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Bamboo Architecture: Structure, Construction and Space: Part 1

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Abstract Bamboo is seen as a low cost, lightweight, widely available and environmental-friendly material. In Vietnam, it also connects deeply to our culture. However, it wasn't seen as a viable material for large structures before VTN Architects. Furthermore, Vietnamese cities are facing the same environmental problems as many developing metropolises in the world. Globally, climate change is a serious issue. The need for sustainable construction material is clear. The increasing development of eco-tourism in Vietnam and Asia is also a background. These become the background to the foundation and the development of bamboo architecture by VTN Architects. The journal analyses our development of bamboo construction, joints, structures, and how to use them to realise space and to create eco-friendly architecture. We will talk about our process of bamboo procurement, our construction methods, our unique joint system, how we make a frame unit and how we construct VTN bamboo structures from units.

Keywords Bamboo construction methods, Structural design, Environmental design

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1. Introduction

Nowadays, we are facing many problems: climate change, global warming, air pollution. Reports have shown unprecedented figures on natural and man-made disasters, brought by global warming and climate change. According to a paper published in the journal The Cryosphere (2021), Greenland and Antarctic ice sheets were falling at record rates, while the melting of ice around the globe was speeding up (Slater, T, 2021). Environmental crises also occur in natural disasters, such as floods, landslide, tornado and wildfires.

Furthermore, we see population growth, rapid economic development creating major environmental issues in Asian countries, especially Vietnam, Indonesia, Thailand, China, and India. For instance, the quality of urban life in Ho Chi Minh city is poor due to the lack of parks and nature, given that there is only 0.7 square meters of green area per resident. We can also precisely measure the unhealthy air quality caused by economic activities and heavy traffic. Pollution proves to be a massive problem in the developed cities.

As an architect, we have the responsibility to help combat against this through the built environment and finding the right material to do this. Bamboo is often regarded as one of the most sustainable material to be used in construction (INBAR, 1997) and is a viable material to build sustainable architecture not only for Vietnam but also internationally.

The two Vietnamese bamboo types used by VTN Architects are Luong and Tam Vong.

Luong bamboo, scientifically named Dendrocalamus, is available only in Thanh Hoa province and Hoa Binh province. Luong is tall, having big culms and small leaves. The maximum height would reach 10m. The trunk diameter would reach 140-150 mm at its fullest growth, averaging of 90-100 mm. Tam Vong is scientifically named Thyrsostachys Siamensis, with origins from Tay Ninh Province. They have solid trunks and short internodes. The highest trunk is around 9-10 meter, with an average height of 7-8 meter. The maximum diameter of Tam Vong is 50 mm, averaging at 35-40 mm. Tam vong is smaller than Luong and resist bending forces easier while luong is better if it is straight.

In Vietnam, bamboo is ingrained in people's everyday life and cultures. Bamboo has affected Vietnamese culture in the realms of literature, folk handicrafts, art, music, building etc for a long time. We see bamboo images in Vietnamese narrative, fairy tales and proverbs. A Vietnamese proverb is "When the bamboo is old, young bamboo sprouts appear". It means 'when the elderly die, the youth grow'. The characters of bamboo as being solid, straight, high and flexible are used here to express the national strength. Bamboo also grows rapidly and reborn quickly, showing the endurance of the Vietnamese. An annual festival in Soc Son uses bamboo flowers to celebrate a mythical national hero named Thanh Giong. Bamboo flowers are considered by Vietnamese as a sign of luck.

Images of bamboos are often linked to the old Vietnamese villages, with bamboo clumps sitting in front of a village's main gate.

Another local context is an increasing development of eco-tourism in Vietnam. Vietnam has 13,000 floral species and over 15,000 faunal species. This evokes an interest in eco-tourism since 1986 (Doi Moi). Ecotourism is travel to relatively undisturbed natural areas to study, admire, and enjoy scenery, plants, animals, and cultural features found in these areas. It has lower impact on the environment, lower needs for heavy infrastructure systems, and it educates tourists about nature and other cultural values. In fact, in Vietnam there are many famous eco-tourist sites such as Can Gio Mangrove Biosphere Reserve, Pu Luong Nature Reserve, Ba Be National Park, Cat Ba, Cat Tien National Park, bringing in millions of tourists every year. Tam Dao National Park sees 120,000-150,000 visitors every year (Tien 2002). Ha Long Bay sees 400,000 tourists every year (Luong 2000).

2. Design of Bamboo Structures

From the unique joint and frame units, we have 6 main types of structural systems: arches, domes, grids, HP Shell, inverse cones, and hybrid systems. This chapter goes through each of them in terms of structural design, spatial design, and environmental strategy.

The bamboo works of VTN Architects see a synthesis between structural joints, bundles, modular units, and structural forms that eventually affect spatial qualities.



Figure 1. A corner of our office, filled with physical models.

Our bamboo structure plays an active and creative role in creating space and modulating materials. This chapter explores the capacity of bamboo structures to enrich the architecture of our projects. We consider the idea of using structural units to create multiple structural forms, with an emphasis on how dealing with the weaknesses of bamboo give raises to a new form of structure and architecture.

We also consider some very important qualities of our bamboo architecture that make us different to our contemporaries. We further dwell into our bamboo design process in our office to shine lights into means that allow us to be experimental and thoughtful before the construction even begins. We compare our ways of working with bamboo to other contemporaries.

In the end, our bamboo architecture carries simple structural beauty that modernises local and traditional bamboo to keep up with contemporary forms of architecture. From the unique joint and frame units, we have 6 main types of structural systems: arches, domes, grids, HP Shell, inverse cones, and hybrid systems. This chapter goes through each of them in terms of structural design, spatial design, and environmental strategy.

The bamboo works of VTN Architects see a synthesis between structural joints, bundles, modular units, and structural forms that eventually affect spatial qualities. Our bamboo structure plays an active and creative role in creating space and modulating materials. This chapter explores the capacity of bamboo structures to enrich the architecture of our projects. We consider the idea of using structural units to create multiple structural forms, with an emphasis on how dealing with the weaknesses of bamboo give raises to a new form of structure and architecture.

2.1. The structural principle of our bamboo architecture: *VTN frame and joint method*

Our structural design comes from our unique frame and joint method. *VTN Architects* uses a unique fixing method to bundle multiple bamboo culms to create modular structural frame units. Each unit sees a sandwich design of segments of bamboo culms, fastened by low cost and **natural fixing methods** like rattan ropes and bamboo nails. The fixing method maintains our commitment to using natural materials in our projects. It is also cost-effective, simple in technology, and is easy to assemble or disassemble.

On a practical level, this fixing method **absorbs the different bamboo sizes** and ensures strengths and precision for bamboo used as load-bearing structural elements. For example, for *wNw Bar*, an early experiment with bamboo, we use thick bamboo bolts and rope as joints to establish a structural bamboo arch system

As a structural solution, this allows each bamboo structural unit to span widely by extending the span capacity of bundles of bamboo culms. For example, our units at *Vedana Restaurant* manage to span with a radius

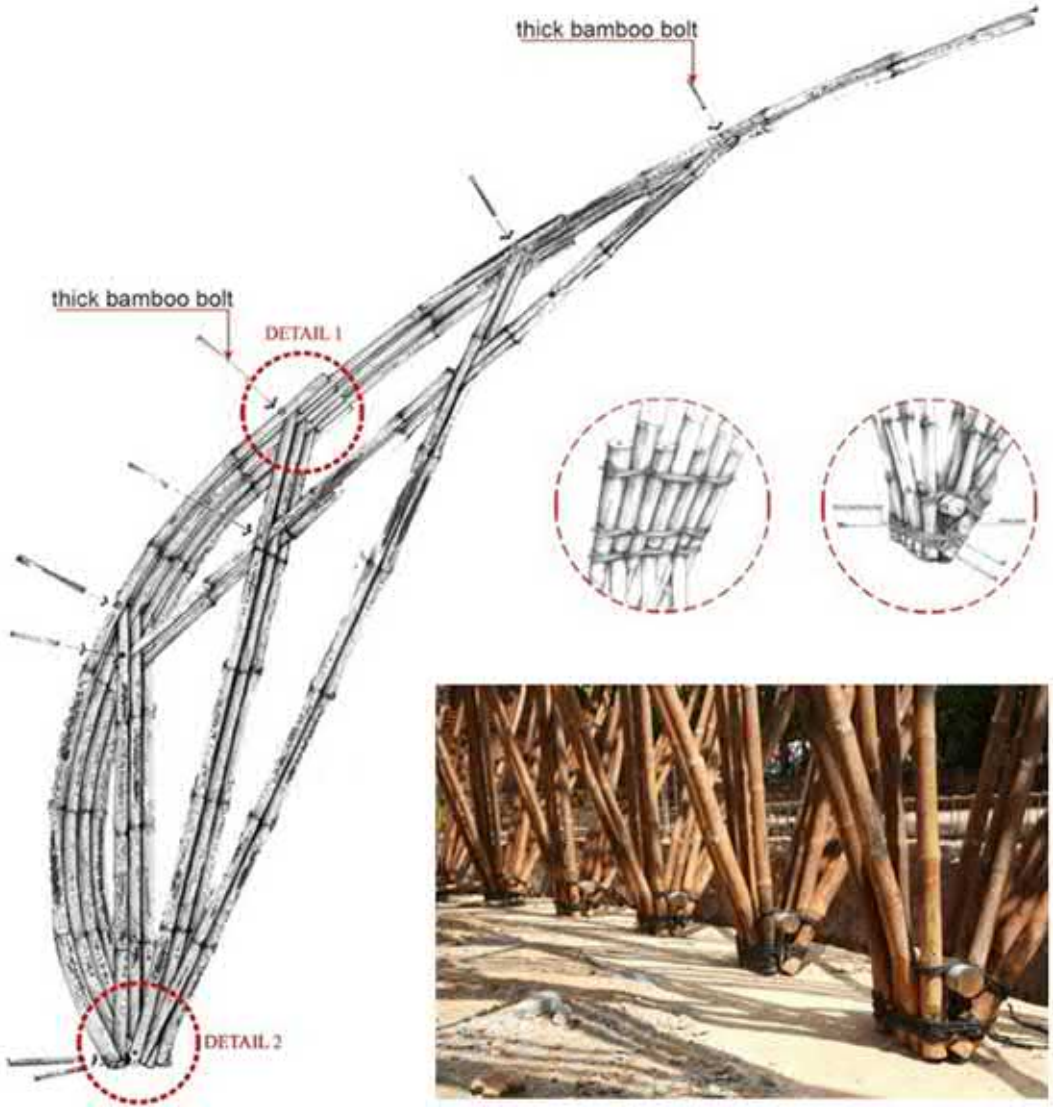


Figure 2. Details of the bamboo frame unit used at *wNw Bar*.

of approximately 18.2 meters. (Figure 3)

Figure 3. Section of *Vedana Restaurant*, showing the spanning radius of each bamboo frame unit

2.2. VTN Bamboo Structural Systems:

6 Types Of Structural Systems

This modular use of frame units system allow us to do multiple things in terms of structural design:

_The frame units allow us to be precise with an imprecise material.

_The frame units allow us to absord the uneveness and inconsistency of Vietnamese bamboo culms.

_The frame units allow us to build fast with minimal means and low cost, whilst we can control the quality at every stage.

_The frame units allow us easily maintain our bamboo projects if some parts become damaged and needed to be replaced.

But most importantly, the frame unit system allows us to **create multiple structural systems** that express different structural beauty and spatial quality.

It also helps when it comes from our **two types of Vietnamese bamboo, allowing each unit to have multiple forms: straight or curved.** The two types of bamboo used by *VTN Architects* are *luong* and *tam vong*. Each type dictates the forms of the individual units. We use *luong* to create straight vertical columns and horizontal beams because luong is strong against axial force (compression and tension). However, it has low resistance to bending. This characteristic is utilised in projects required a sense of verticality such as *Son La Restaurant.* We use *tam vong*, which is smaller in diameter to form arches, domes, or hp shells due to its dense core and high resistance to bending. The bamboo arches are bent under their weight from the beginning to avoid sagging during use. These two forms allow us to use bamboo units to

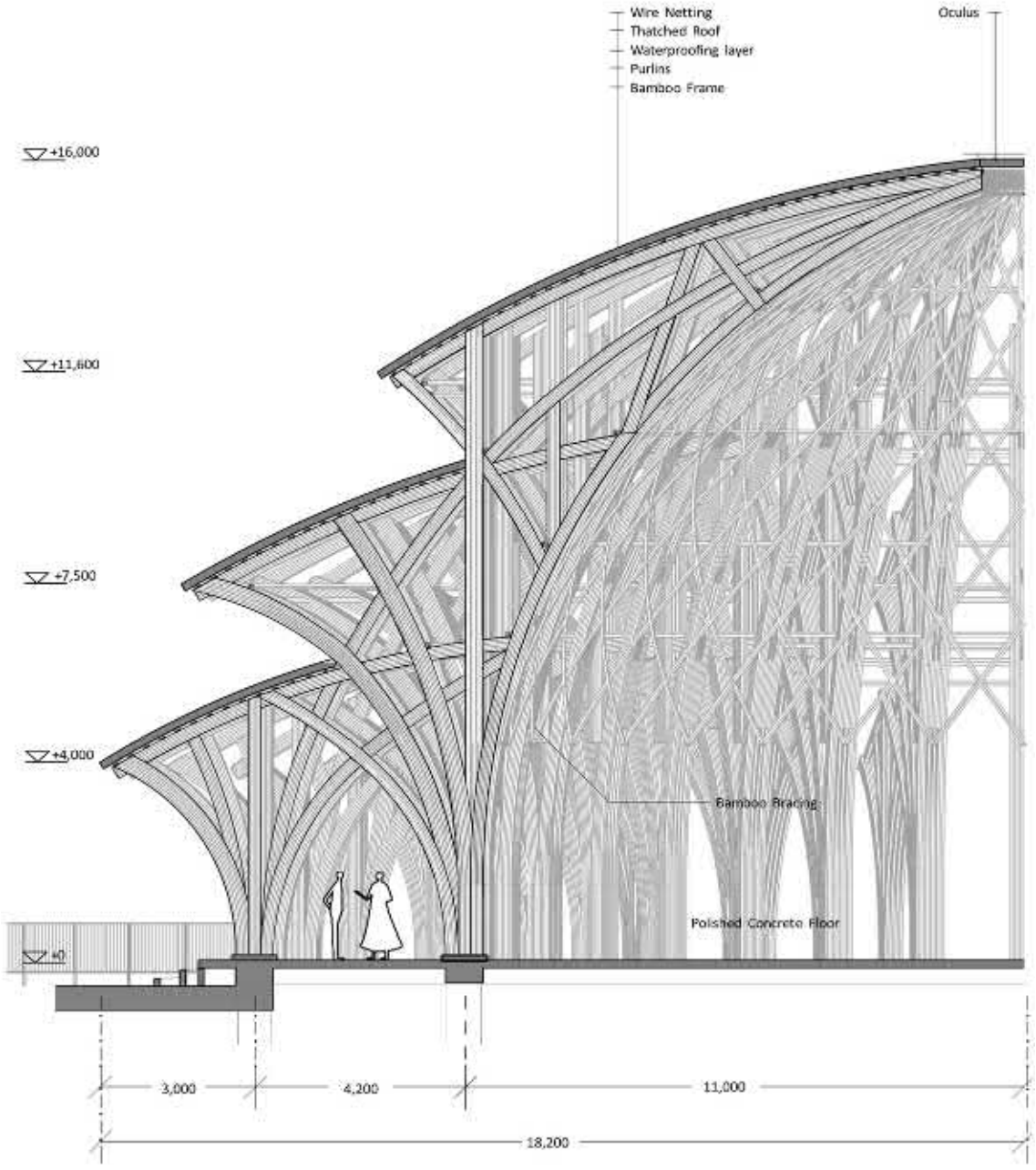


Figure 3. Section of *Vedana Restaurant*, showing the spanning radius of each bamboo frame unit.

create flexible and complex structural forms that accommodate multiple need, typologies, and architectural expression.

We have **6 main types of structural systems** that are expressed using our bamboo unique frame units: Grid, Arches, Domes, HP Shell, Inverse Cones, and Hybrid.

2.3. Arches:

A simple way to utilise our frame units is **to repeat them across a grid system to assemble a simple portal form.**

This structural form works like this: these **arch frame units act as load-bearing elements, transferring vertical loads** into the ground. We uses **braces** in between the frame units to connect the frames together, to keep the form rigid and consequently, to **help the structure resisting horizontal loads** (strong wind and storms). At *Huong An Vien Visiting Center*, we also put **tensile wires** on the roof from the core outwards 2 or 3 frames to hold tension of the whole form, further making the structure stronger and more rigid (Figure 6,7).

This structural system brings simple beauty to projects such as *NamAn Retreat Conference*, *Bamboo Wing* or *Huong An Vien Visiting Center*.



Figure 4. The interior of *Huong An Vien Visiting Center.*

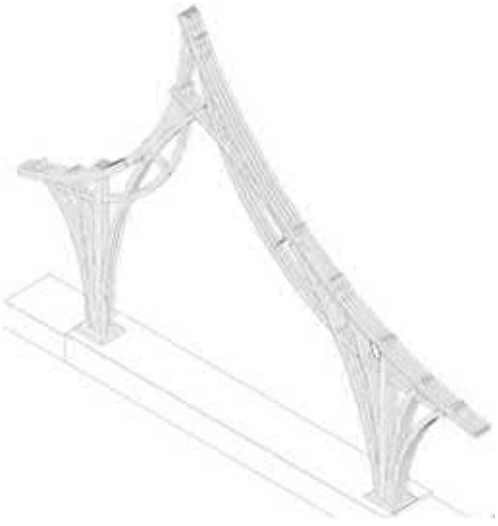


Figure 5. An arch unit of Huong An Vien Visiting Center.

With *NamAn Retreat Conference*, the bamboo units, made from *luong* columns and *tam vong* arches, span 13.5 m in the hall and 4m in the corridor, raising the roof upwards 9.5 m. Due to the unique flexibility and bendability of *tam vong*, arches are created expressing a formal beauty. This arch form creates a unique spatial quality that emphasises on openess, creating semi open space, blending the interior with nature, and utilising the natural world for ventilation purposes.

Projects like *Bamboo Wing*, on the other hand, sees **unique cantilever arch units** that span 12 meters, balancing themselves on one leg, thanks to the unique combination of **cantilever bamboo units and steel tensile cables**. The combination frees the space from the need to use structural columns, leaving the bamboo units appearing like bird wings in the middle of the sky. The roof is suspended, with tensile cables (many of which are not straight) holding the structure together. The bases are held back into the

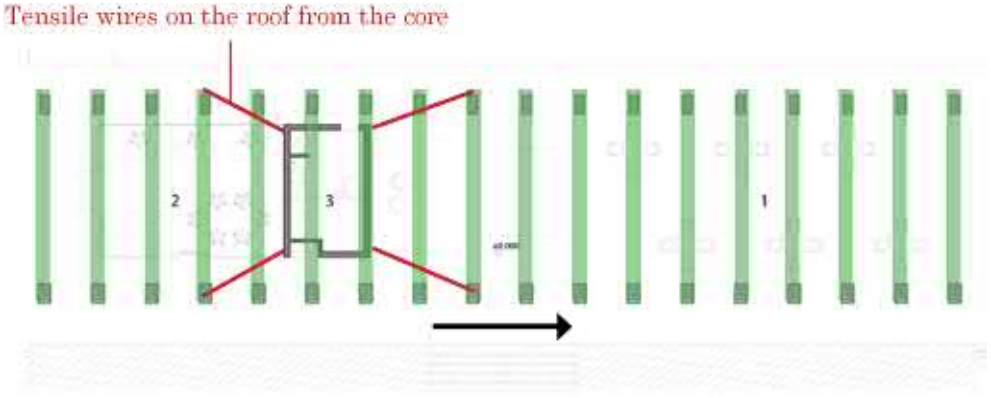


Figure 6. Repetition of arch units to form arch structural form.

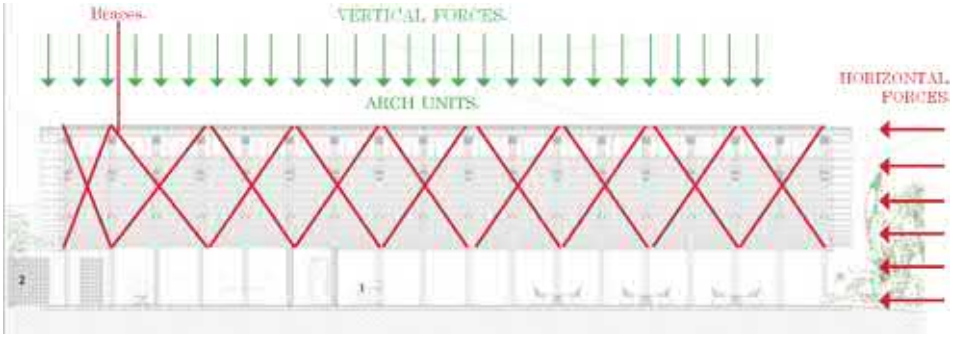


Figure 7. Structural System of Huong An Vien Visiting Center.



Figure 8. Unique spatial quality of *Huong An Vien Visiting Center.*



Figure 9. Assembling a unit on site.



Figure 10. Tam vong is used to create arches.



Figure 11. NamAn Retreat Conference.



Figure 12. Bamboo Wing structure - under construction.

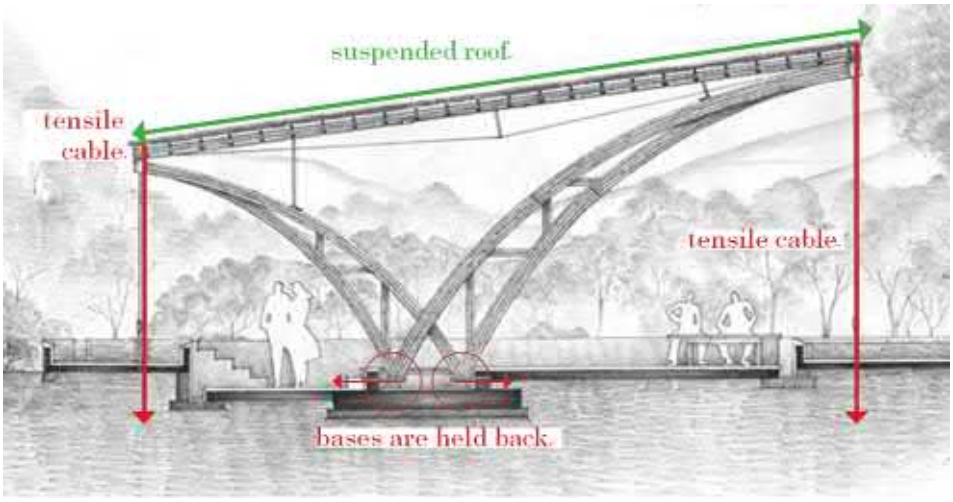


Figure 13. Bamboo Wing structural system.



Figure 14. Bamboo Wing spatial quality, utilising nature.

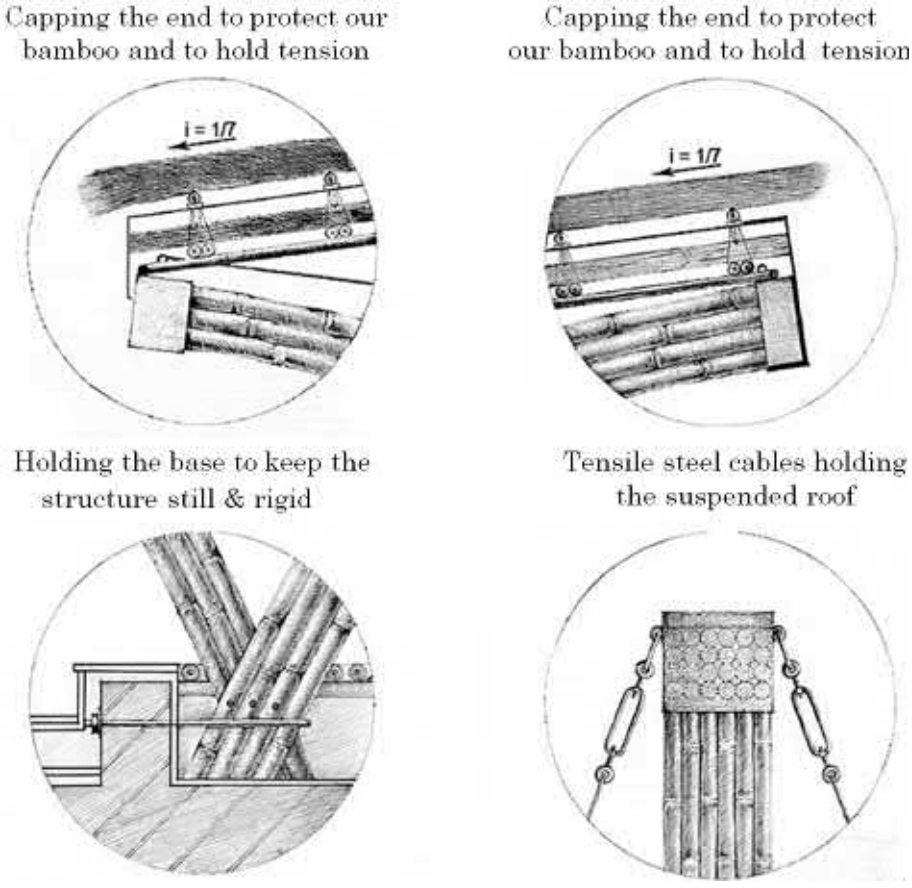


Figure 15. Bamboo Wing bamboo details, explaining how the cantilever structure is formed.

concrete footings, helping to resist lateral loads (Figure 13).

In conclusion, this structural form can use both types of bamboo, *luong* for vertical elements and *tam vong* for arches elements. The larger span of bamboo units and good structural height allows for free plans and larger open spaces compared to the previous structural forms.

At heart, there is still a sense of simplicity in the structures, but overall it still manages to be formal and impressive because of its expressive arches and dense layers. Arch cantilever form at *Bamboo Wing* also expresses the impressive strength of the material.

2.4. Domes:

We can then rotate multiple arch units to form dome structure. It is due to the unique qualities of bendable tam vong that form arches in individual units. As a combination of arch units, an impressive dome structure



Figure 16. Dome structures at *wNw Bar* and *Vedana Restaurant.*



Figure 17. Assembling multiple units to create at Vedana Restaurant.

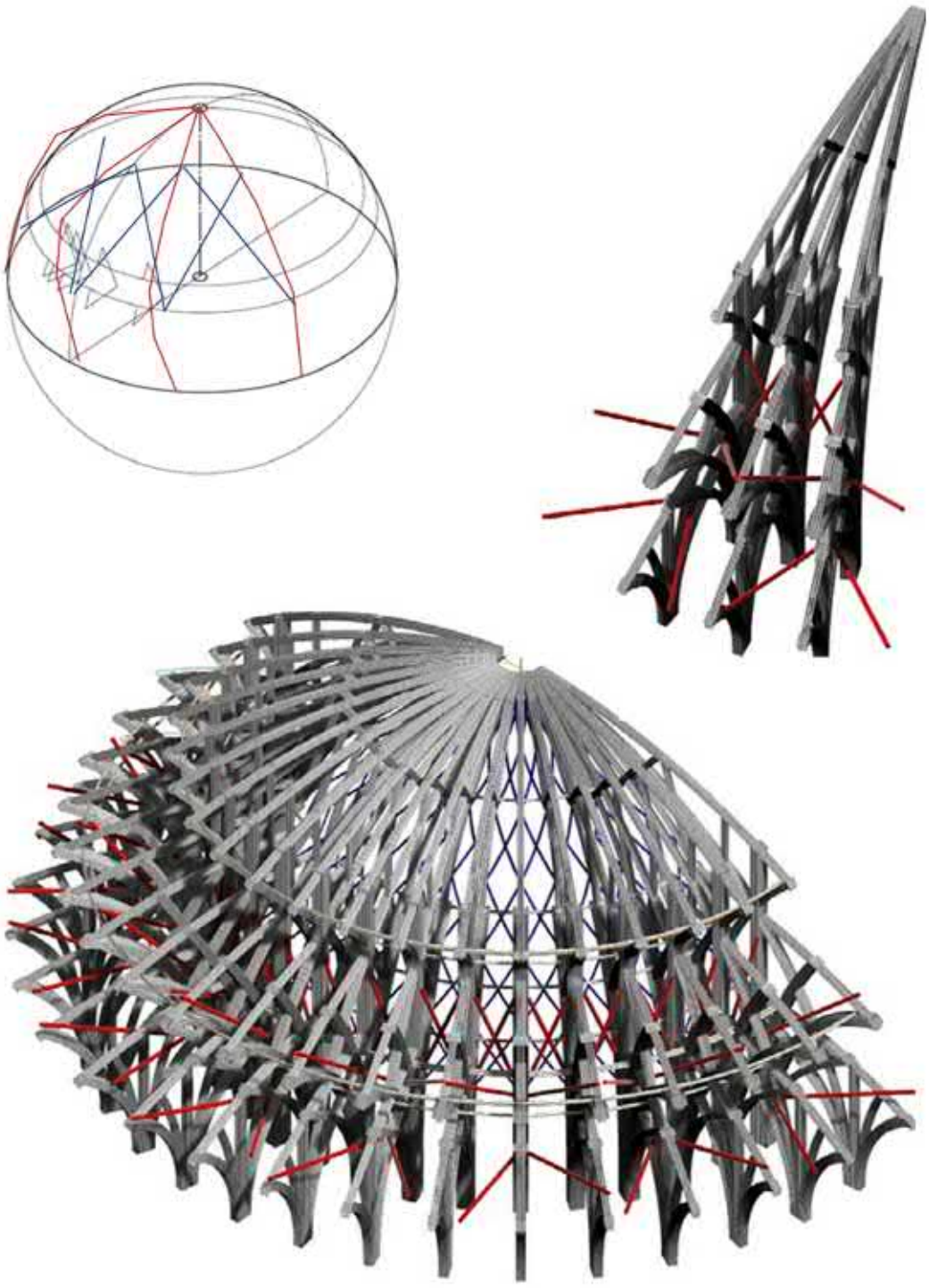


Figure 18. The structural principle of dome structures, as seen at *Vedana Restaurant.*

is formed with a compression ring to create an oculus on top. **Bamboo braces** is also woven be- tween units to strengthen the overall structure and **help resist lateral loads**. This structural system allows the units to go up to 10m high and span 15m across, in the case of *wNw Bar*. At *Vedana Restaurant*, the dome has an impressive radius of 18.2 meters and is 16m high.

The fundamental idea of our dome structure is that **we have to braces between the frame units** to stop the structure from twisting under heavy wind loads and other horizontal loads. This is easily illustrated in our *Vedana Restaurant*, where in between frames are heavily braced to keep the whole dome rigid, structurally adequate, and to resist lateral loads.



Figure 19. Woven pattern as structural elements.



Figure 20. Dome structures at Diamond Island.



Figure 21. Bamboo units at Diamond Island Community Center.

Our units **can be assembled manually on-site**, like the case of *Diamond Island Community Center.* The double-layer structure was woven by our professional bamboo workers to create a dome that is 24 m in diameter and 12.5 m in height. This traditional method creates smooth curve lines as bracing elements, proving the flexibility and versatility of our structural units to be used efficiently. The weaving pattern created by multiple units turns the structural functions of bamboo elements (vertical arch ribs structure + horizontal bracing structure) into an aesthetic that is unique to the material: complex, impressive, yet easy to assemble, low cost and natural.

The large span of bamboo arch units and the structural height of the form allows free plan and large open spaces, even larger than conventional arches system. Dome structural form is excellent in creating vast, massive open free spaces. There is a heightened sense of height and spirituality attached to this form. Similar to the previous arch form, the dome aesthetic is also suitable for hospitality space, where impressive sculptural quality become suitable for restaurants or community

To understand how our dome structures work, we can look at *Vedana Restaurant*, with a system that involves a dome combined from a series of arch units to resist vertical loads and braces as well as rings tying the whole frame units together, resisting lateral loads.



Figure 22. Bamboo arch units at Diamond Island Community Center.

Wind and Water Bar, on the other hand, sees the dome fully closed off to the out-side because of the need to sound insulate from the busy noise of the surrounding urban environment. The braces are simply crossed accross 2 or 3 ring distance to help resist lateral loads. The arch units are rotated to form a rigid dome to resist vertical loads.



Figure 23. Vedana Restaurant exterior.
*Vedana Restaurant: *Arch Units Rotated To Become Domes + Braces In Between Units*

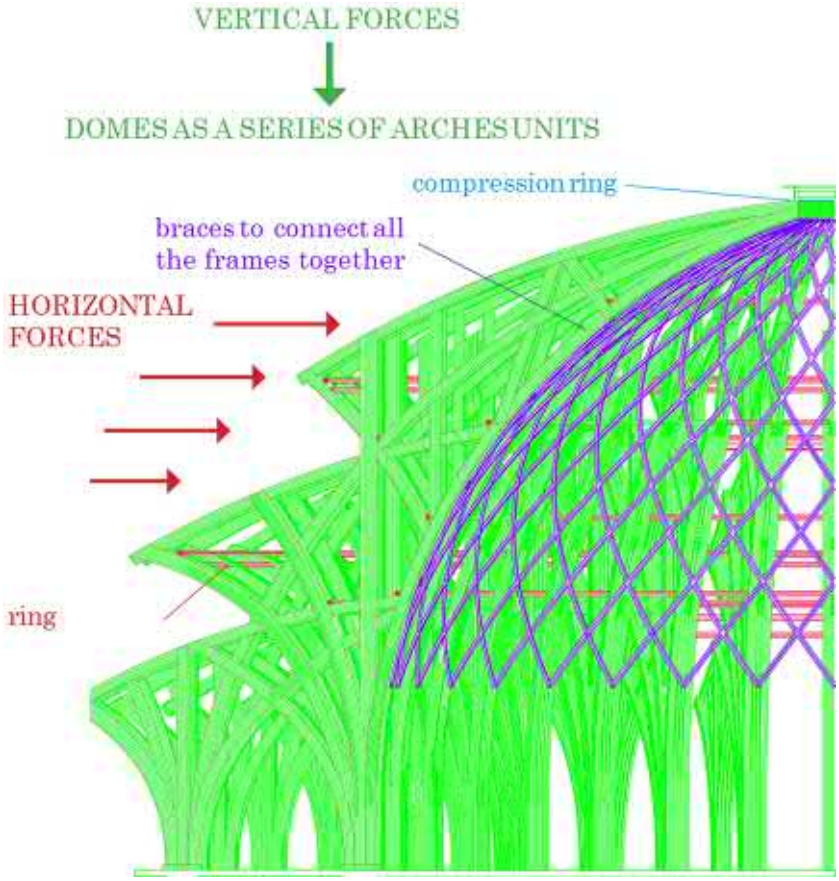


Figure 24. Structural System of dome.

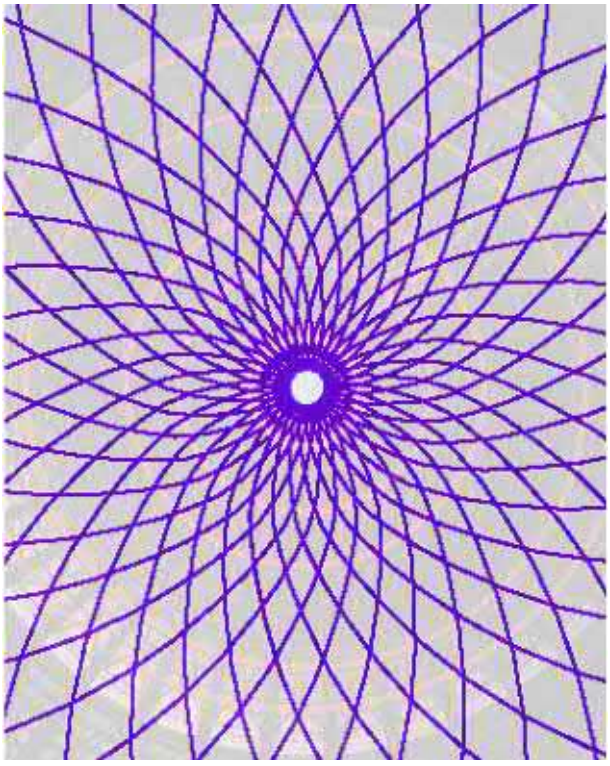


Figure 25. *Vedana Restaurant* structural system.

2.5. Grids

Due to difficult terrain, Son La is accessible from Hanoi by a 7 hour car trip along precarious cliff roads, which makes transportation of building materials difficult. Thus, the project maximized the use of **local resources**, including local workers and **affordable local materials**. In this situation, a **local bamboo called "Luong"** and **stonework** were selected to be the main materials of the building. The local Luong bamboo is strong as a straight element but weak against bending. Structural mechanics appropriate to the material influenced the design of the structural system. So structure consisted of straight elements like wooden was selected in this project.

In *Son La Restaurant,* **the structural system is simple: bamboo grid to resist vertical loads and stone walls to resist lateral loads**. A traditional structural form is created Son La Restaurant employs a grid of posts and beams, made from 96 bamboo columns and 10 layers of beams. Each column bundles 4 bamboo culms. Beams and columns are crossed and sandwiched, fixed by bamboo nails and ropes, giving an impression of a wild forest inside the restaurant. Due to the accumulation of many *luong*, the columns have enough strength to raise the roof, creating a semi outdoor open space below (Figure 29). Shear loads induced on the structure are braced by 10 layered crossed bamboo beams that are connected to the stone walls (Figure 30 and Figure 31). Horizontal loads are transferred to reinforced concrete. (Figure 32)

VTN can also multiply the simple post and beam system to form an **'expanding' system, stacking layers of grids onto each others**. For *Green Ladder,* VTN uses tam vong not to create arches but to form a frame of smaller grids of straight horizontal and vertical elements, fixed by ropes and supporting the planter pots in between. The grid system creates an intimate form that connects people to nature literally by allowing them to walk through the dense frames and enjoying the plants scattered within their surrounding.

At heart, the grid structural system is conventional, with a simple aesthetic. It is easier to assemble than our bending structures because the culms don't need to be bended into curves and the overall frame only contains vertical and horizontal elements. Due to its structural properties, this system is not used to create massive free plan as it need multiple columns within an interval grid spacing, creating a dense forests-like structure.

2.6. HP Shell

In *Castaway Island project* located in Cat Ba Island, the structure needs to resist strong wind and storm which often happen in the area. So new structural system was selected and tried. HP Shell structure was realized at first in VTN bamboo architecture to meet the demand of such site context and space quality. (Figure 33)

HP Shell surface makes the structure rigid and this structural system is a surface system. Surface is made by straight bamboos by connecting 2 points systematically. In the cross joint, each bamboos are tightly connect by using bamboo nails and ropes to make the surface united and strong. Each bamboo units are made from 80 straight bamboos and 13 HP shell units are formed to make structure. (Figure 34) The strong surface also resists wind & heavy storm with column and beam together. Formed into one surface, the shell units define the organic roof form of the restaurant.

Connection of HP Shell structure is complicated because different 3 dimensional angles of frames are connected in one joints. So comb-like joint for 2 dimensional frame cannot be used in this structure. So simple steel joints were used to realize HP surface. (Figure 35) Hook shaped steel joint can deal with different angles flexibly and be connection of each bamboo frames with beam. Cross joint of each bamboo frame making HP surface is adjusted one by one to show aesthetic of structure. (Figure 36) To protect interior space from strong wind, all surface was covered by thatched material and it makes wall. Open space of structure became window to take into outside space. Structural system is also element to make spatial quality.

This sophisticated structure sees variation in structural depth so that the roof surface is not plain. The interval spacing and the density of tam vong over a united HP Shell surface create a rhythmic pattern, pushing bamboo structural elements to express a unique form of texture.



Figure 26. wNw Bar.
*Wind and Water Bar: *Arch Units rotated to become Domes + Rings + Braces in between units*

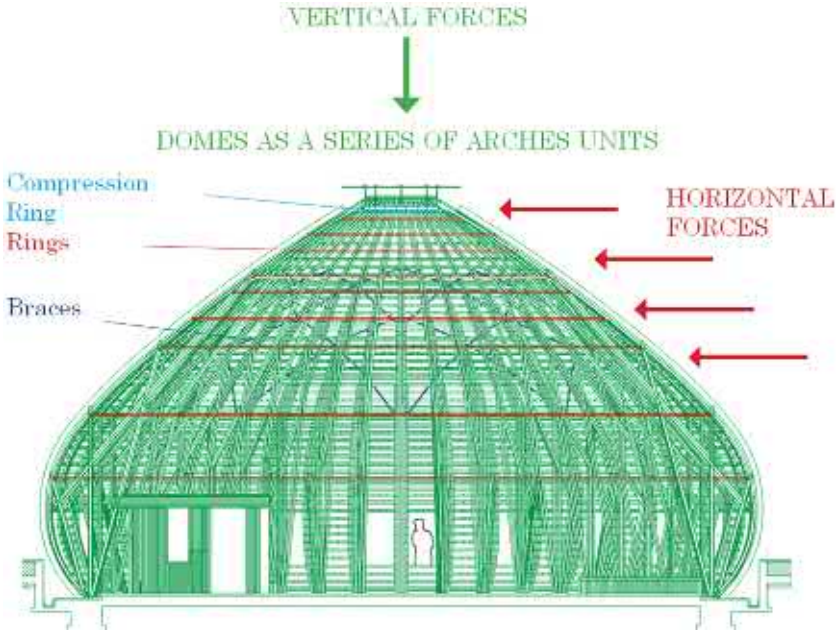


Figure 27. Structural System of wNw Bar.

Bamboo Stalactite

When VTN were confident with the material, VTN further experimented with different forms of structure. VTN realised it was possible to form HP shell structures to create organic architecture from natural materials without complicated modifying. And technically, Castaway project also became the starting point to develop steel joint more.

Structurally, shell structures are surface structures. This allows them to make thin yet strong curved surfaces to

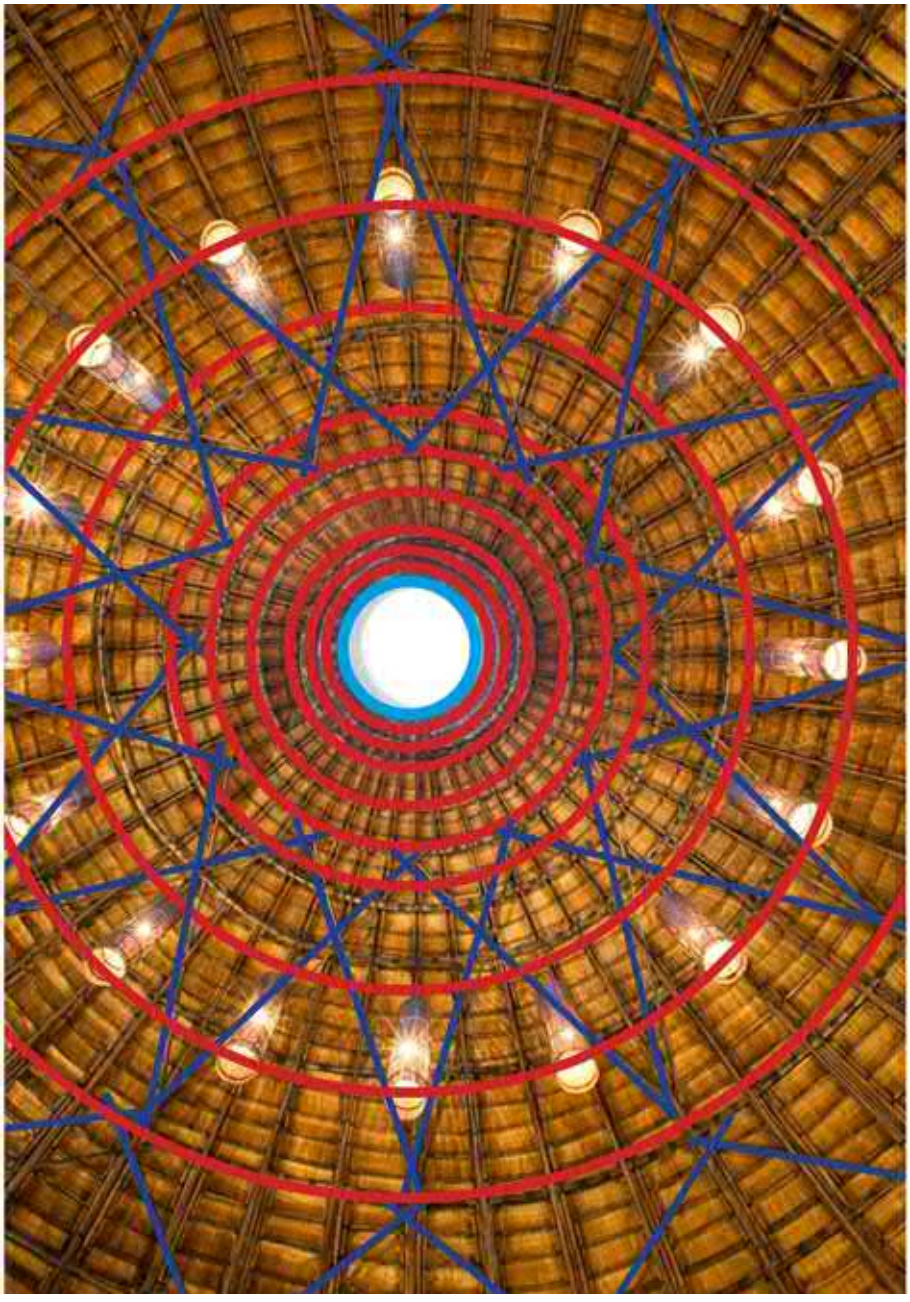


Figure 28. Structural system of wNw Bar.



Figure 29. Interior view of Son La Restaurant.

resist loads efficiently over their thickness. They rely on their curved geometry, orientation and position of supports for their structural performance. The structural elements are woven together as one united surface, forming a unique texture when used with bamboo.

For example, VTN project named Bamboo Stalactite realized in Venice (Figure 40) sees 11 bamboo modular units, each of which is formed by two HP shell structures. (Figure 41, 1.42) These bamboo elements of tam vong are tied firmly with natural fibre strings and ropes. The HP shell structure creates an independent strength, allowing the pavilion only to be anchored. It is appropriate to use the term Stalactite to describe the structure as it

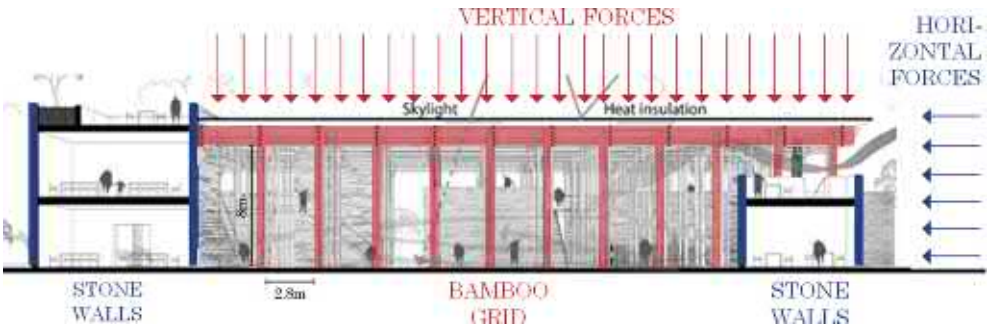


Figure 30. Horizontal loads are resisted by stone walls and bamboo grid resists vertical loads.



Figure 31. Layered beams brace shear loads.



Figure 32. Horizontal loads are resisted by stone walls.

appears to be hanging from the sky and only touches the ground lightly to not to fly away. The structural elements generate a series of organic vaults as roof form for shading and become a functional architectural expression. (Figure 43)

The profit of HP structure is in easy syste matic construction with straight bamboos without bending process by utilizing steel joint even shape looks complicated organic one. As this site location of was outside of Vietnam, VTN needed to select simple and systematic structure to



Figure 33. Exterior of Castaway Island.

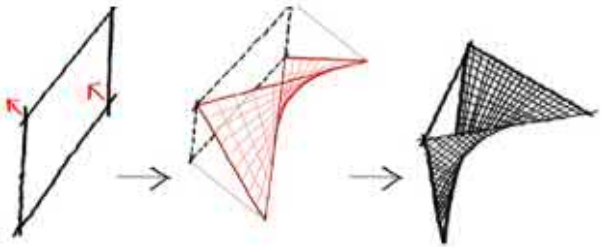


Figure 34. The principle to form an hp shell surface unit from bamboo.

control architectural quality by using small work force and HP structure met these demands. So with the help of architectural professionals and students involved in the project, only eight Vietnamese specialized bamboo workers were needed for the construction. The bamboo beams for the structure were prefabricated in Vietnam. And this bamboo structure is easily taken apart and transported because of simple construction.

2.7. Hybrid Systems:

At *Bossco Cafe* in Gia Lai, VTN uses a hybrid structural system of complex modular frame units that are different in sizes to accompany the HP Shell modules as bracing. (Figure 44)

The modular frame units are not visible to the visitor. Instead, they observe impressive arches created by the united surface of the HP Shell modules. Compared with

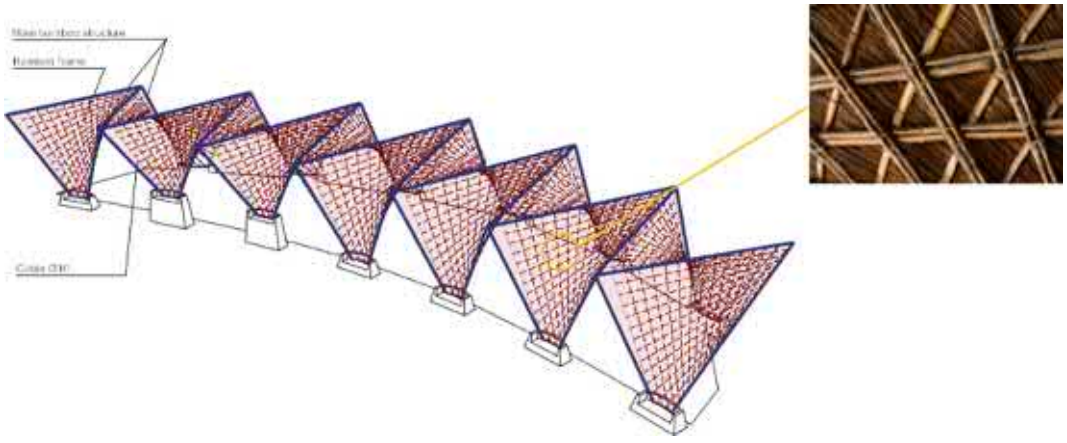


Figure 35. The way to make HP surface, unit and structure.

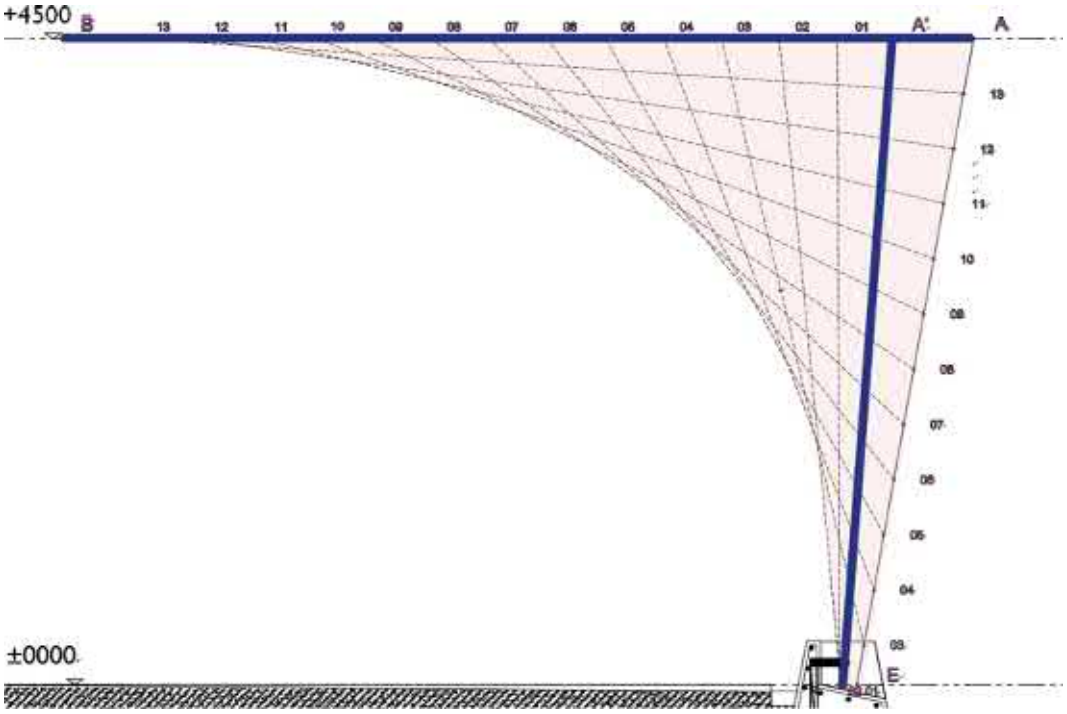


Figure 36. One HP unit of Restaurant in Castaway Island.

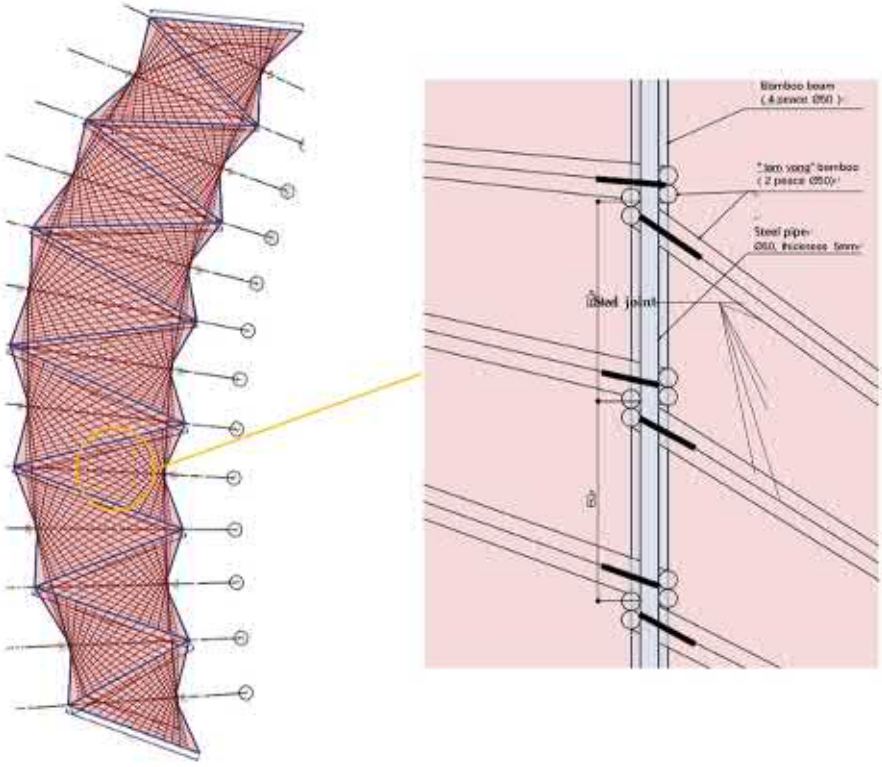


Figure 37. The joint to connect each HP units.

Castaway, as each modular frame size are different in this project, so ceiling height is changing in interior (Figure 45, 46, 47)

Unique HP Surface space as spatial quality are realized in this project. Arch Units resist to vertical load and HP Shell resists to horizontal load. Each structural system support each others to make structure be strenghten. (Figure 47)



Figure 38. A HP Shell surface is made from multiple straight bamboo culms.

Hybrid system as a mixture of systems is used together when VTN Architects needs. For example, a primary structural system (either post-beam, arches, or dome) need cross braces using HP Shell system or other system for its aesthetic quality like the case of Casamia Clubhouse. In another reason, there are pavilions that need multiple systems for aesthetic reasons and structural capacity, like the cases of Bamboo Forest or *Vinpearl Phu Quoc*.

Vinpearl Phu Quoc

Vinpearl Phu Quoc (Figure 50) also sees a complex hybrid of structural forms. The project is a combination of domes, grids, arches, and cross braces. (Figure 49). This is one of our design proposal as it focuses on the solution which combine the joint system, the frame units, the structural systems

First, two enclosed dome structures are erected from multiple bamboo units. Then, arches are put in to create a pathway across space. A system of grids that involves densely crossed horizontal and vertical elements are inserted over. We finally use cross bracing across the parameters to ensure the firmness and the strength of the overall structure. This dense hybrid with layers over layers increases the visual complexity of the structural form.

Composed structure by Arch + Dome + Grid systems reacts to Vertical Forces and cross brace installed in grid structure reacts to Horizontal Forces. (Figure 51) Each structure are adjusted carefully in one design to make different type of space and aesthetic in bamboo architecture. (Figure 52)

Casamia

VTN combine arch modules with other structural ideas to create a hybrid structure. For example, Casamia Clubhouse sees a combination of arch units and brace system.(Figure 55) Complex load-bearing column and beam system in each unit is hidden inside the bracing (Figure 57). However, VTN uses exposed arches to tie the shell surface together and to create vaults inside the space.

This hybrid system allows for rhythmic organic texture in the roof-scape of the clubhouse. It also ensures the firmness of the whole structure to resist vertical and horizontal loads efficiently (Figure 56).

Dong Na Clubhouse

In Dong Na Clubhouse, arch modular units and smooth decorative surface are combined to make Hybrid structure. (Figure 58, 59) Arch modular units are connected with different angle at one joint. In this project, even one column, it consists of several units to make some direction for surface.

Between units, sevedral number of steel guides are put to suport smooth bamboo surface. This steel guide is adjusted as smooth curved line to form smooth bamboo surface by following it. And steel guide is hidden inside of surface by putting bamboo densely. (Figure 62) As a result, many kind of curved surface was combined to

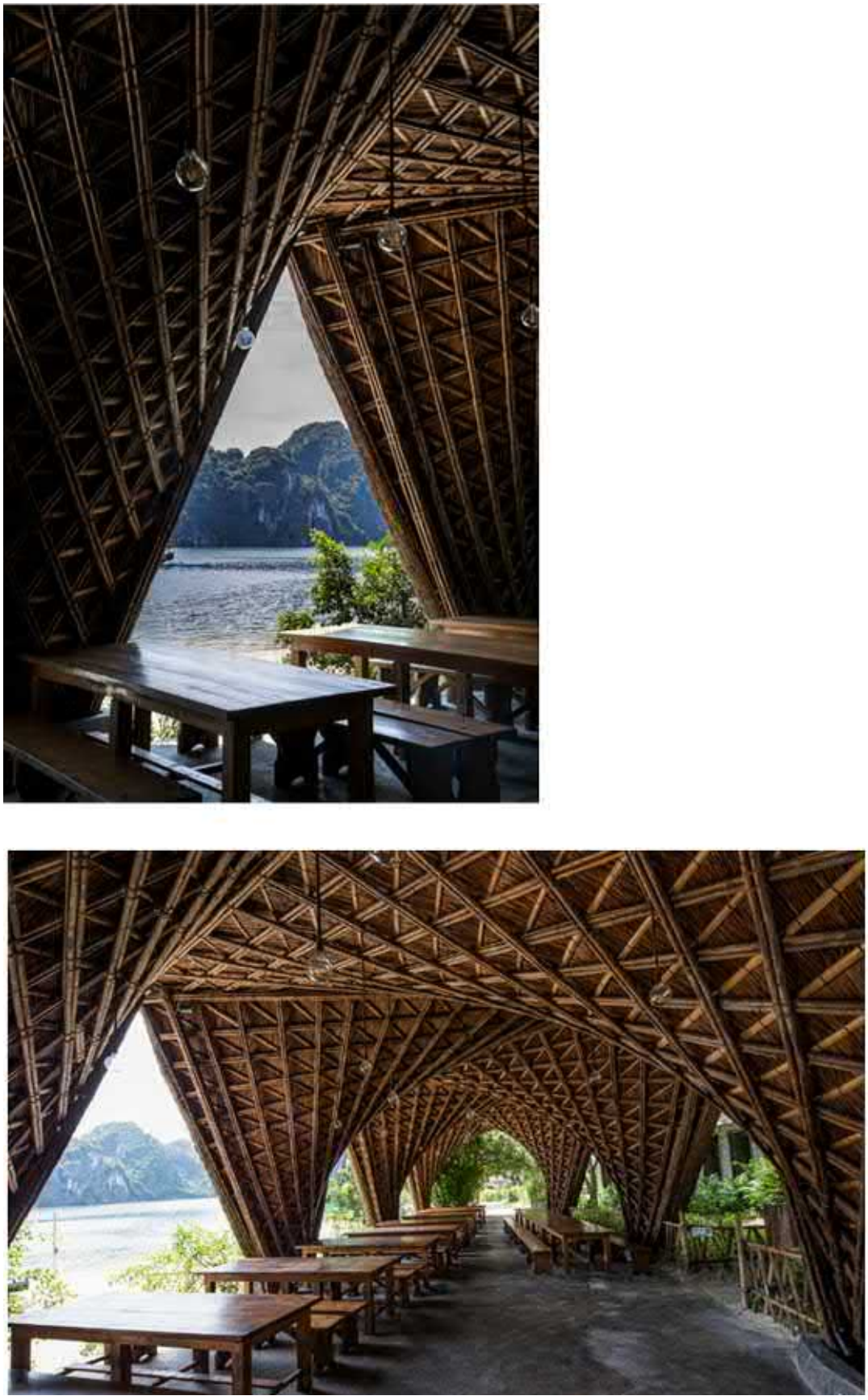


Figure 39. Interior view of Restaurant in Castaway Island Resort.



Figure 40. Exterior view of Bamboo Stalactite.

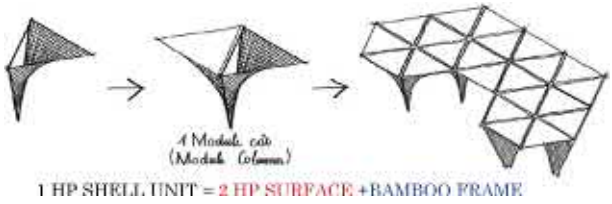


Figure 41. The way to make HP unit and structure.

make unique interior space. Surface is expanded from column to the whole ceiling and covers whole interior. It can realize variety of surfaces by utilizing simple modular structure and steel joint.

Service Center in Fujian

At Service Center in Fujian, China, we use a hybrid system of bamboo units that form a dome structure and



Figure 42. Detail of HP Unit.



Figure 43. An Open free space for community under the HP structure.



Figure 44. Exterior view of Cafe Bossco.



Figure 45. Interior view of Cafe Bossco.

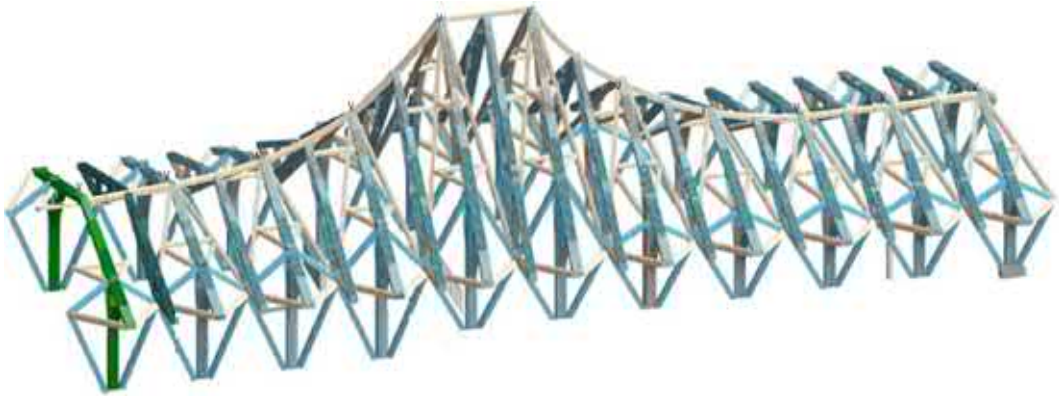


Figure 46. Different unit-frames sizes to create an interesting roof.

HP shell modules as bracing elements. (Figure 63)

The HP shell modules are woven from dense criss-cross layers of tam vong. They act as structural bracing. They also cover the load-bearing column and arch units to create a decorative surface/ a unique texture for the Center. (Figure 64)

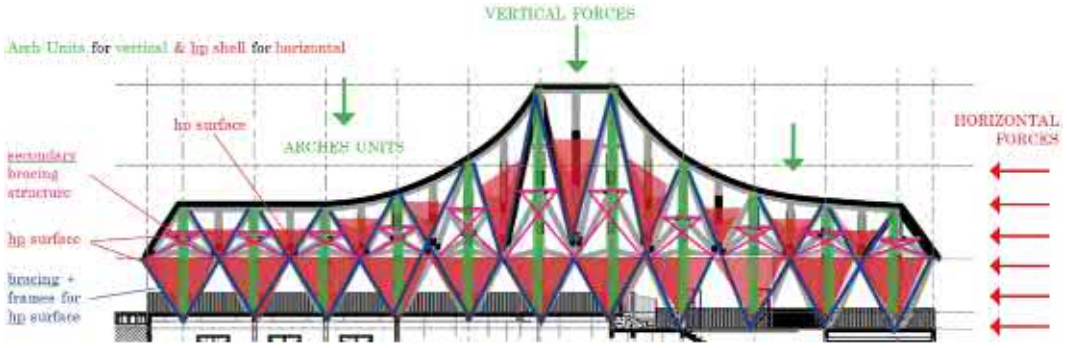


Figure 47. Arch Units for vertical load and HP Shell for horizontal load.



Figure 48. Interior view of Cafe Bossco.

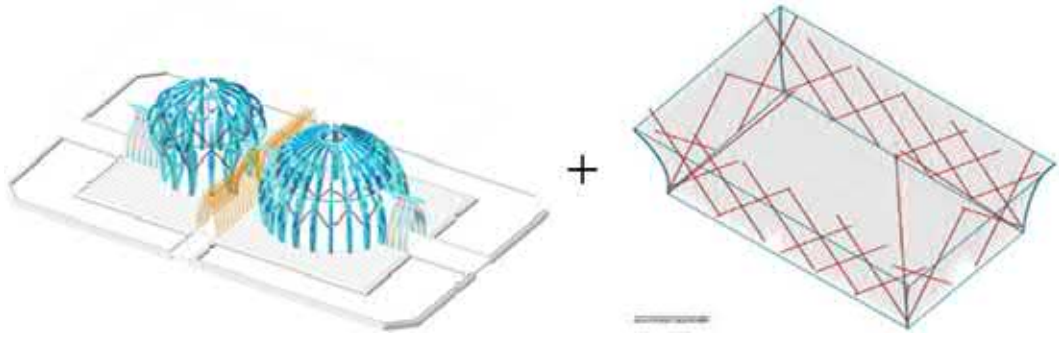


Figure 49. Several structure system has combined in one project.

Bamboo Forest

VTN can hybridise the previous structural forms to create a complex system of grids, arches, and boxes. For example, Bamboo Forest at TOTO Gallery, MA uses 3 systems. The first one is Grid: an intersection of posts and beams to create a series of volumes. The second one is Arch: 11 arch units were inserted into the grids to form a vault over an open space. The third one is Box: 31 boxes were installed to solidify the whole structure. No metal joints were used in the construction.



Figure 50. Exterior view of Vinpearl Phu Quoc.

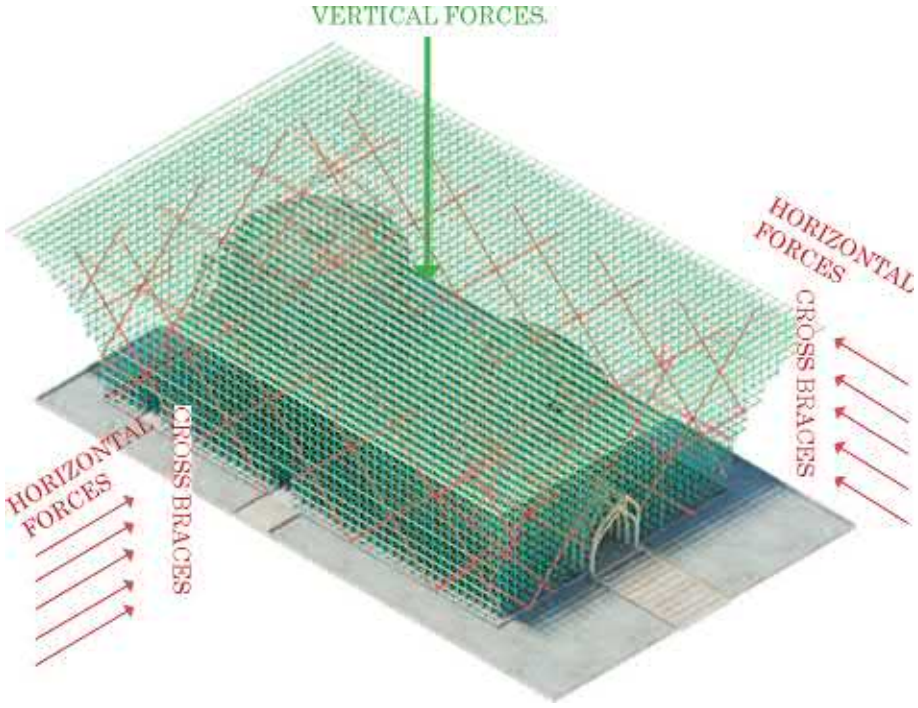


Figure 51. Hybrid structure to react to horizontal force and vertical force.

2.8. Inverse Cones:

The inverse conical structure at Kontum Indochine Cafe has an inspiration from Vietnamese traditional basket for fishing. (Figure 69) It's created from 15 bamboo units (bamboo columns, cross braces and steel rings) fully covered and strengthened by exposed bamboo arches to support a light roof of thatch and polycarbonate.(Figure 68)

The steel rings inside each cone balance and ties the arches to the column and brace units to keep the arches in places, to prevent buckling and to help adsorb horizontal



Figure 52. Grid and Brace structure from exterior view.



Figure 53. Exterior view of Casamia.



Figure 54. Interior view of Casamia.

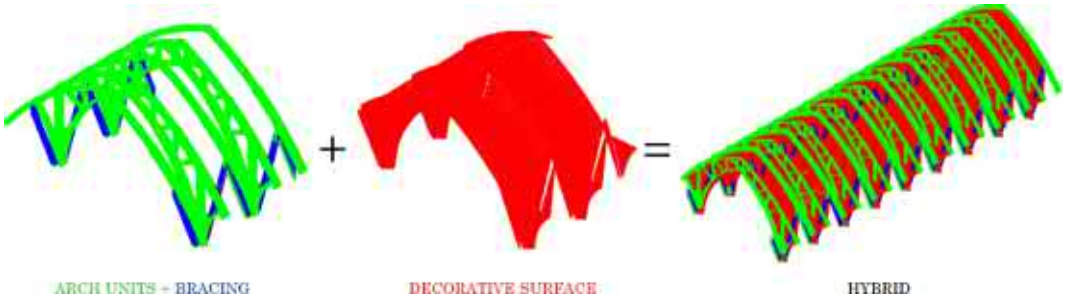


Figure 55. Hybrid structure made by Arch modular unit and Bracing.

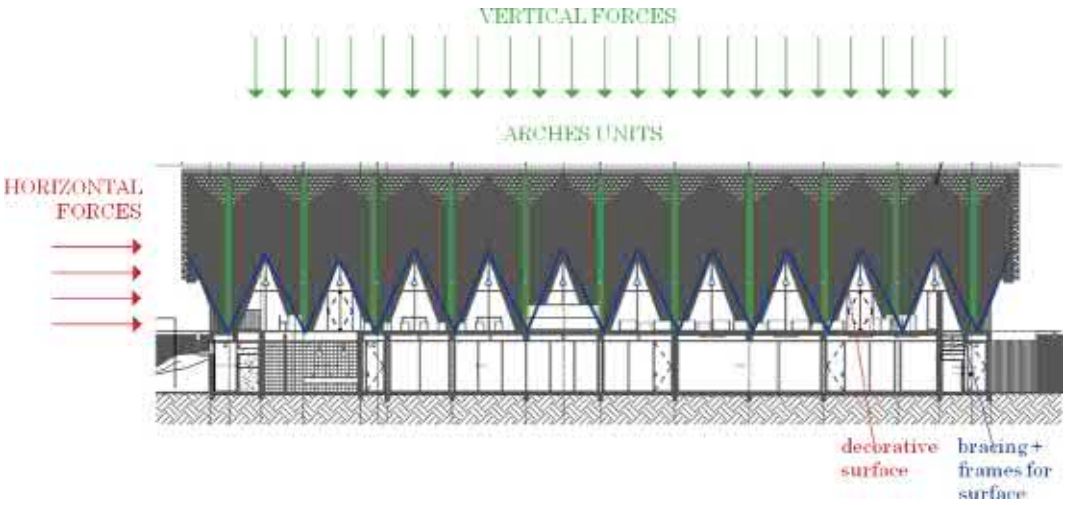


Figure 56. Hybrid structure to react to horizontal force and vertical force.



Figure 57. Massive & formal open space with surface.

loads. The arches are simply fixed by ropes and bamboo nails. They are narrow at the base and open widely towards the roof to form the strong visual of inverse cones. The curves and the density of the outer layer create



Figure 58. Exterior view of Dong Na Clubhous.



Figure 59. Interior view of Dong Na Clubhouse.

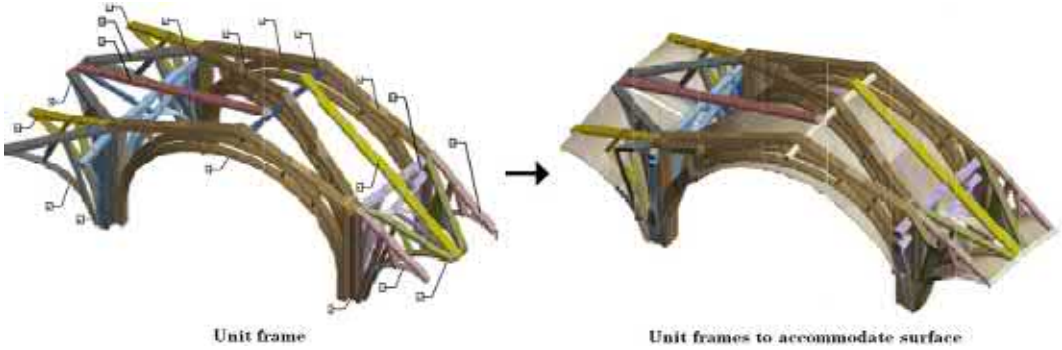


Figure 60. Unit frame and decorative smooth surface.

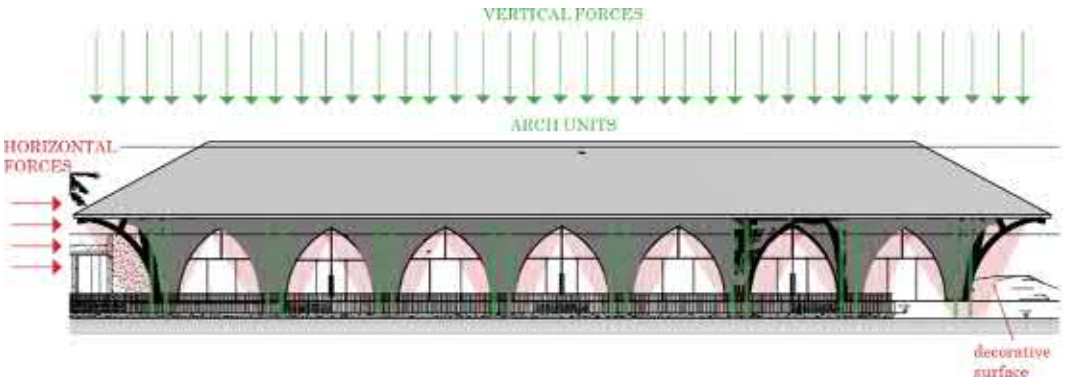


Figure 61. Hybrid structure to react to horizontal force and vertical force.



Figure 62. Interior view of Dong Na Clubhous.

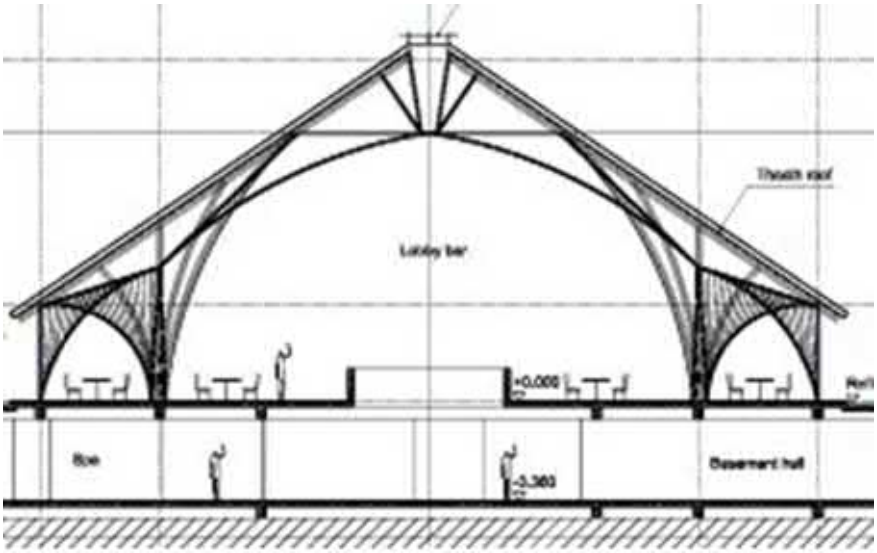


Figure 63. Section showing the hidden structural units and the hp shell bracing.



Figure 64. Dome structure with hp shell bracing.



Figure 65. Exterior view of Bamboo Forest.

an interesting screen surface that plays with light, shadows and air. The project proves the capacity of bamboo structures to be transformed into a pleasing and beautiful architectural.

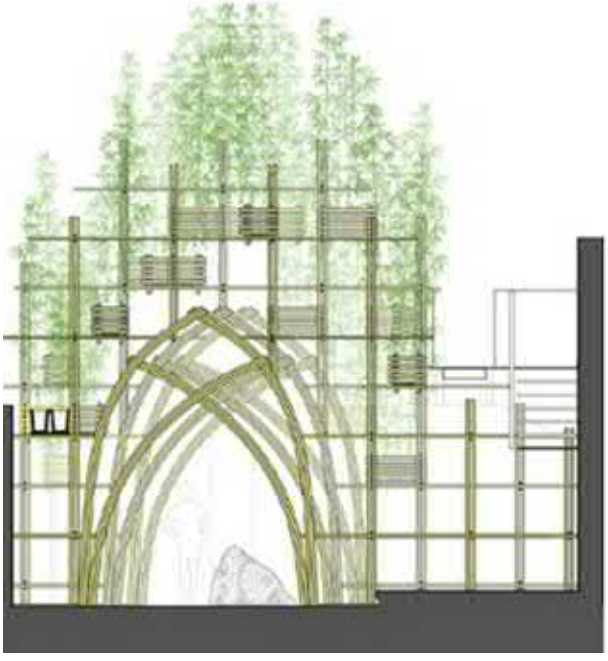


Figure 66. Section of Bamboo Forest.

Hayhay Restaurant & Bar

A same structure is used at Hayhay restaurant & Bar, which transforms the cones from performing purely structural functions into beautiful forms and texture for the columns. (Figure 70) Impressive space is realized by layouting inverse cones bamboo columns.

Due to the simplicity (yet actually being very complex) of the structural form, this brings a sculptural quality to



Figure 67. Inside Bamboo Forest.

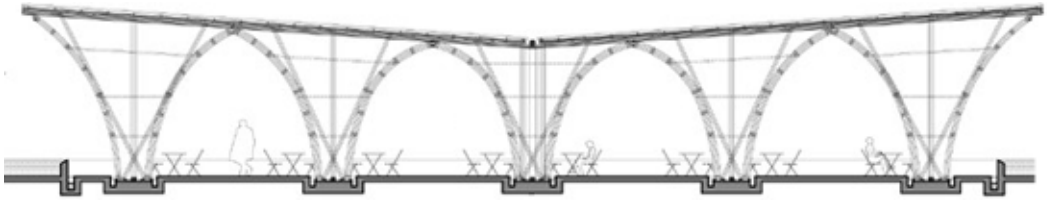


Figure 68. Section of Kontum Indochine Cafe, showing the inner and the outer layers of each bamboo unit.



Figure 69. Bamboo units at Kontum Indochine Cafe.



Figure 70. Inverse conical columns at Hayhay Restaurant & Bar.

the spaces. Also, due to the inverse conical form, it opens the space upwards, making it seems more vast and impressive. This structural form has been used a cafe and a restaurant. This focus on aesthetic makes the form suitable for hospitality spaces, where sculptural quality and first impression is needed for attracting customers.

In the end, this is a good form to create impressive small spaces and not overarching massive spaces that need large spans of structural elements. Fundamentally, this form is still a series of columns within an interval space.

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Figure 71. The restaurant at night.

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