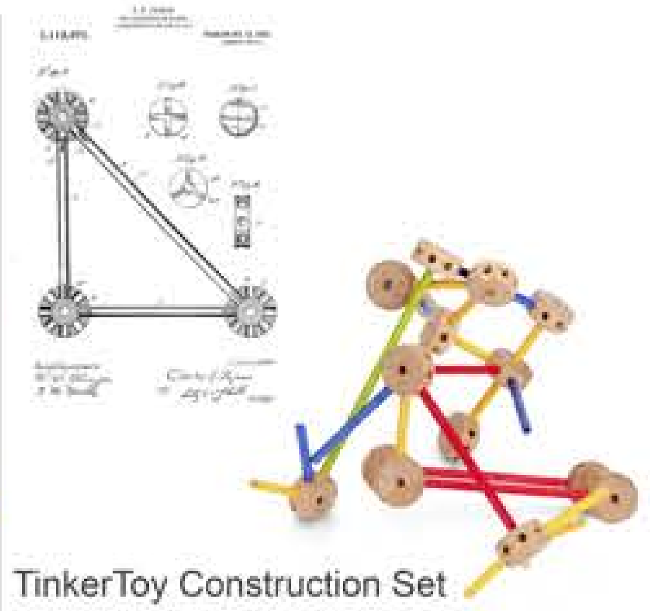
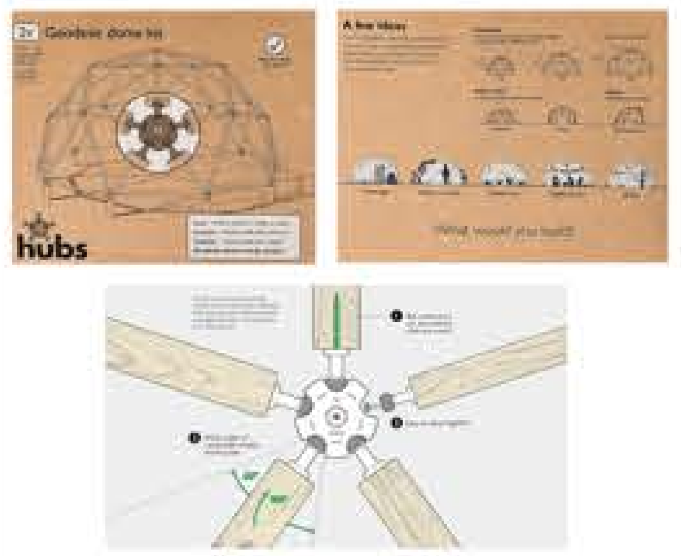
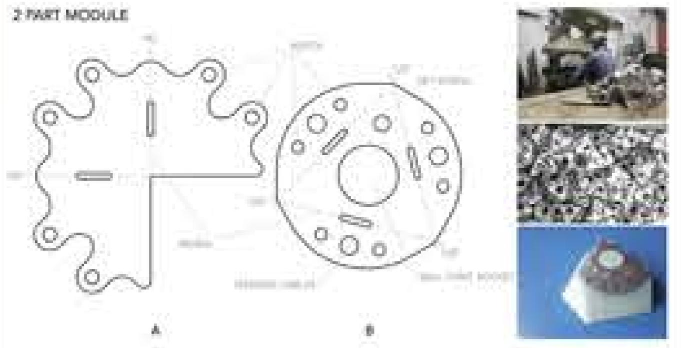
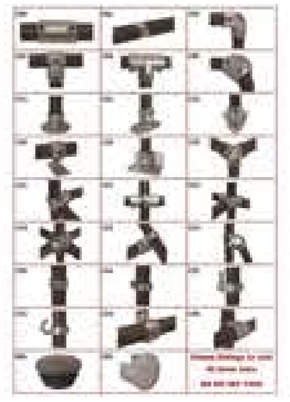
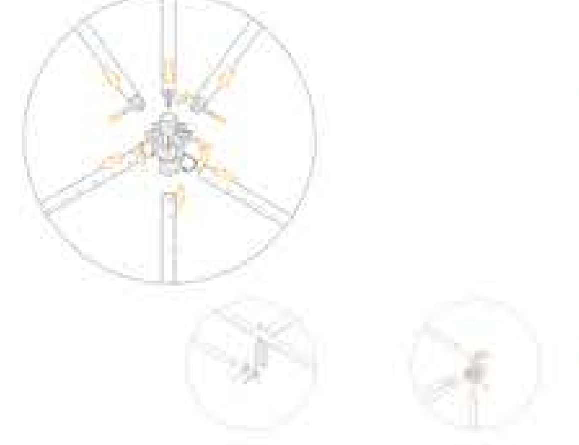
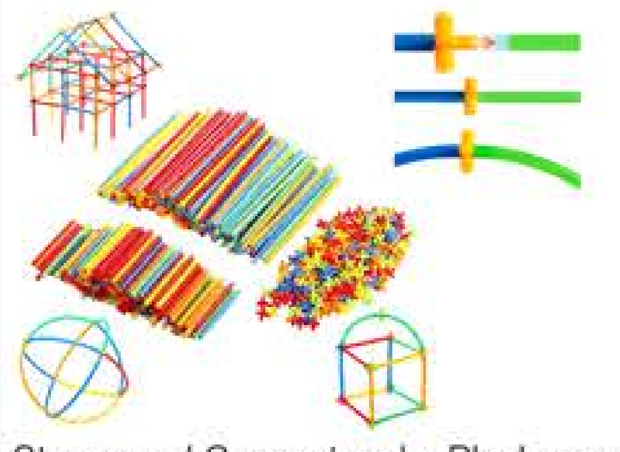
Statement

"Using paraboloid geometry, simple tools, repeated operations, and common materials, the architect can create accessible, non-invasive long spans that can be adapted and developed to define current and future trading points in developing communities."

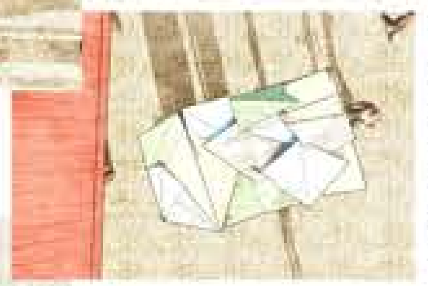
Architectural Exploration

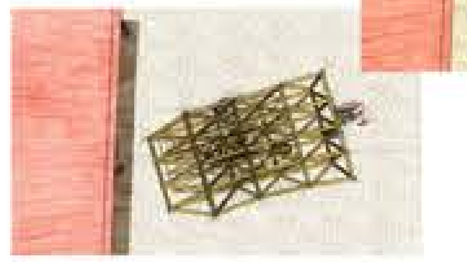
"Comparison of Parts" Connection Precedent Matrix

This speculation looks at several modular connections that are specifically for tubular building components. This is not an exhaustive list. Some of these connections are toys and not used in the construction of sheltered program space, but the principals of form and function still apply. I am trying to find attributes of each that can possibly be combined and tested to create a repeatable, flexible, connection requiring minimal or no tools. For a "kit of parts" to be successful it has to solve or address human error in assembly. How much play and adapting do these connections have in the field? How many different outcomes are there?

Connection	 K'nex	 TinkerToy Construction Set	 Toobalink	 Hubs	 Joint for Complex Structures	 Pipe Connectors	 ACSA Steel Design Competition	 Straws and Connectors by PlayLearn
Number of Parts	9	1 Main	5	1	1	25+	4	2 Main
Type of Connection	Triodetic	Triodetic	Tuball Node	Hemispherical Dome	Tuball Node	Varies	Hemisphere Dome	Tuball Node
Number of Angles	7 (Plus 360 Rotation)	5 (Plus 360 Rotation)	4 (Plus 360 Rotation and double nodes)	4 (With 180 tolerance)	Varies	Varies	5 (With pivot)	4 (With 360 Rotation)
Adaptable (Flexible)	Limited	Limited	Yes	No	Yes	Limited	Yes	No
Tools Required (Ease of Install)	N/A (toy)	N/A (toy)	N/A (toy)	No	In Fabrication	Yes	Wrench	No
Summary and Observation	The user is limited to a set of pieces and angles but the range of the build is vast. Because of the limits it is harder to veer from the intended use. The flexibility is in the rotation. The human error is minimal.	The user is limited to one piece with set angles but the rotation is where the flexibility and potential human error comes from. The human error is still minimal and hard to veer from the intended use.	The ability to connect joinery adds a level of versatility, but this may have structural set backs when transferring loads in a real application. This product also has several parts just for connections to be installed.	Even with the flexibility during construction, it is still limited to a dome. It is only scalable based on size of members not flexibility in the connection.	This joint is designed to be made by the end user. Once past that the ball joints allow for a great level of flexibility. One joint can create complex space frame geometry. There is a great deal of human error without any limit of angles.	There are many connection types but the user is still limited to the catalog of connectors. The available ones are not modifiable the flexibility comes from the vast number of connection types.	This connection gives great flexibility but there is a great level for human error because of the infinite set of angles allowed. This will have an impact on load transfer.	Very limited angles do not allow for much flexibility. Everything is done on the x,y,z, axis plus a 45 degree angle. Any flexibility is in the members.

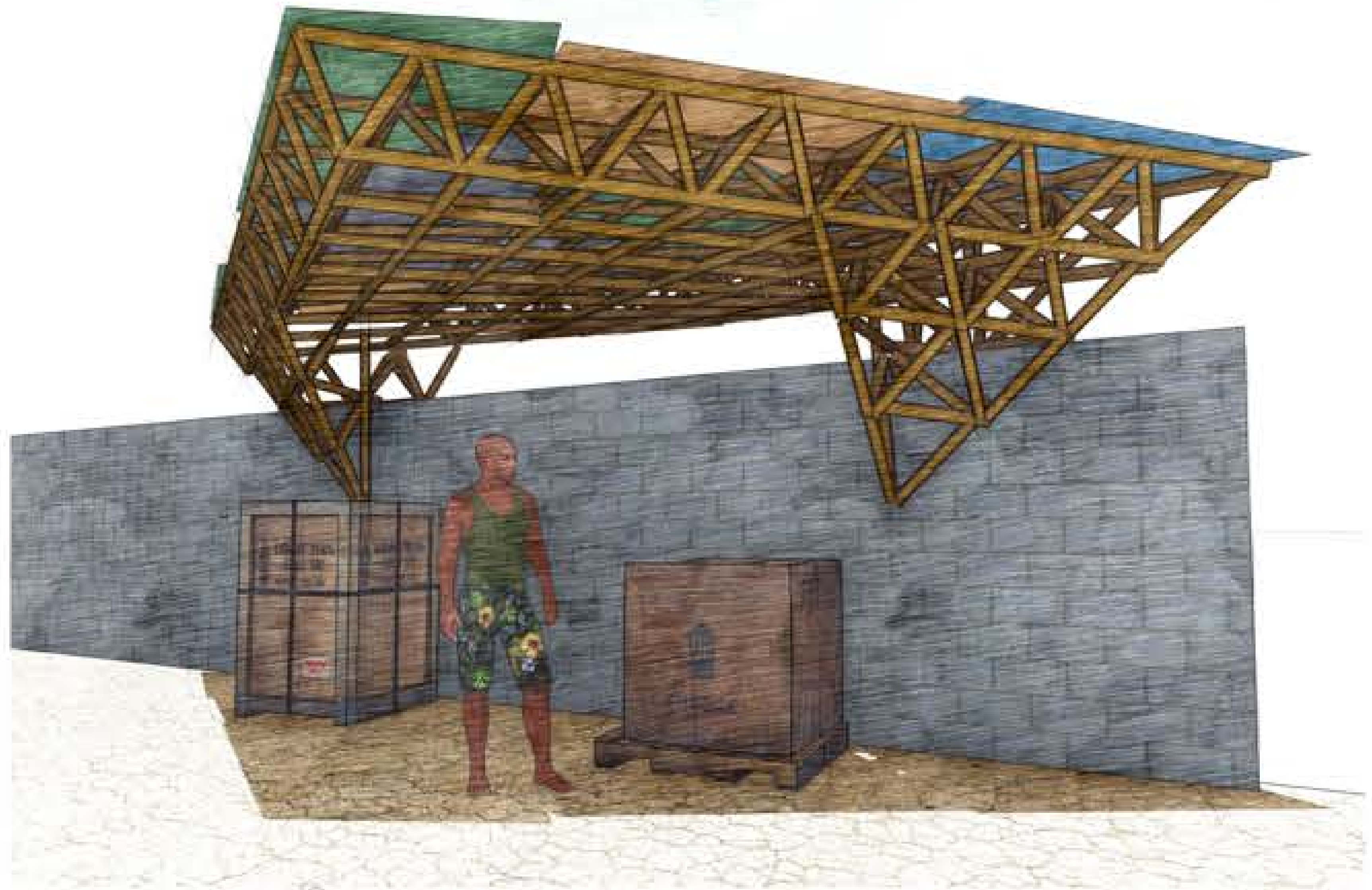
"UMBRELLA"

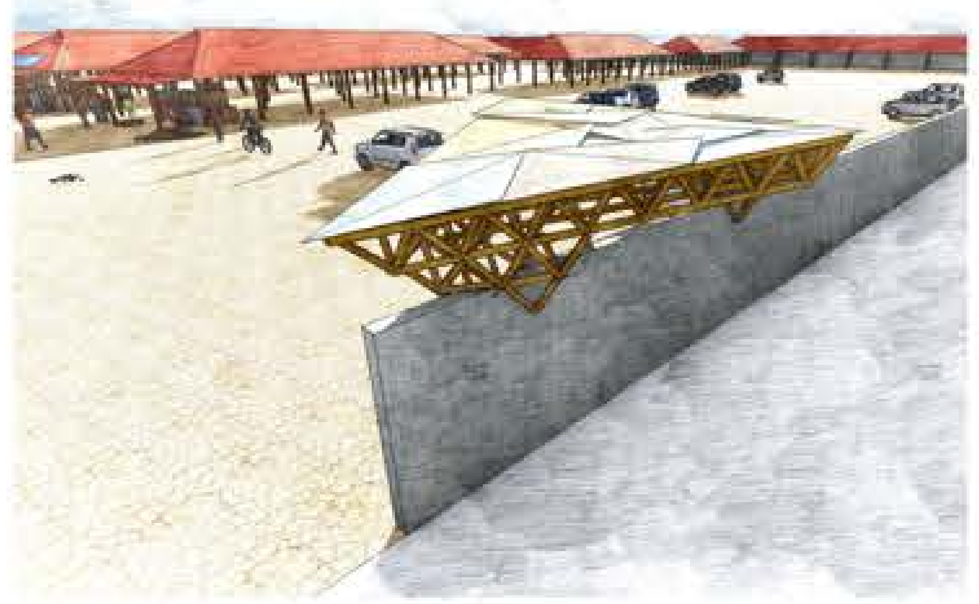


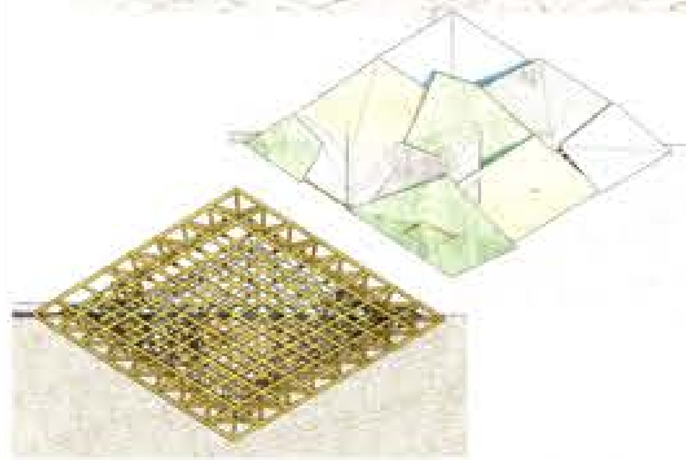


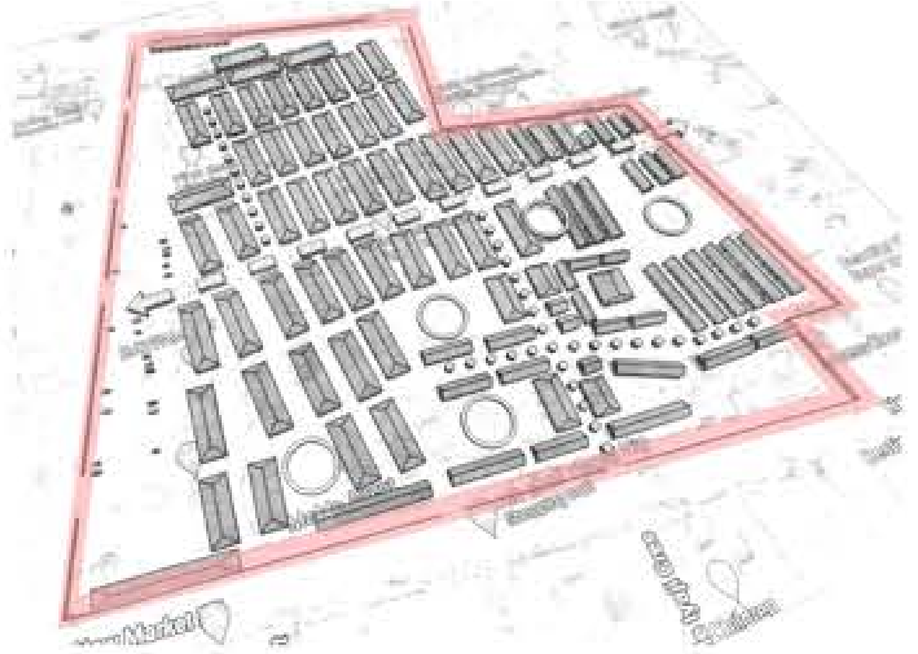
The "Umbrella" is a freestanding element and is an early phase in the Gwagwalada Main Market Plan. Its purpose is to give individual vendors without permanent structures, a larger alternative to the literal umbrella. Like all of the speculations shown, there will be a cloth material and moisture sealer to complete the shelter. The Umbrella type of structure is the only of the four elements that is independent from the existing context but still relates to it by expanding social spaces where the longer spans do not reach. This also becomes a "filler" option for vendors to expand trade points.

"WALL CANOPY"



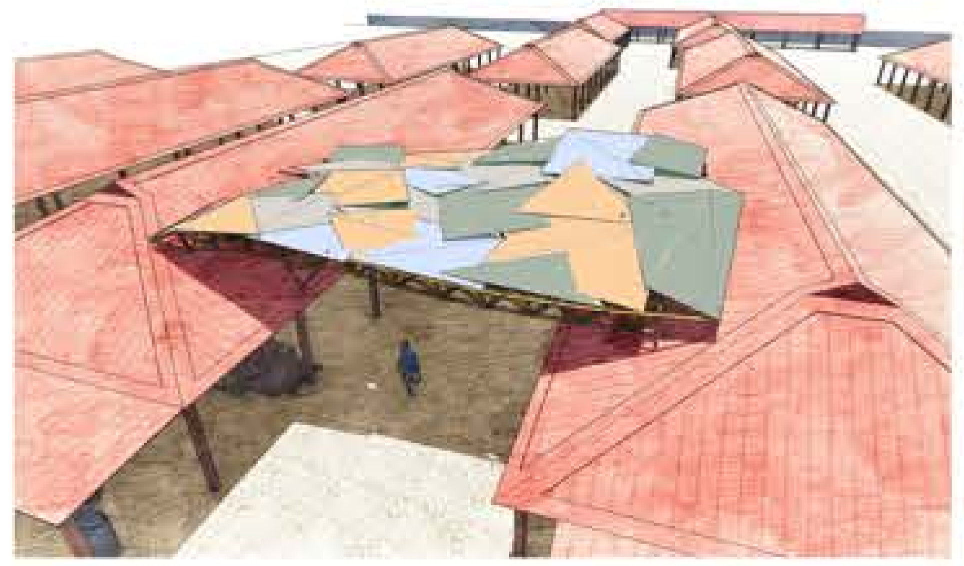


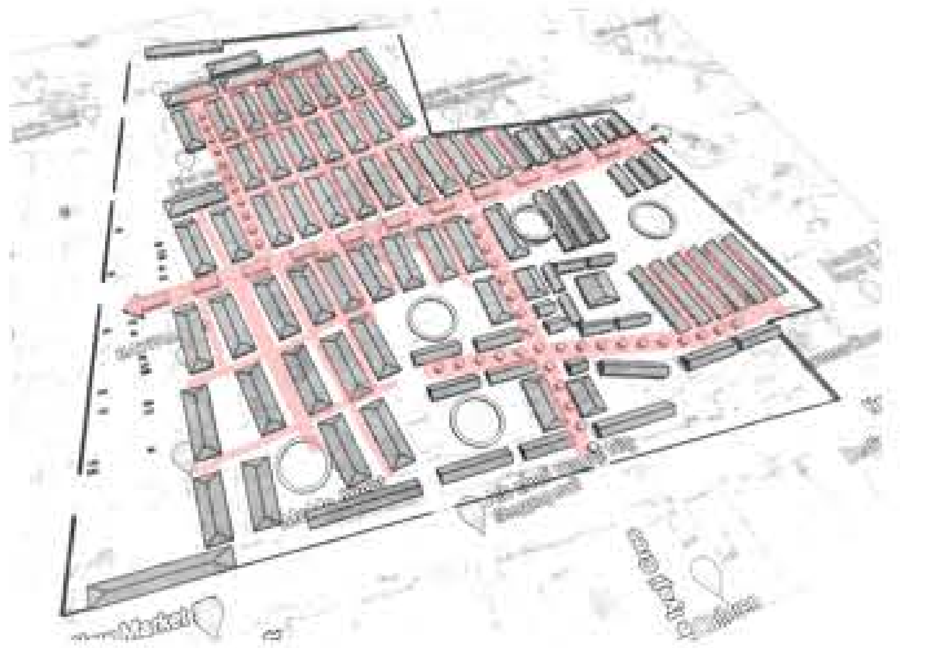


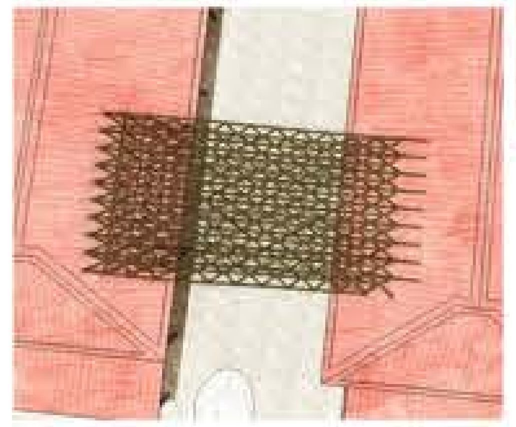


The "Wall Canopy" can take on many anticlastic cantilevering shapes, but it focuses on using the existing perimeter wall as its base. The market is currently surrounded by additional people exchanging goods and services along the perimeter streets. They are currently sheltered by personal umbrellas. The goal is to surround the perimeter wall with sheltered vendor locations. This will define a new space that will attract patrons and allow the market to expand as the surrounding areas continue to develop. The design also incorporates a sheltered defined space within the perimeter wall.

"STREET"

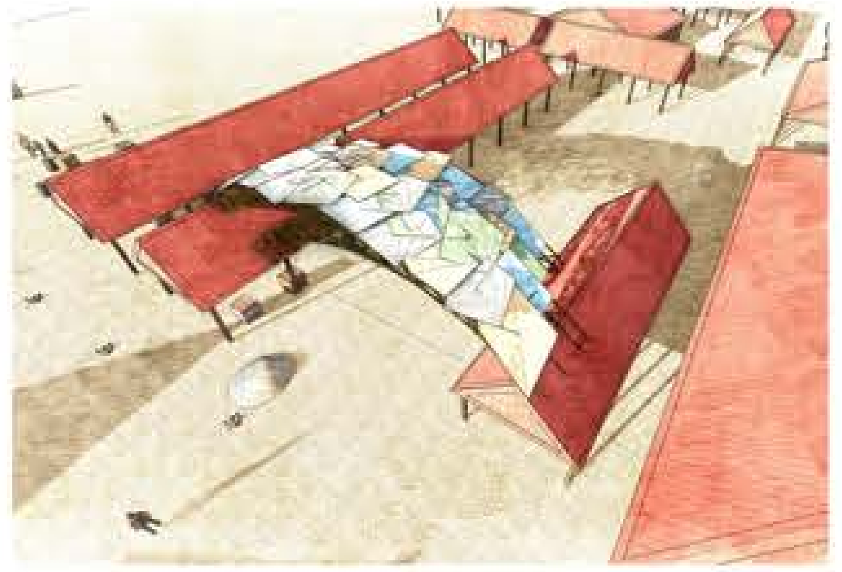


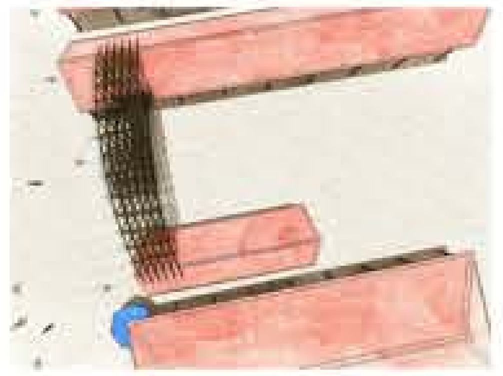


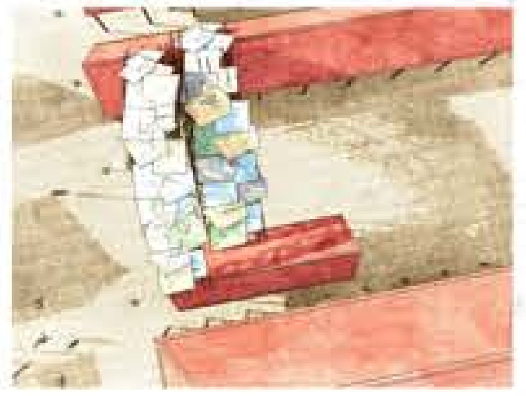


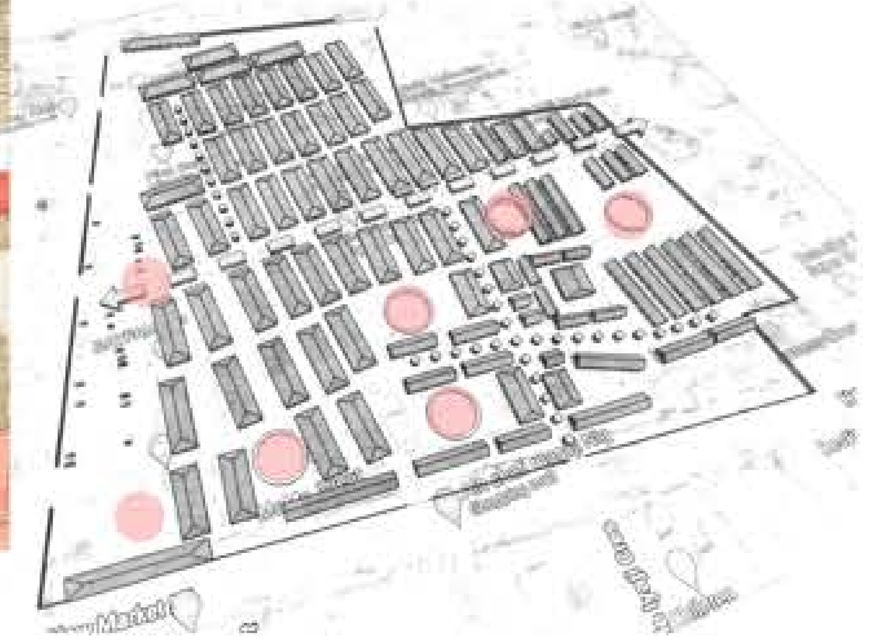
The "Street" focuses on defining spaces between the existing structures. Depending if two adjacent buildings have the same owner will define the type of structural span used. In both cases the structure will contour to the pitches of the roofs and can vary to adapt to the existing spans. The Street forms, aside from the obvious shelter they provide, can be used to define new circulation paths through the buildings.

"PLAZA"







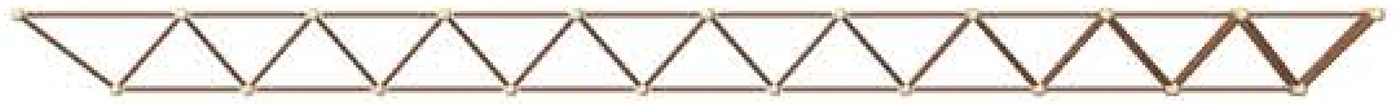


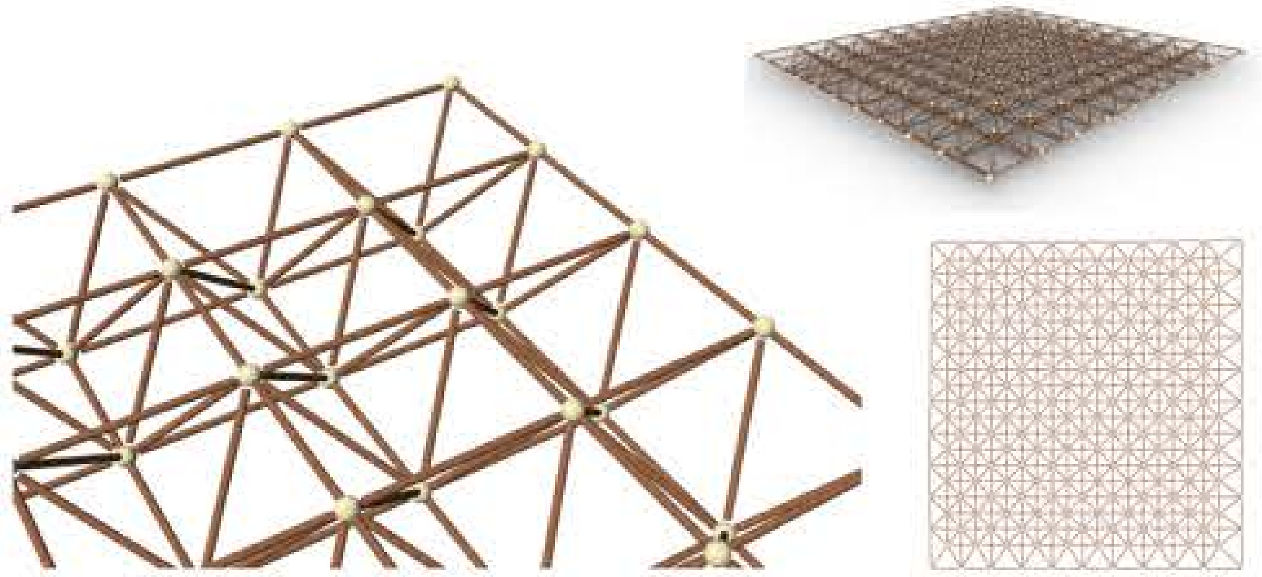
The "Plaza" is the form with the opportunities for the longest spans and the most impactful from the social gathering aspect. These can be used to define entrances to the market and concentrated vendor areas.

Exploration of Form

Efficiency of Structure

Length of Span

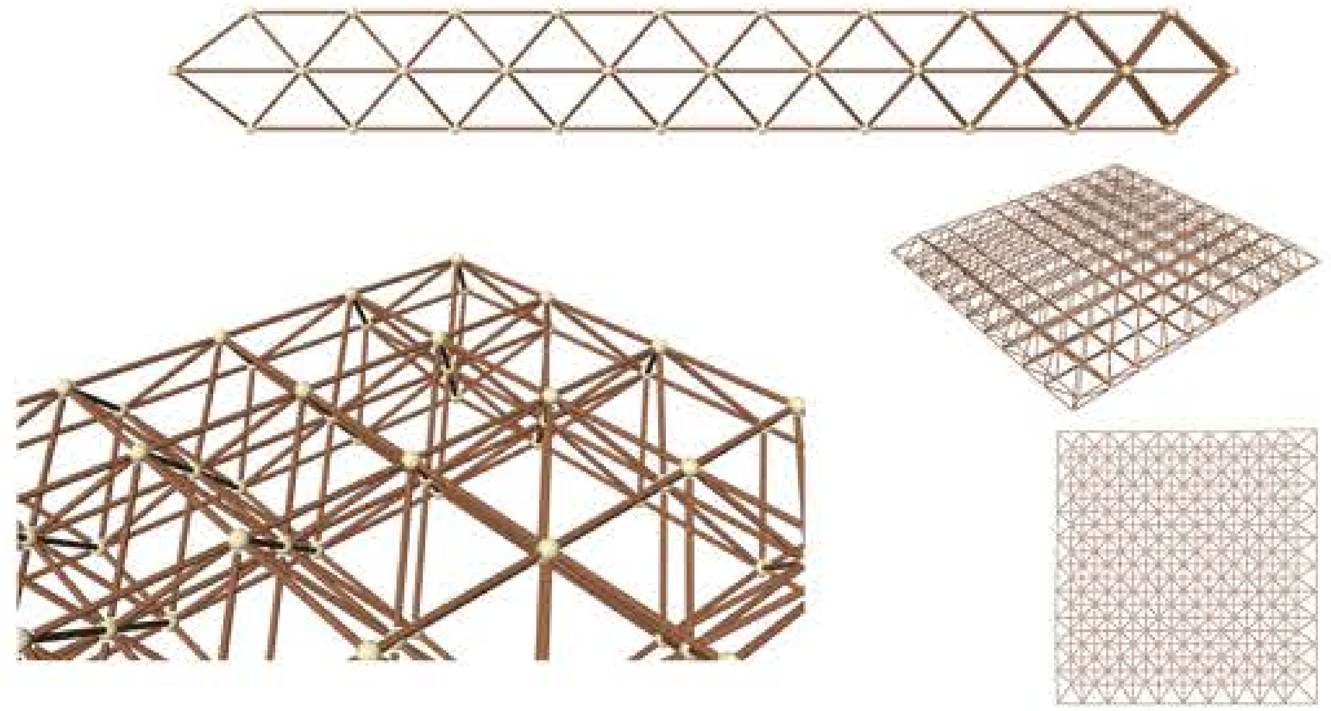




Nodes: 1

Flat Double Layer Grid

Lengths: 1 or 2 (Depth Varies)



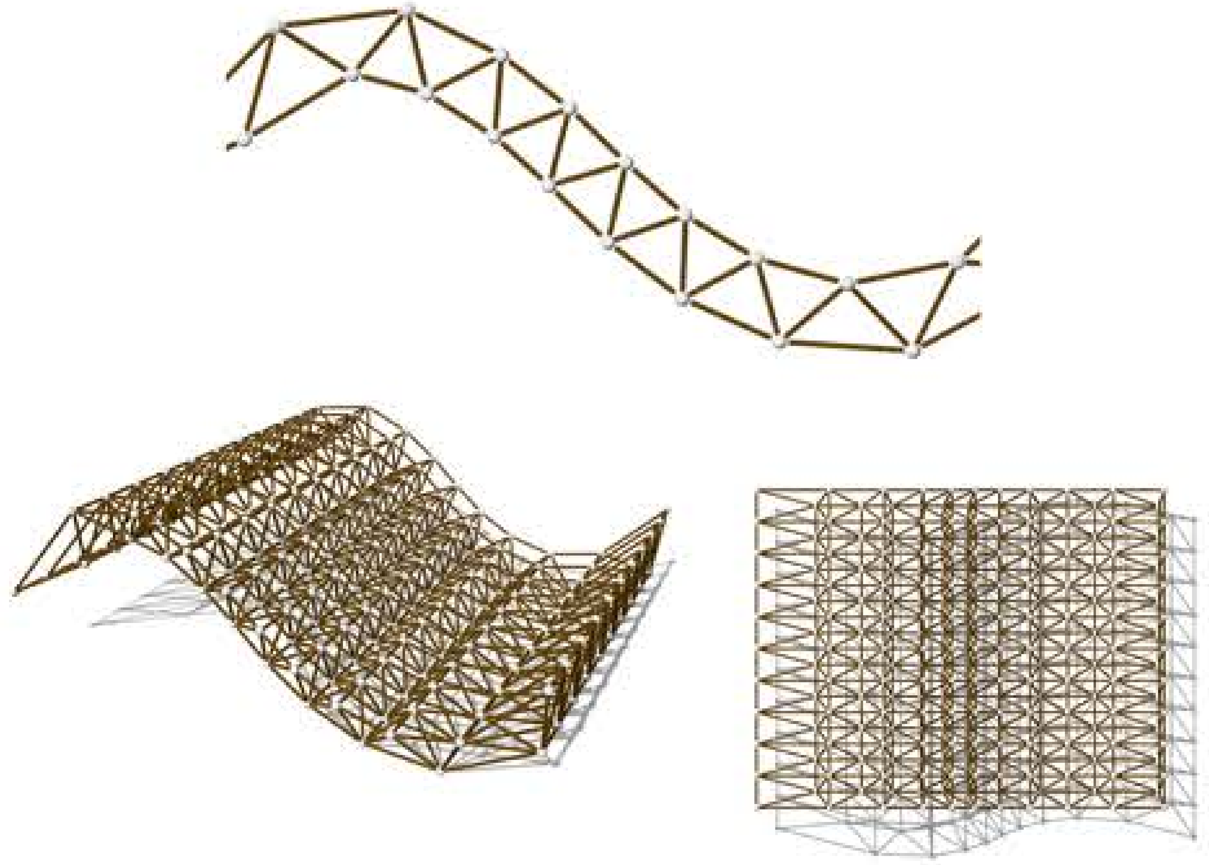
Nodes: 2

Flat Triple Layer Grid

Lengths: 1 or 2 (Depth Varies)

Complexity of Construction

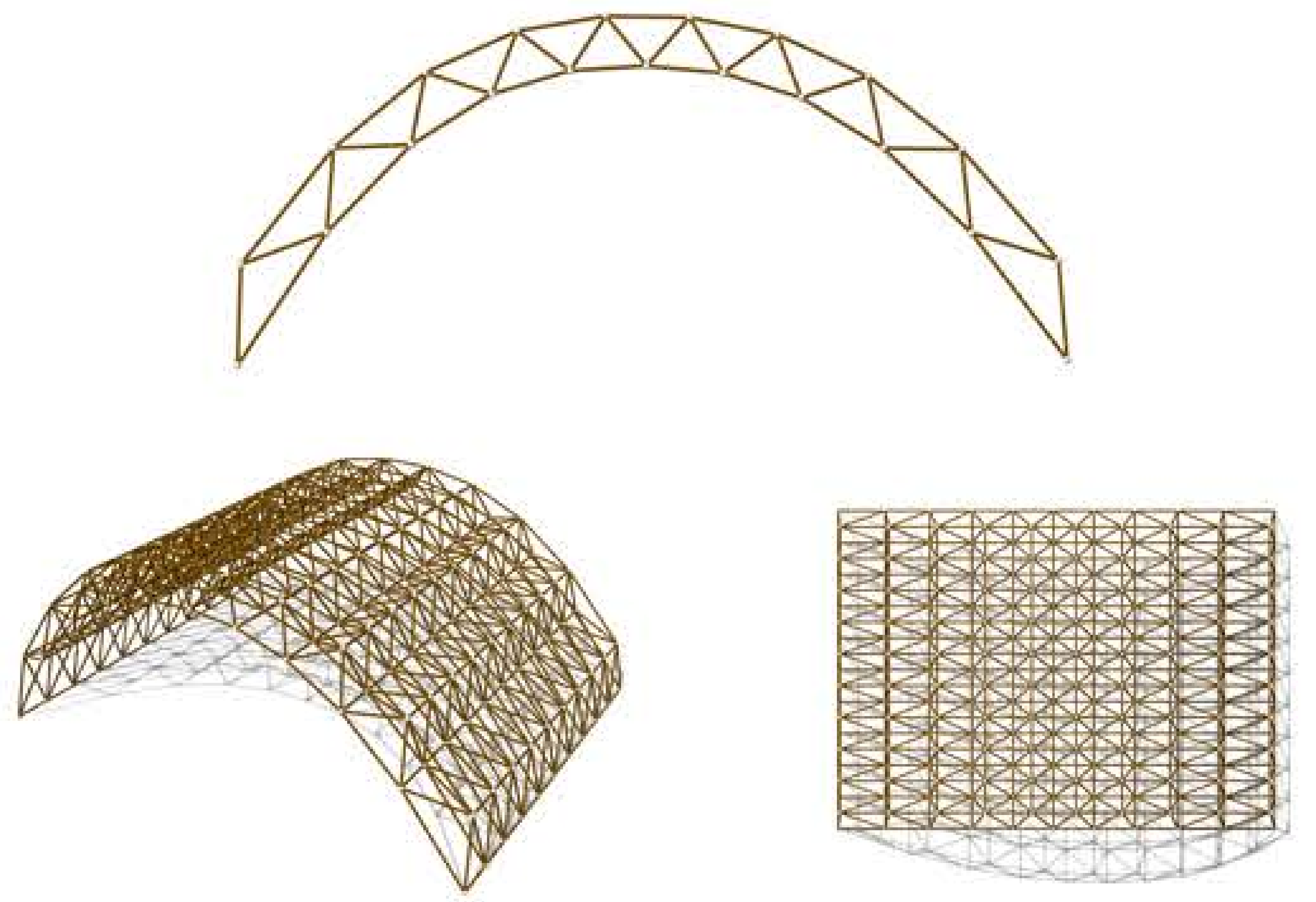
Number of Parts



Double Layer Freeform Arch

Nodes: 2 (Countinuous Curve)

Lengths: 2 or 3 (Depth Varies)



Nodes: 2 (Countinuous Curve)

Double Layer Barrel

Lengths: 2 or 3 (Depth Varies)

Analysis of Form

DATA

Paper Tubes

3" Diameter
.2" Thickness

Fb = 0.48ksi
Ft = 1.16ksi
Fv = 1.16ksi
Fcp = 0.32ksi
Fc = 0.64ksi
E = 145ksi
Emin = 52ksi
Nu,v = 0.38

DL = 1.5 PSF
Node = 4 lbs
Tube = 0.4 lbs/lf

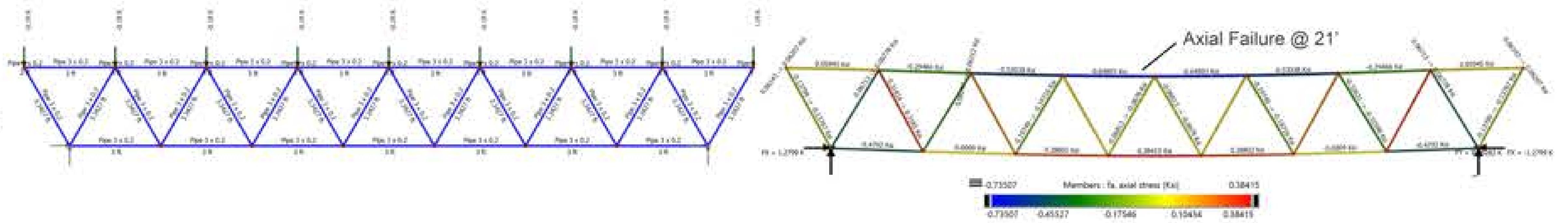
LL = 1.2 KN/m^2
(20 PSF)
Nigeria Building Code

Load Applied
0.19K
(190lbs @ each node)

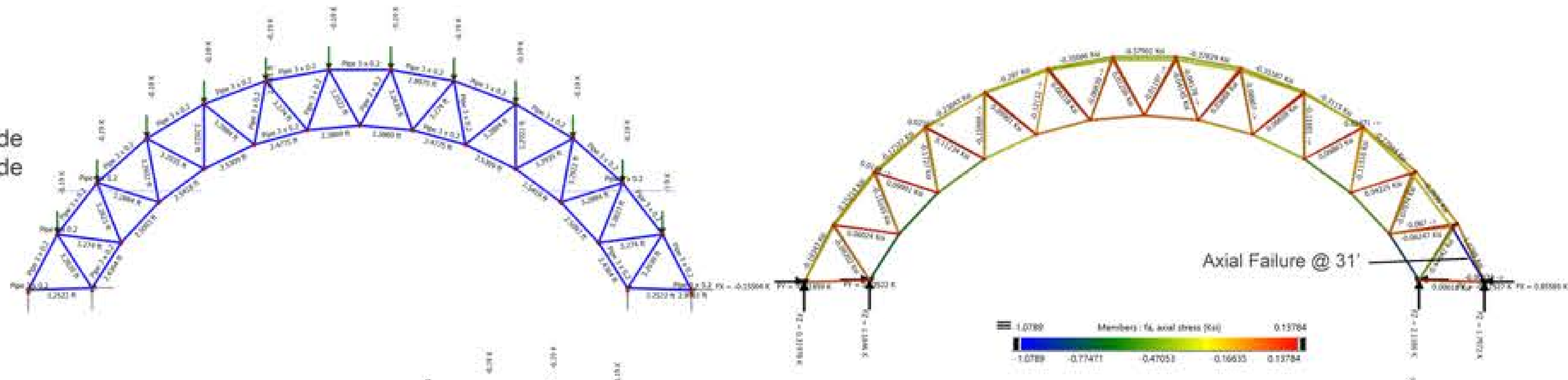
Wind Applied
100mph (40PSF)

Larger spans can be reached with increased thickness.

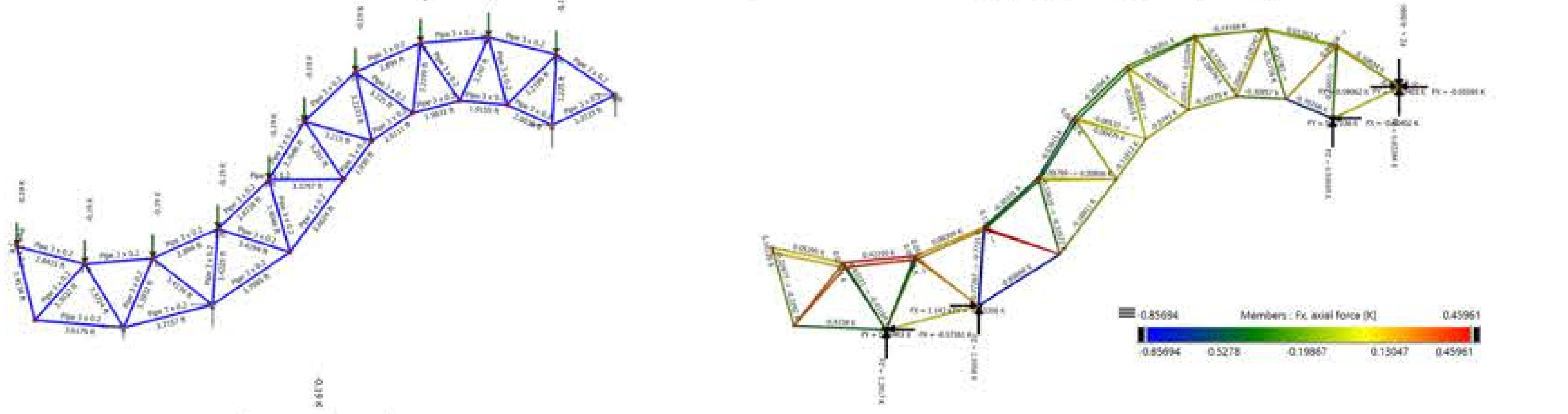
Flat
Span 20'
Single Form



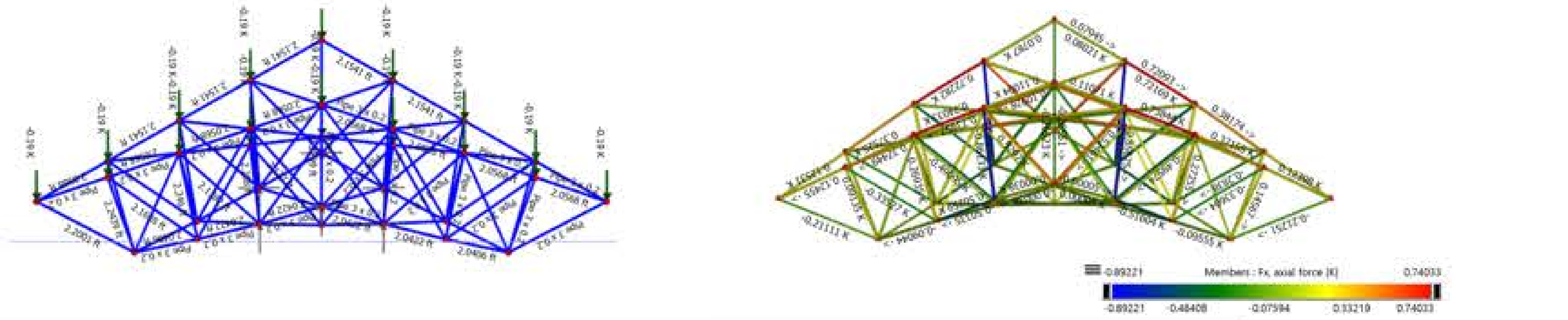
Arch
Span 30'
2 Forms
10 Degree Node
20 Degree Node
Catenary Arch within Boundaries of Truss



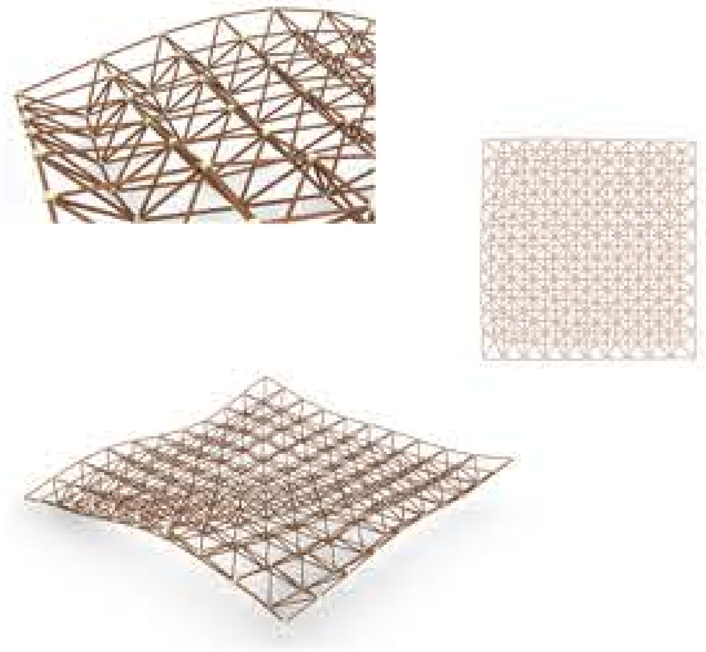
Freeform Arch
Span 15'
2 Forms
10 Degree Node
20 Degree Node
Catenary Arch within Boundaries of Truss



Hyperbolic Paraboloid
Span 15'-20'
Utilizes altered square hemi-octahedron.

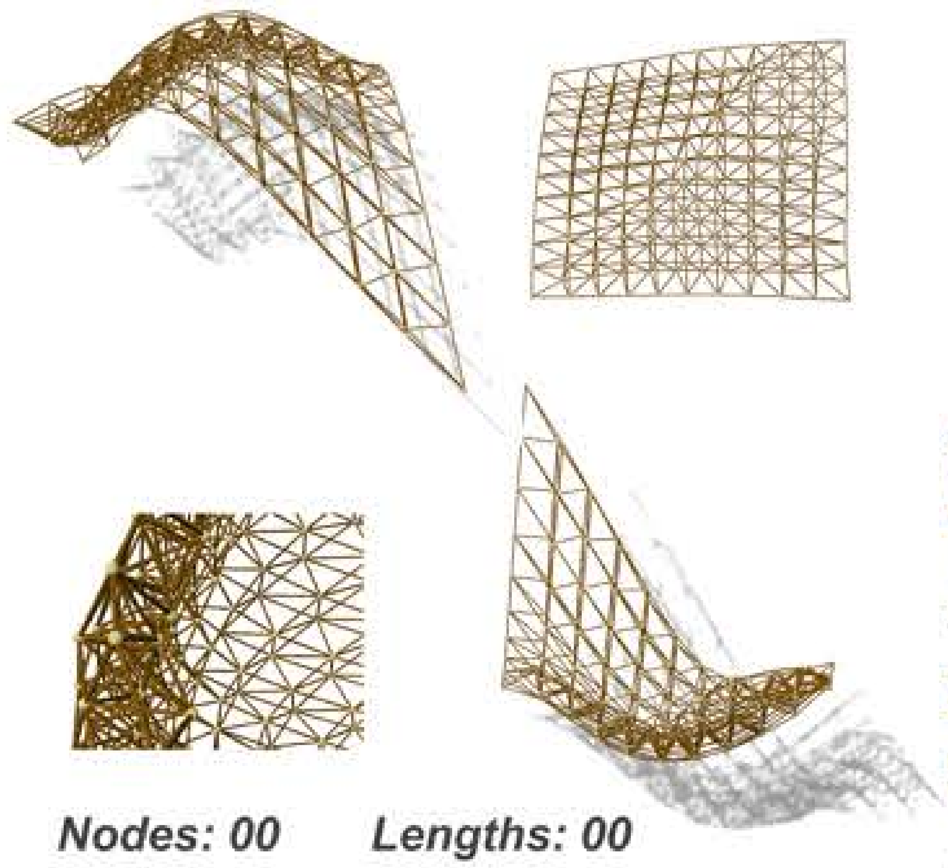


In order to acheive true complexity the node angles and length of members all become unique, and with that, becomes hard to control or regulate in regards to the end user. We can allow for flexibility in each dire nplecty but clo



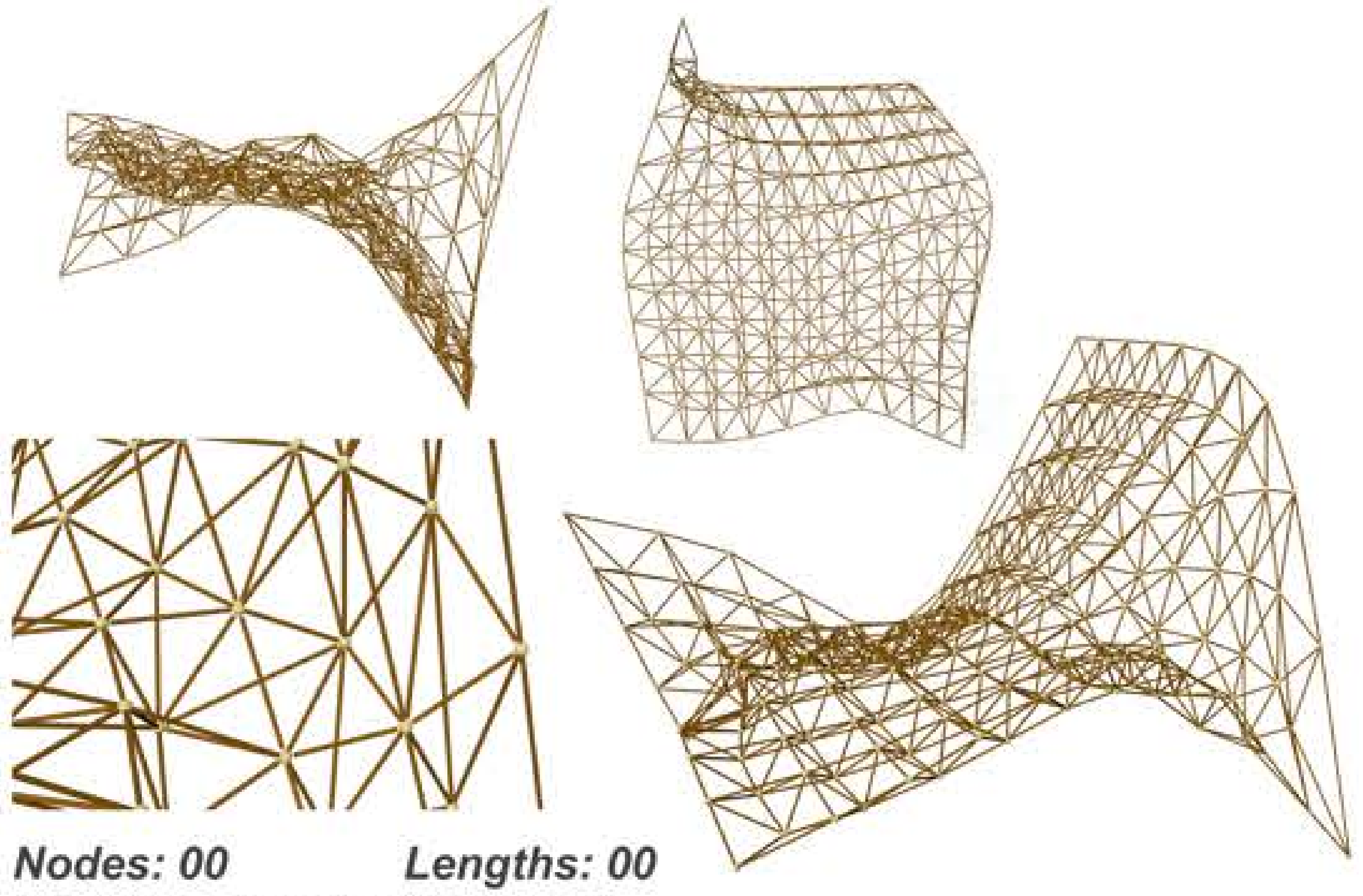
Nodes: 00 *Lengths: 00*

Double Layer Freeform Grid



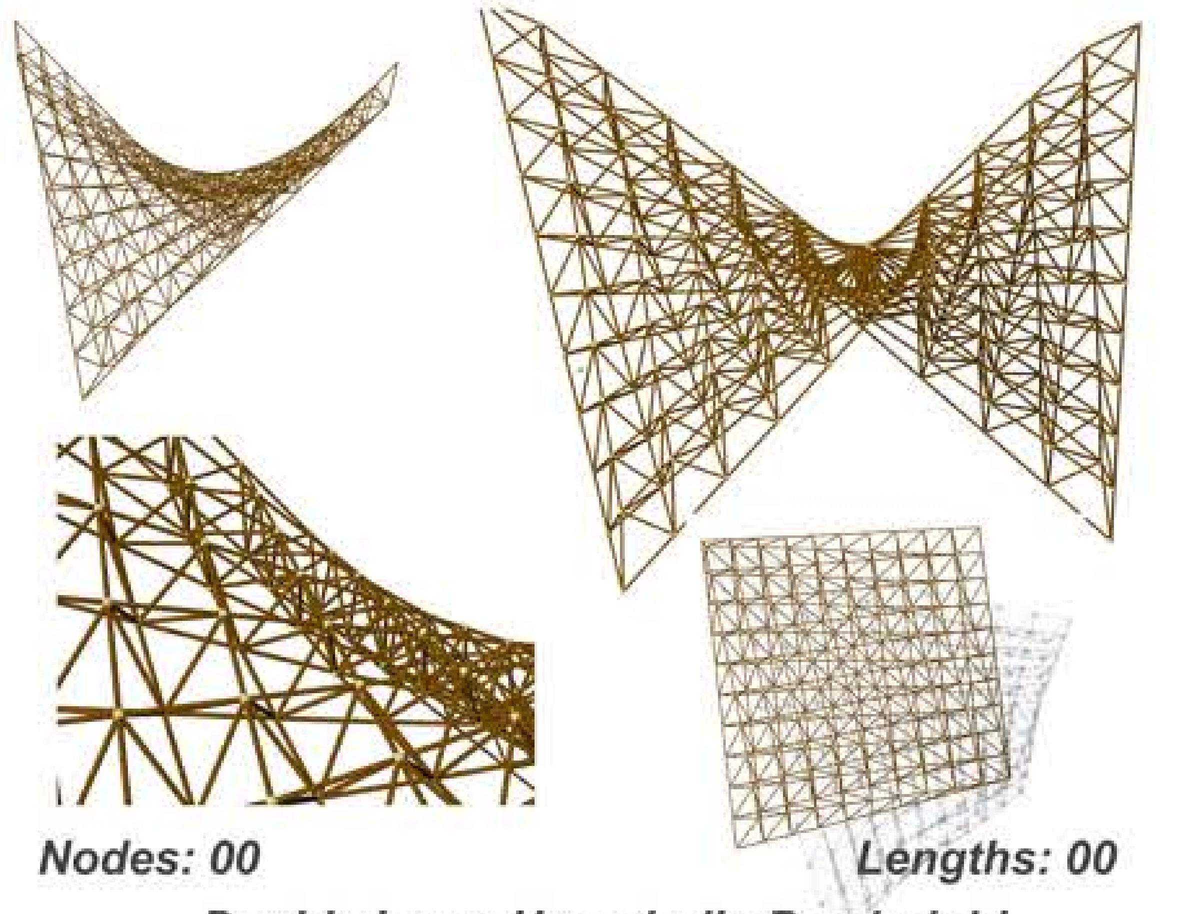
Nodes: 00 *Lengths: 00*

Double Layer Freeform Grid



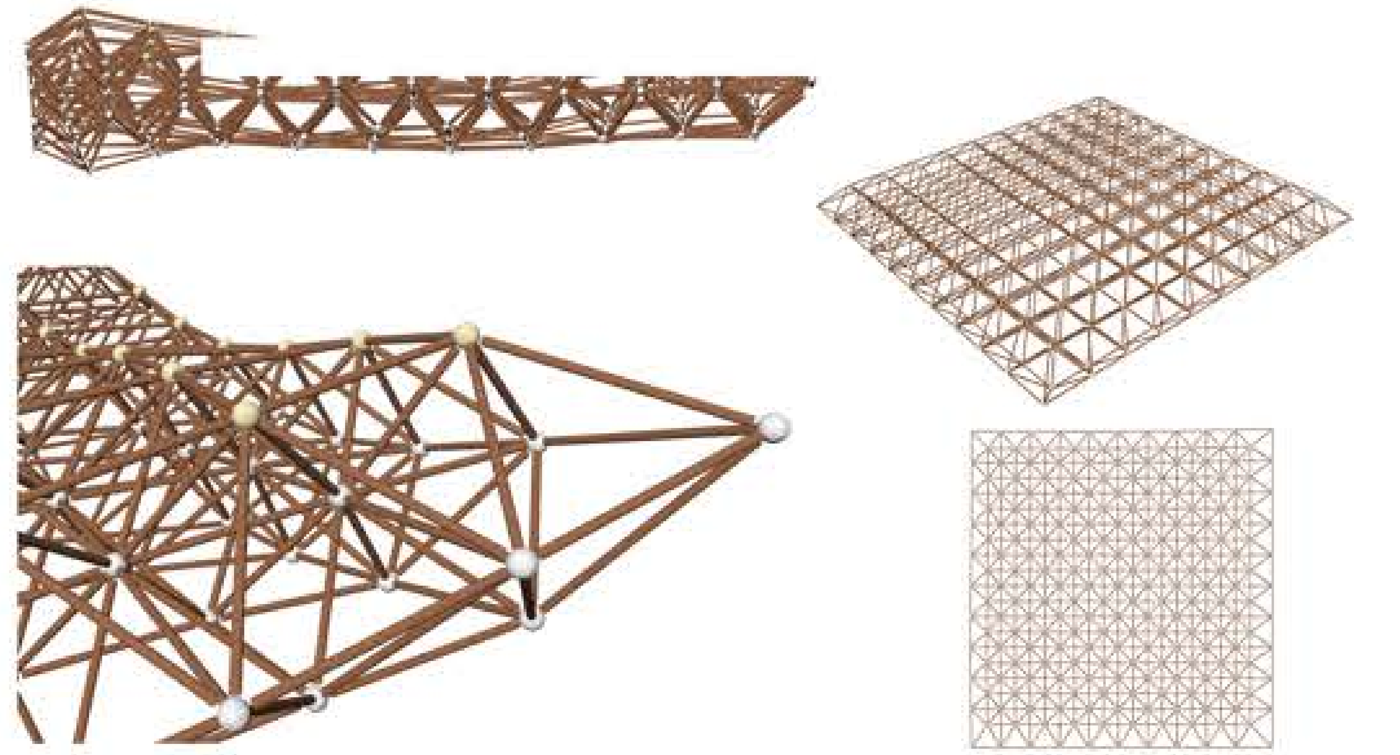
Nodes: 00 *Lengths: 00*

Double Layer Freeform Grid



Nodes: 00 *Lengths: 00*

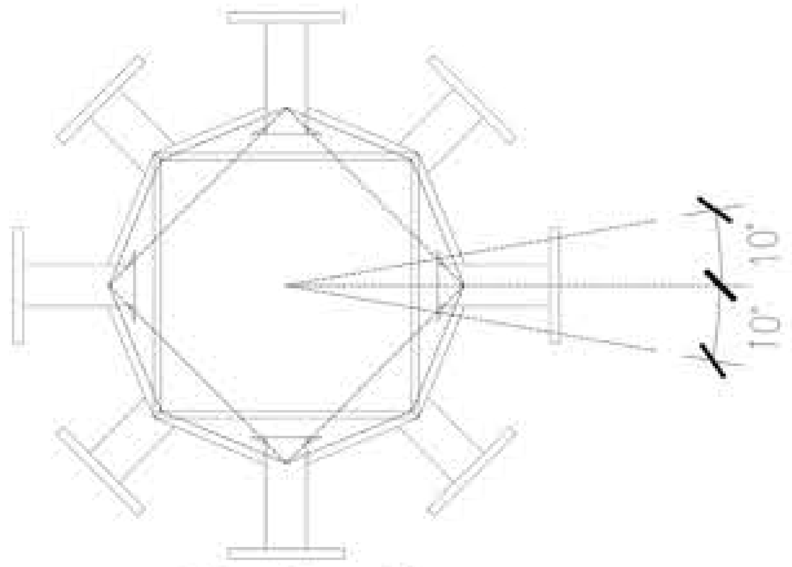
Double Layer Hyperbolic-Paraboloid



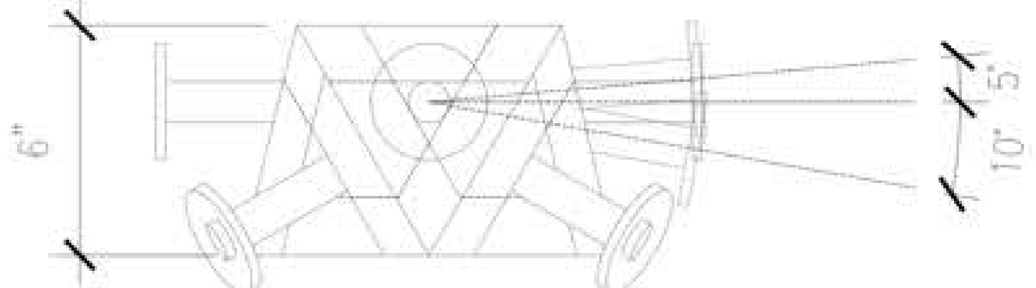
Nodes: 00 *Lengths: 00*

Triple Layer Freeform Grid

PROTOTYPING

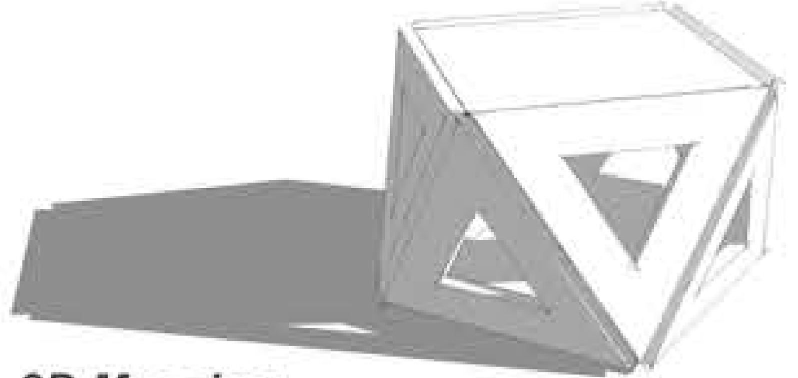


Plan Detail



Elevation

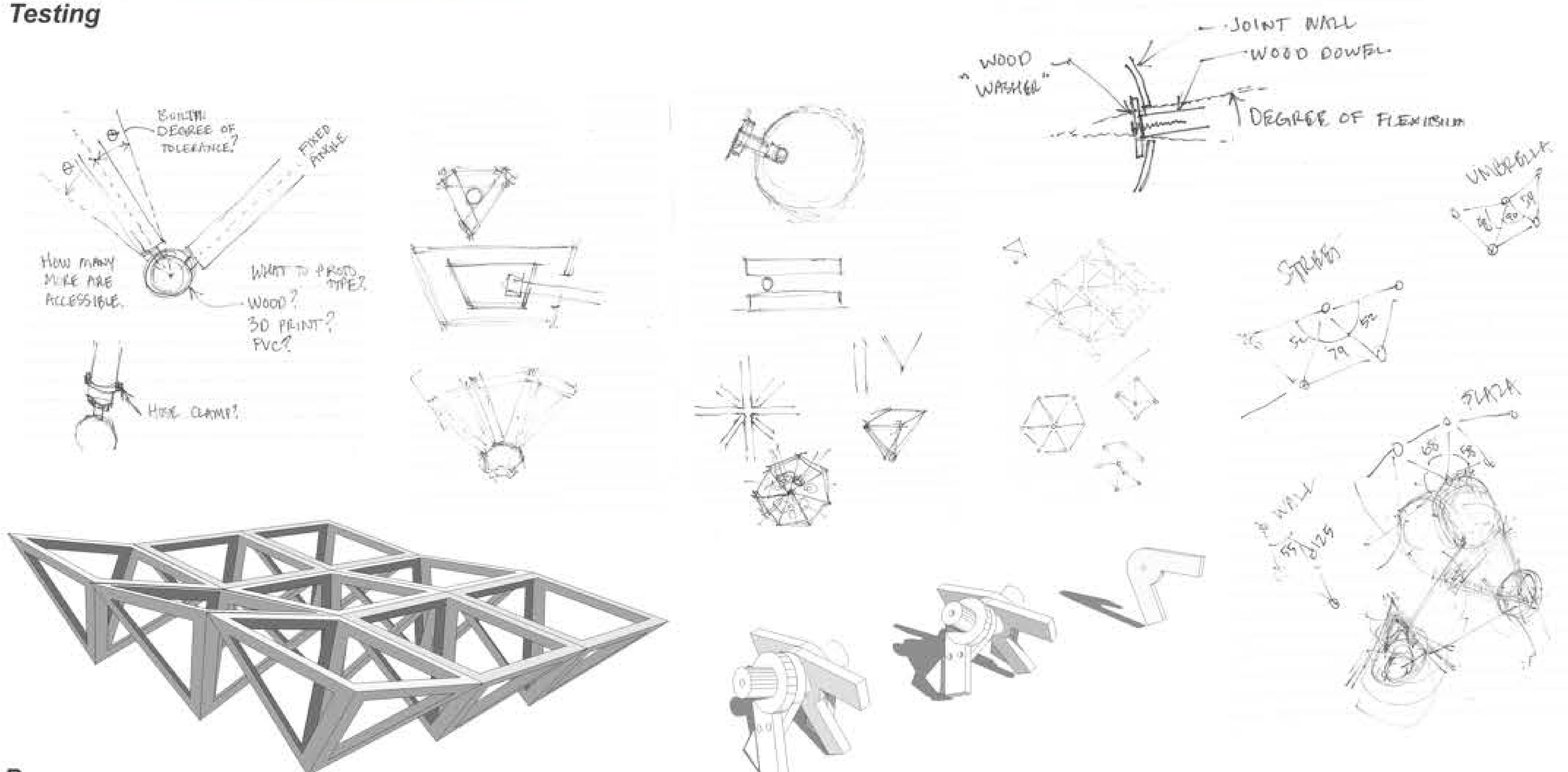
Node Prototype 1



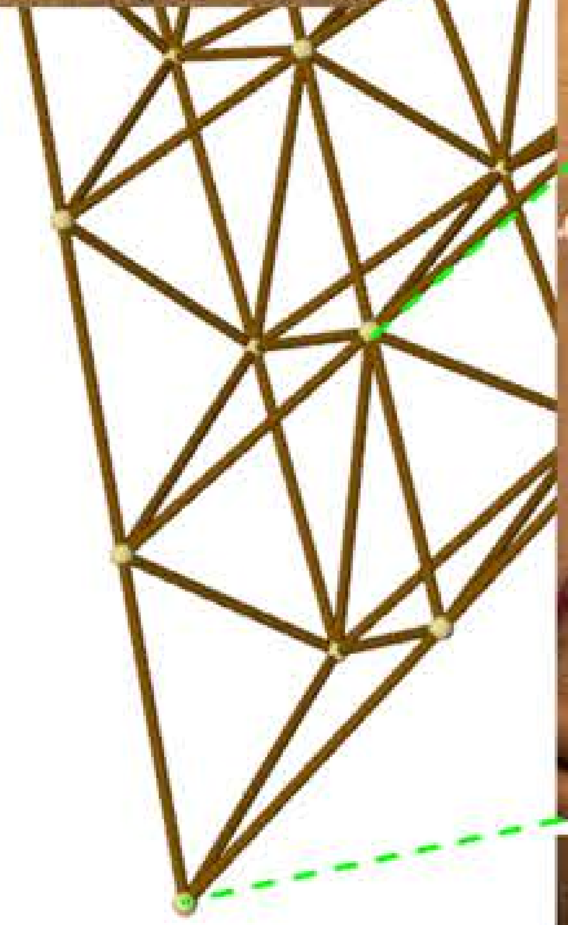
3D Massing

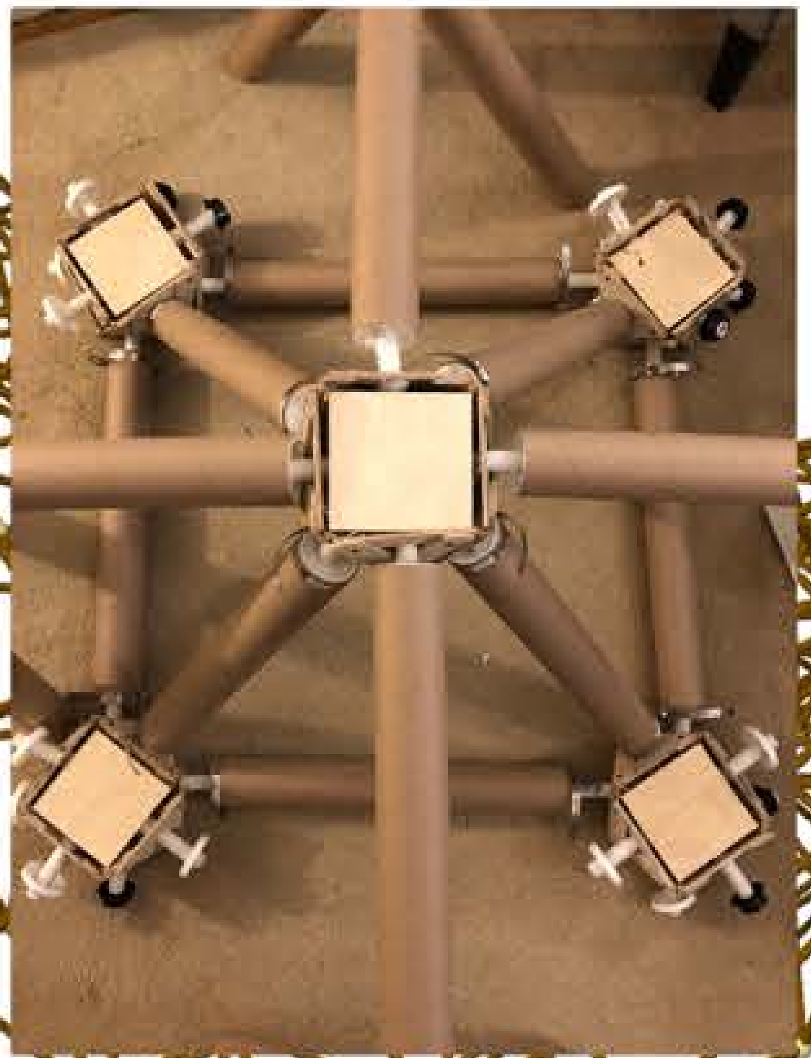
Testing

For proof of data, and safety of family and friends, I tested the paper tubes I have been collecting. I loaded them in different axial directions to compare to the data researched of paper tubes.



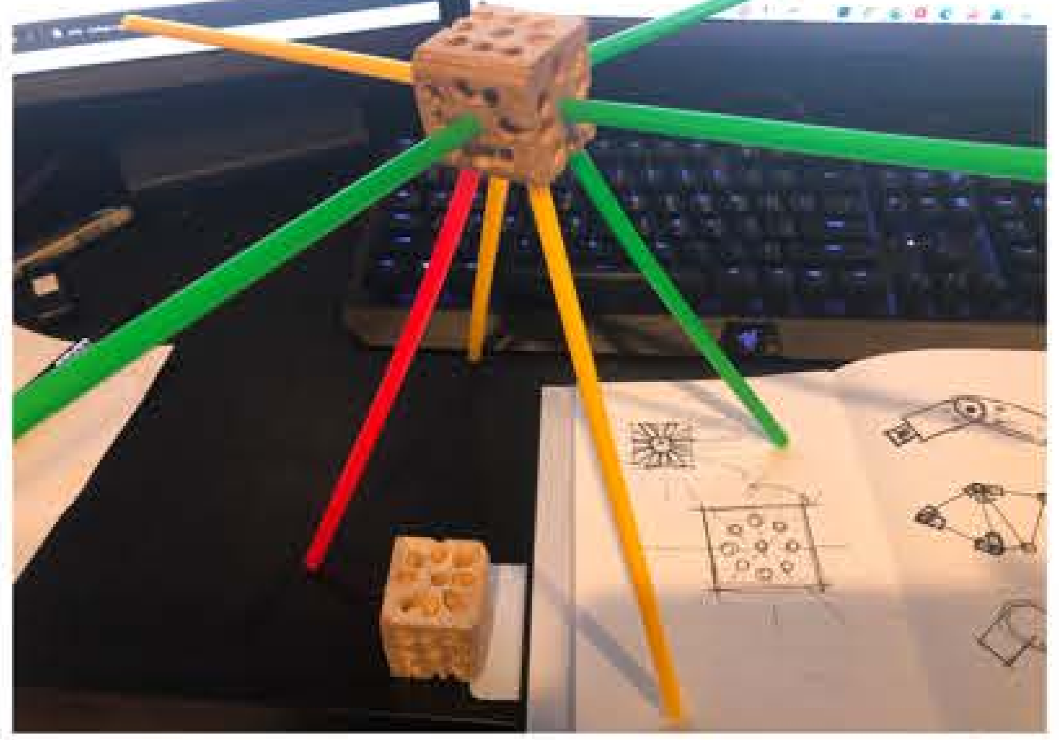
Process

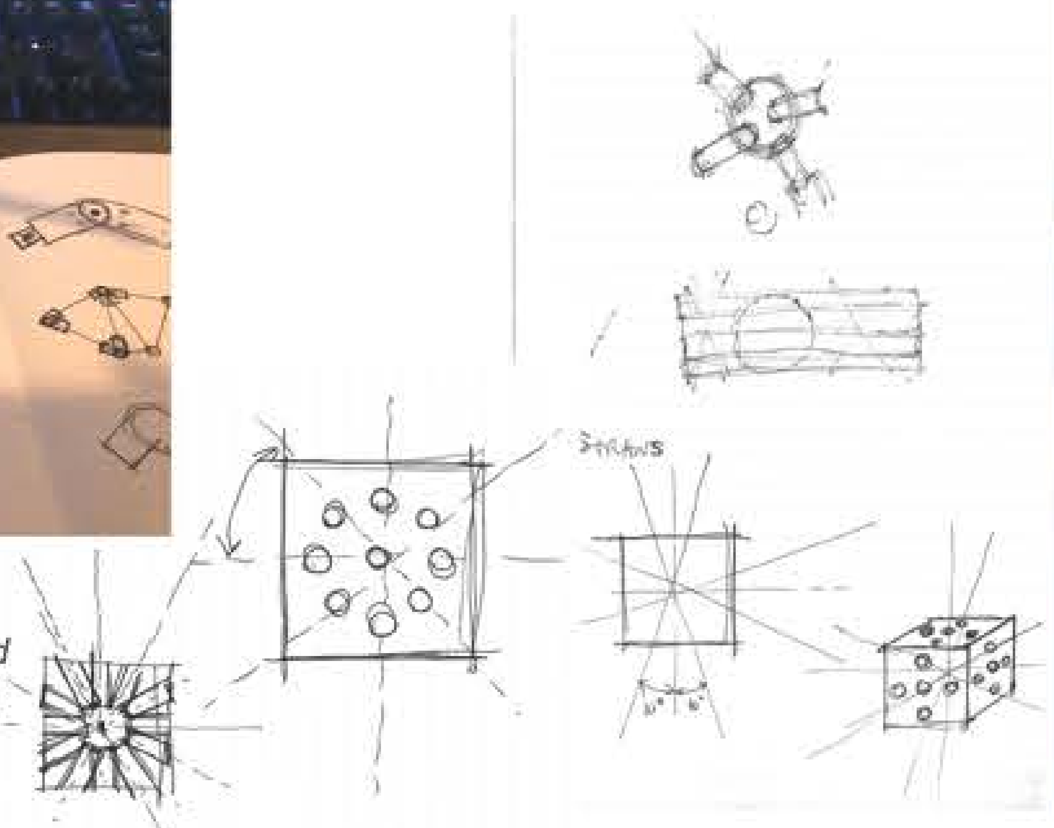




Node Prototype 1

I used the data gathered from the scripting of various known forms to narrow down the approach to prototyping. With the limit of flexibility in mind, I compared number angles and lengths of members and found that with just 5 to 10 degrees of tolerance a lot of the speculated forms could be constructed. I will be continuing this analysis as I continue my prototyping to help locate the common angles. From this, I worked out a prototype with scrap plywood and other materials in my garage as well as paper tubes I have been gathering over the past semester. In theory it could construct most of the images I shown so far, but it would require varying lengths of tube. The exception is the geodesic domes because of the requirement for a more complex joint in a tetrahedral space frame. This prototype of a joint is a single repeated joint that can position itself within the 10 degree range and can placed on the top and bottom of a space frame. The challenge and current failures of this prototype is that there is still too much flexibility. The joinery still needs to be able to lock into place once an angle is selected or else the structure will simply crumble. Also if there is a limit to number of angles, I can assign lengths of tube to those angles to limit the number of parts. Lastly if the user is going to supply their own tubes I need to have a universal connection.



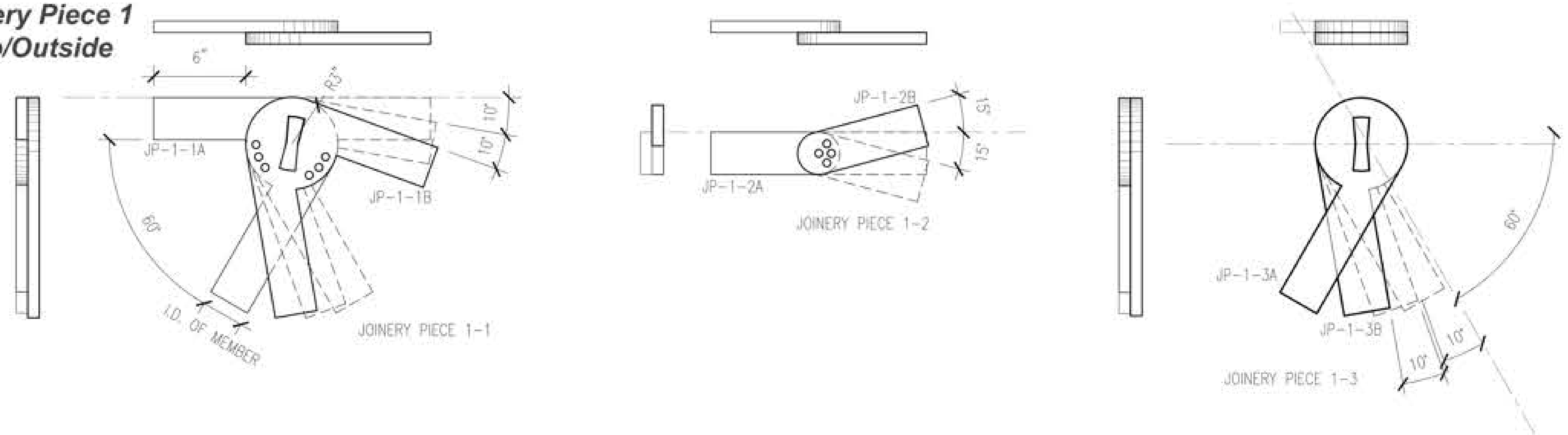


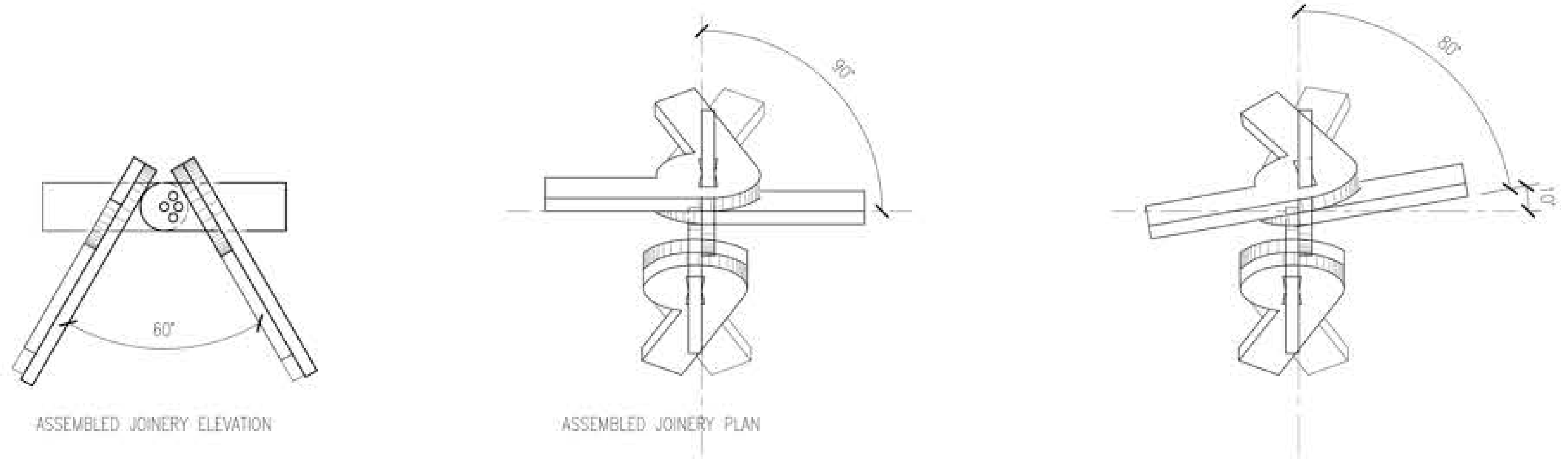
Node Prototype 2

This prototype focused on the limitations of angles and all linear members transferring loads to a central point of the node connector, but it failed to limit the user to a polyhedron form.

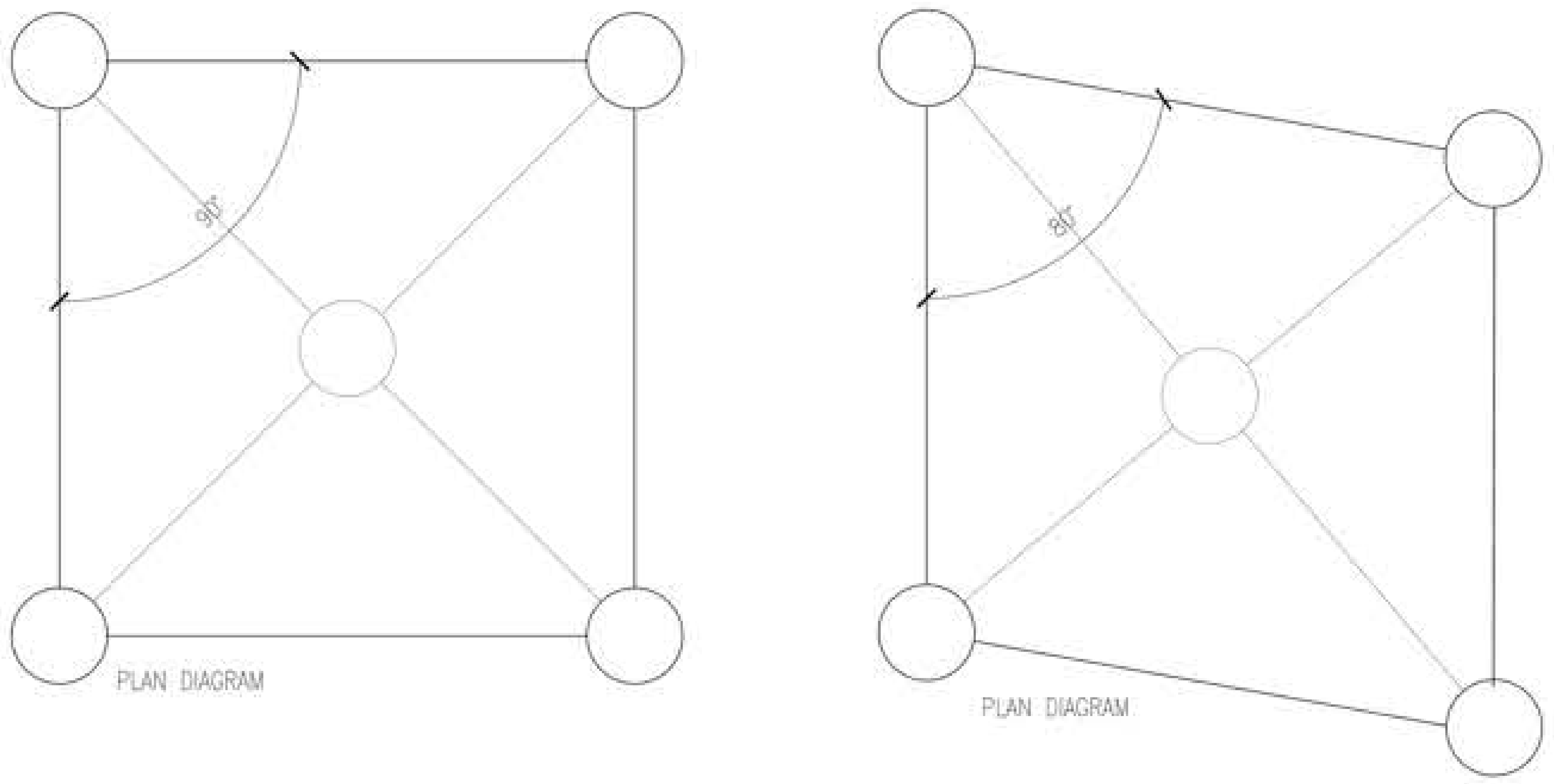
PROTOTYPING

Joinery Piece 1
Top/Outside

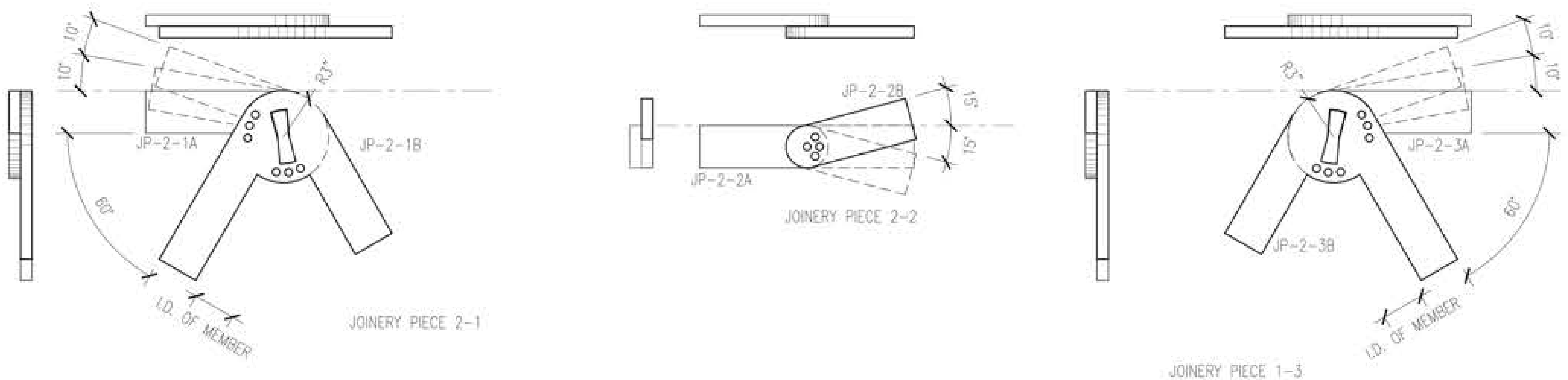




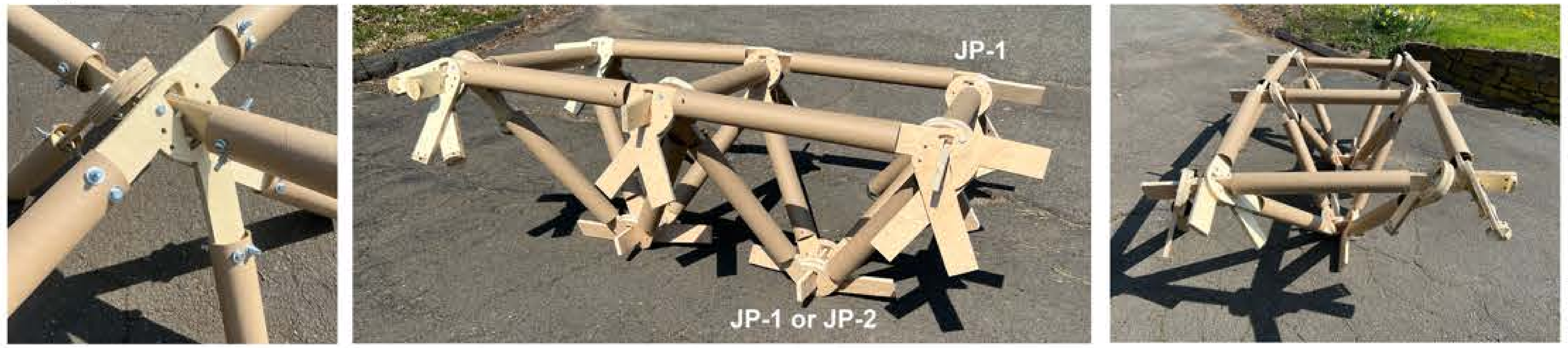
This prototype is my current running prototype that can be made from "scraps" and can be adapted to the users bulk material (diameter). It has fixed angles to create equilateral triangles (for strength) in hemi-octahedron modules. It also has built in four adjustable angles to allow the user a controlled complexity for adaptability to the existing context. The fourth angle is the point in which the user has reached complexity. Until that fourth angle of adjustability the user is only able to work in barrel forms. The fourth angle of flexibility allows a paraboloid form to be created.



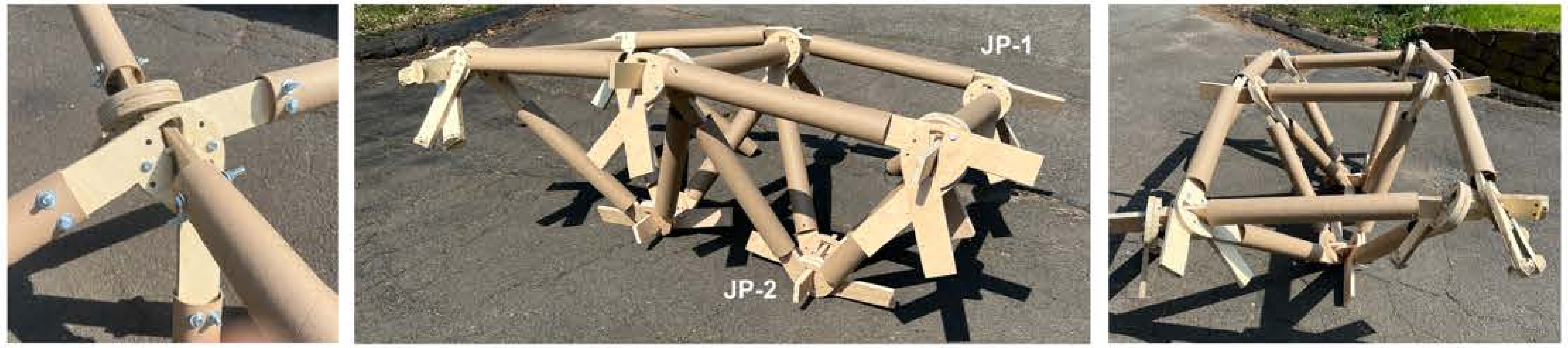
Joinery Piece 2 - Bottom/Inside of Arch



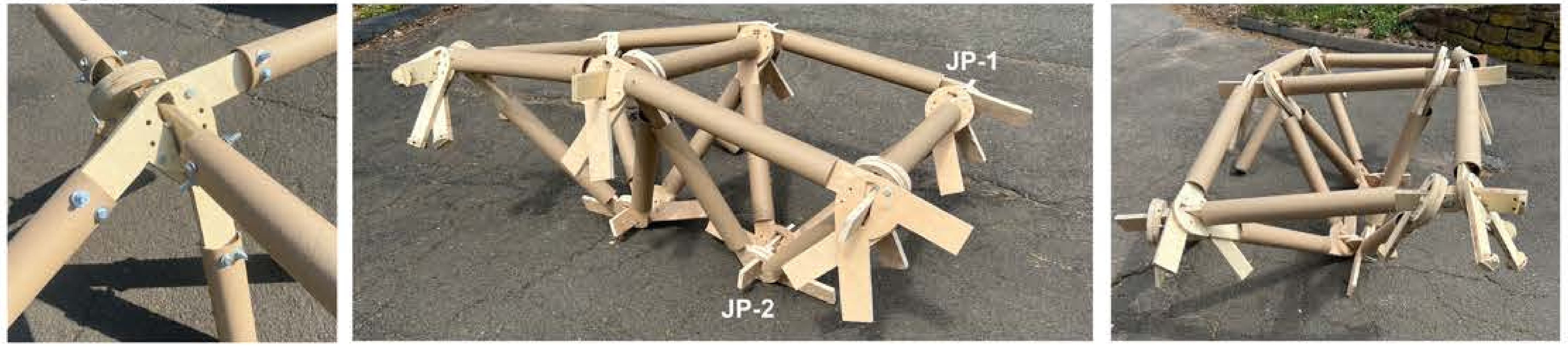
Straight - "Flat"



10 Degree - "Arch"

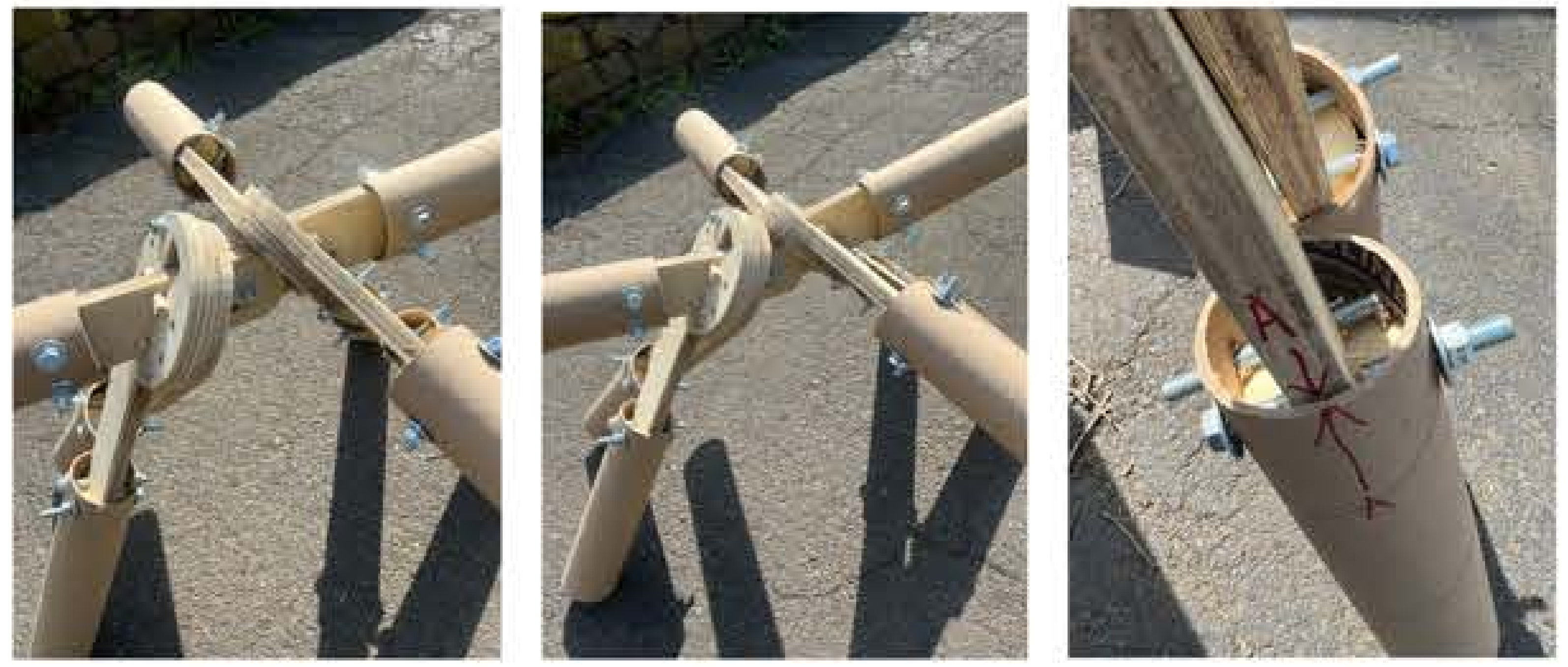


20 Degree - "Arch"



Paraboloid

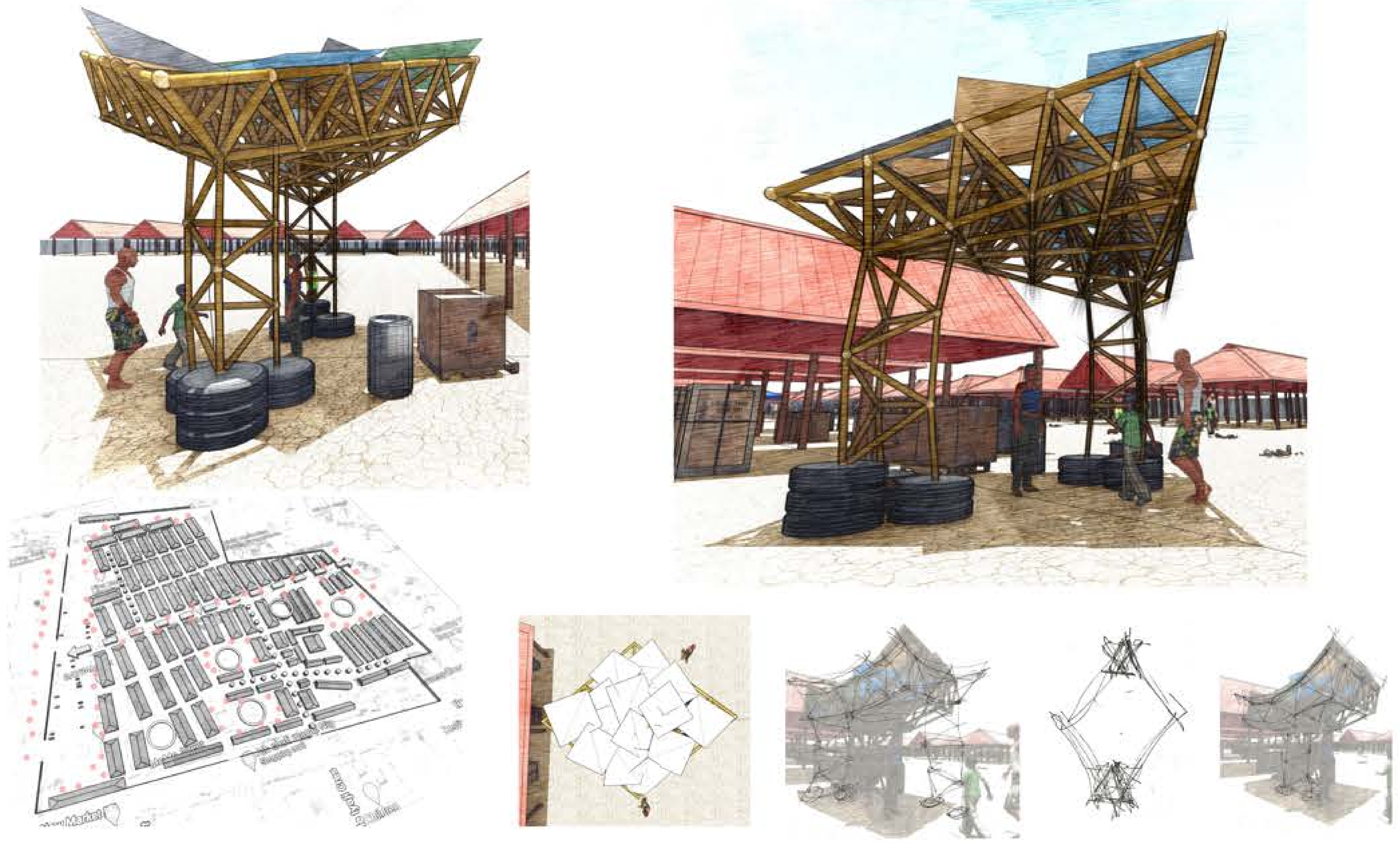
Bamboo sleeves



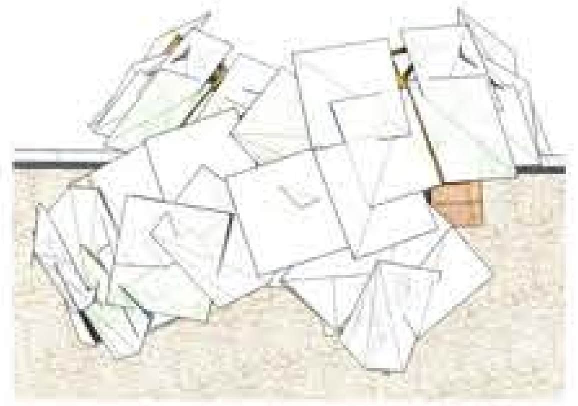
TOP: These images show two built modular hemi-octahedrons formed from the joinery. The joinery forms fixed equilateral triangles to control structural spans.

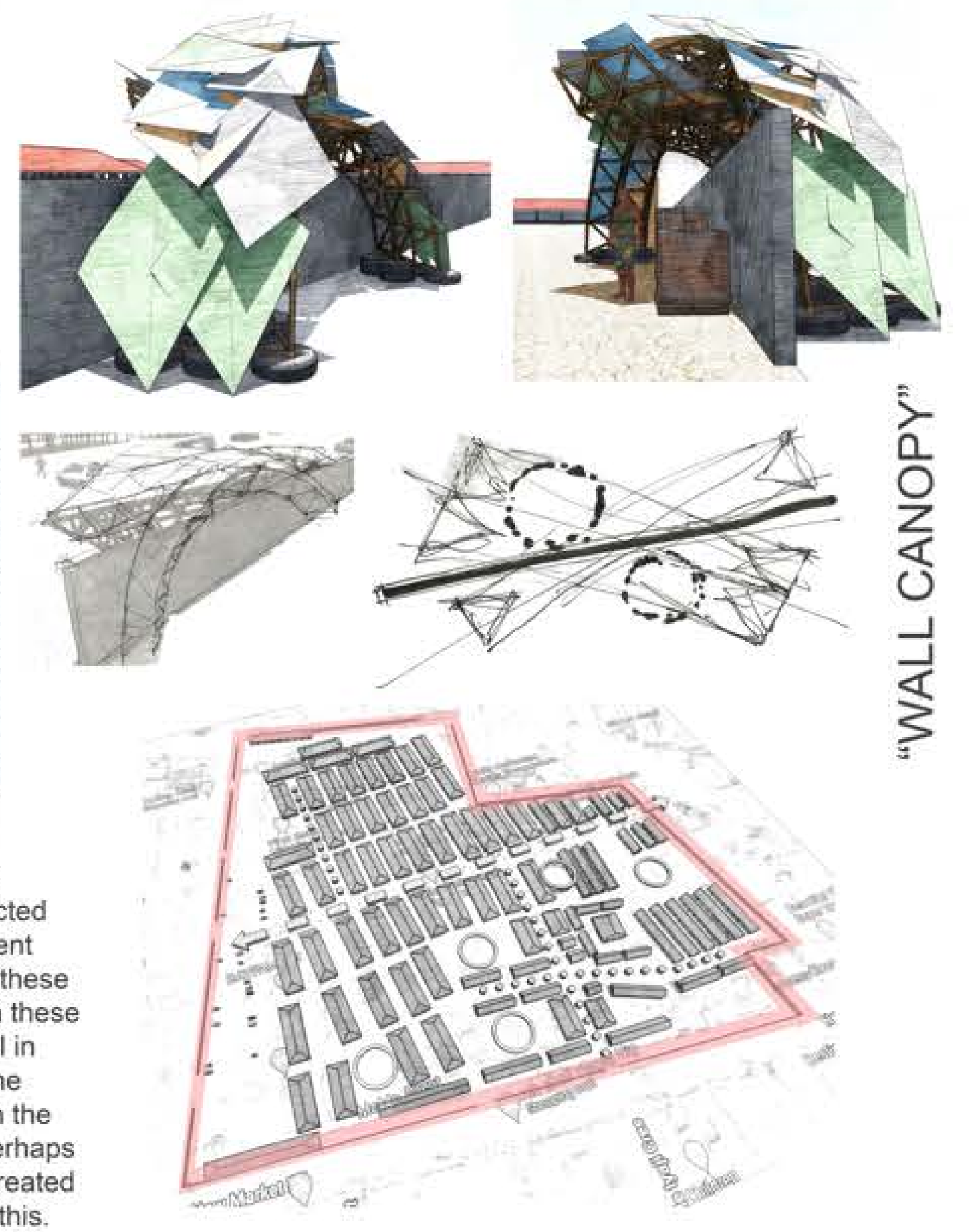
LEFT: To avoid crushing and axial stresses on the paper tubes the true joinery will have the option for oversized bamboo sleeves that will receive the paper tubes. The prototype is simply showing paper tubes to represent this.

"UMBRELLA"



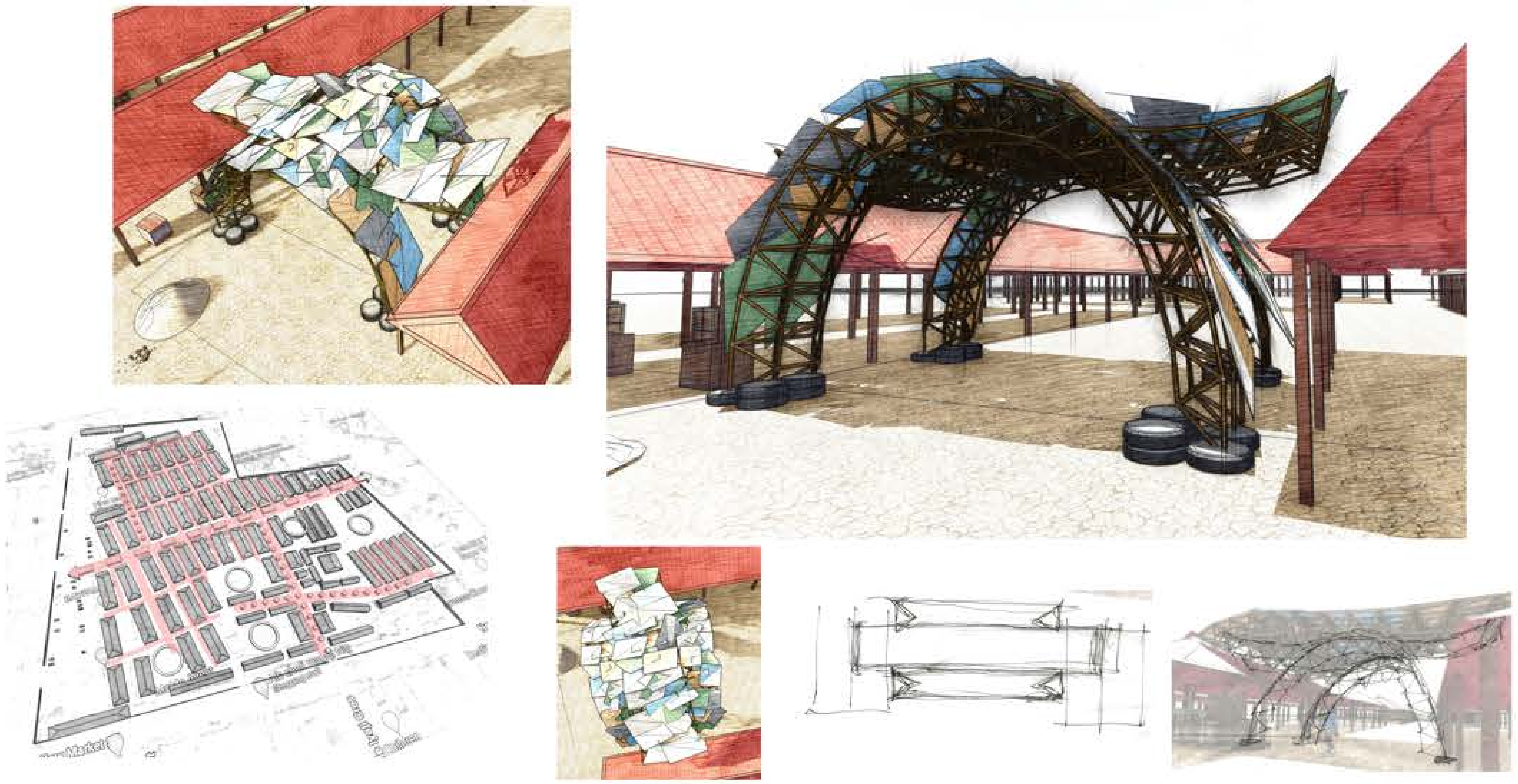
Returning to Gwagwalada to implement the new prototype with the defined level of control, I speculated what could be constructed by the people to form the previously defined forms. I am confident that these forms can be created with the current prototype and these joints can be constructed from accessible resources as well. In these images I am showing barrel forms because they proved optimal in analysis for the long spans proposed. But as mentioned with the fourth angle of flexibility a paraboloid form such as seen here in the update umbrella form can be created. I could argue still that perhaps even giving limiting settings in the four directions, I may have created a joinery that is too complex, but there is still one way to prove this.





"WALL CANOPY"

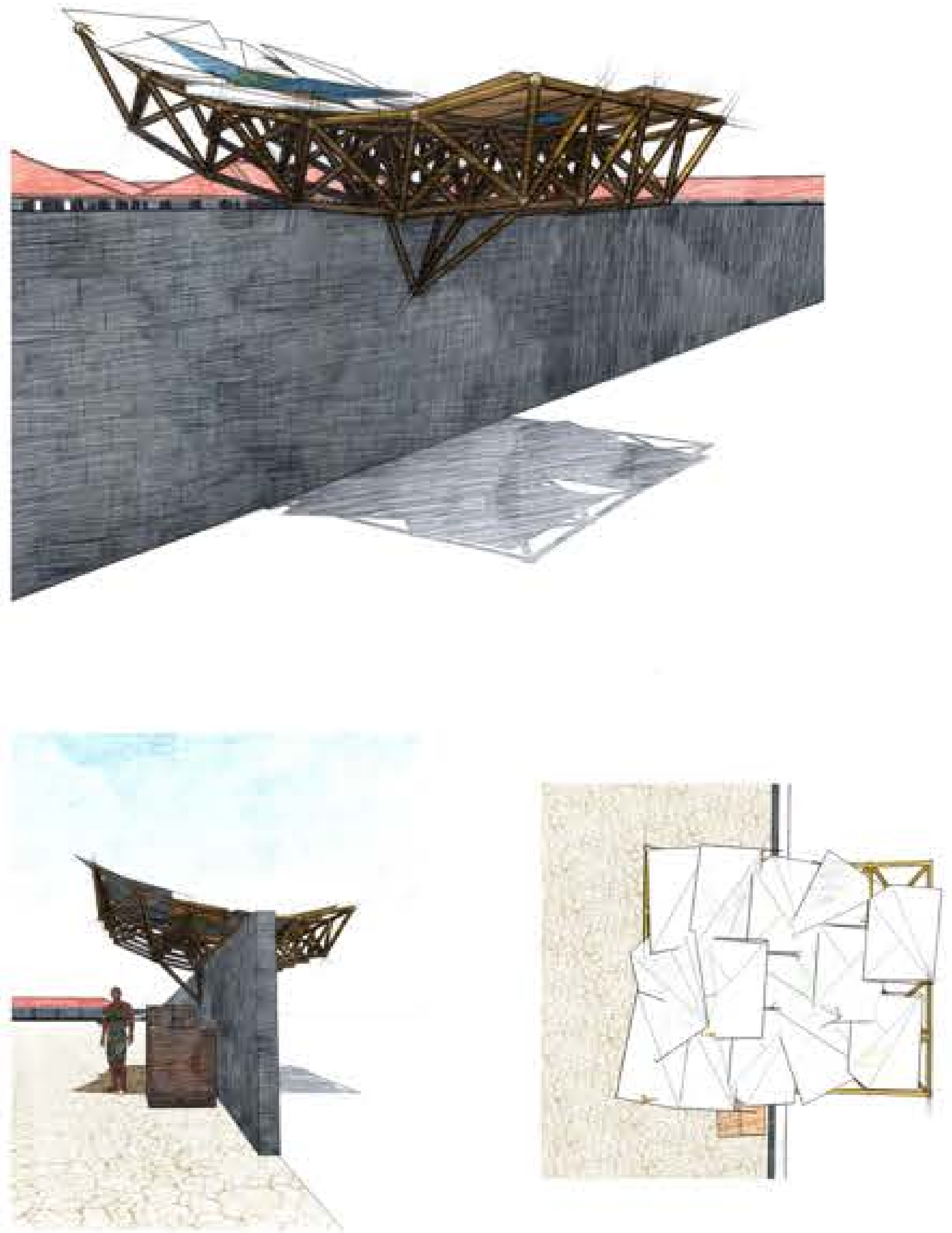
"STREET"



"PLAZA"

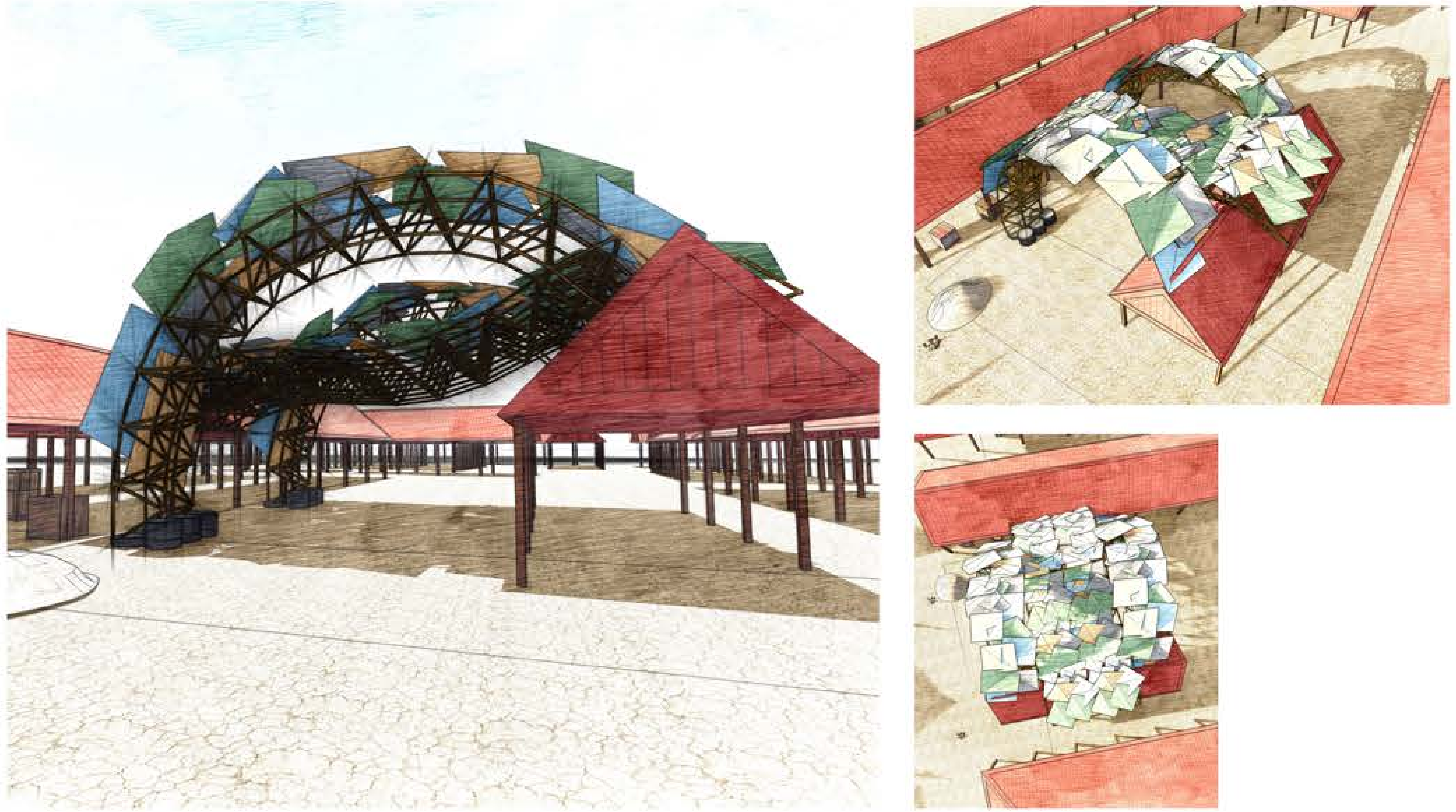
“UMBRELLA”

Continuing speculations show the flexibility of the prototype.The future is to build full scale as the research has already begun to do in prototyping. The Umbrella remains a freestanding structure and the wall canopy engaged with the wall. The street takes on a new form and interaction with the pedestrian flow using paraboloid overhangs to create a miandering path. The Plaza explores longer spans by using the arch forms to support the lesser spaning forms like the double arch.



“WALL CANOPY”

“STREET”



“PLAZA”