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Designing & engineering pre-fabricated connectors for bamboo structures in Thailand

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Abstract

Bamboo architecture has become the trend to answer to the sustainability, due to its renewability and low carbon footprint offering. The creation of Bamboo architecture has the most challenge corresponding to the available technology of local people. It is about how to connect structural bamboo members together. Bamboo connections are also the process that takes the most time during construction. These are real studies on the experiment of how steel connections are introduced to the pre-fabrication process of the bamboo construction. The innovative connections are designed to put bamboo culms together and faster. Yet the strength of connections are viable and substantial, by applying the uses in real construction. The experimenting study is designed into two parts. Firstly, the connection prototypes for bamboo culms and bamboo splits are designed. They are made into the receivers and the nozzles. Receivers can be noticeable as the female connector, acted as a receptor at footing or foundation when transferring loads to the ground. The nozzles are called as the male part that looks like an extruder attached to the end of culm or splits to connect to the receivers. Nozzles are designed to be two kinds, for a single culm and for a bamboo split bundle. The experiment also designed the straps for bamboo split, to wrap the split together into one bundle. All the connectors are made of stainless steel as a material to gain great strength, and potential for mass production. These prototypes are also applied to various actual constructions in real bamboo architectural projects to verify the validity on how they are performed. Secondly, steel connectors are designed and engineered for triangular truss framing. This offers flexibility in bamboo truss design. Besides creating nozzles for culm members, the star plates are designed to receive nozzles from many different members, according structural truss frame design. Star plates can receive 3, 4, and 6 nozzles in this experiment. They are put into triangular truss frames. The findings show that bamboo connectors create great performance and able to minimize time of construction. They can also perform greatly in strength and make attractive look. The studies also explore further to many applications in real construction projects. These findings can surely assist and motivate architects and builders to explore possibility to bamboo architecture in pre-fabrication process, to make bamboo construction more effectively.

Keywords Pre-fabricated bamboo; Bamboo connectors; Bamboo joints; Bamboo connectivity.

1. Introduction

Bamboo architecture has become the new trend to contribute to the SDG goals No.11, Sustainable cities and community. Bamboo is a fast-growing plant and abundant, especially in Tropical area, so it is considered the renewable material. Working with Bamboo then turns to gain more interest because of its sustainable aspects. Promoting more uses of this material will share contribution to a sustainable environment and low carbon production to every scale society. Interestingly when looking into the creation of Bamboo architecture, it has been corresponding to the local culture and available technology. Different parts of the world have their own language of bamboo architecture. This may be because there are some influences involves of each culture, such as local wit, belief, technology, available tools and skills, etc. Designing bamboo architecture seems to be expressive with local culture. Mostly they are done by local handy men in the community. With that notion, the design and technology may not be too complex, and utilize all possible material properties. Some bamboo buildings are good design, while some buildings still need more understanding on how to work with this material. The consequence is that the architecture cannot last for a long period of time. The structure is falling apart, due to the capacity of connections. They can also deteriorate through time via many factors. Local people do not mind because there are available materials to build new ones and inexpensive. However, that is not the sustainable way to utilize the material. So, the design of bamboo architecture should be aiming into a direction that can create the life-long sustainable buildings. The study then looks into ways of creating connections that can last long, and fit with a more advanced industrial production to answer modern day architecture, yet remains its sustainability aspect.

2. Working with Bamboo Geometry

3. Bamboo is a versatile material, due to its long cylinder form that offer lines of transferring forces or load. However, there are also ways to make the most use of cylinder geometry, by breaking them into different geometry. In practice, there are three types of bamboo most people is working with; whole bamboo culm, bamboo halves, and bamboo splits. This does not include manufactured bamboo, like bamboo laminates. When designing bamboo structure, architectural forms are shown to be curved, bended, weaved, and bundled, and so on. It is indeed that bamboo culms can offer strong member, but when it comes to making tight curves, bamboo splits may be better to use. Bamboo splits are made of series of smaller pieces that are easy to bend together, and also provide solid mass. Bamboo halves



are offering one flat surface to work with, when there is a flat area for installation.

Bamboo culm

Bamboo Halves

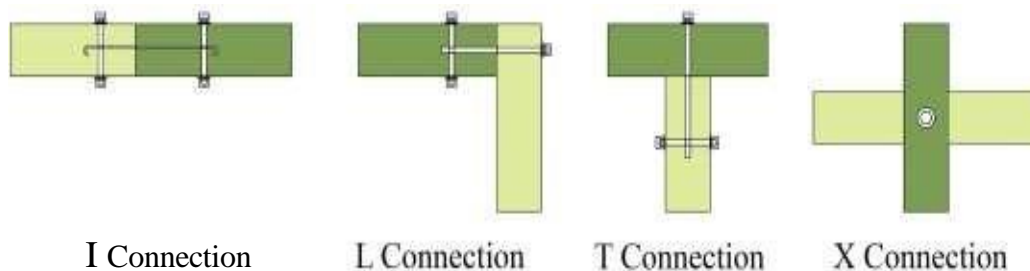
Bamboo Splits

Fig. 1. Three common types of bamboo used in construction

In bamboo construction, designers have to work together with different types of bamboo, so it will lead to many ways to connect them together. The study then decided to do the experiment to use innovative bamboo connections. They will work with new ways of putting bamboo culms together. Before designing connections, it is important to understand what have been done in practice.

4. Connecting bamboo, the basic

Bamboo geometry is like a form of sticks. Constructing stick forms together may be simple. However, in real practice, putting bamboo together has become the most challenging process. Bamboo has nodes, irregular dimensions, hollow, and easy to split, so that they add extra understanding to connect them. In designing connections, it is to understand how bamboo culms are configured together. We can simply call this “bamboo joint”. This relates to how the structure is designed and put into geometry, so we know how the structure member are connected. The joints are formed together into the simple geometry. The basic geometry is shown in following.



I Connection

L Connection

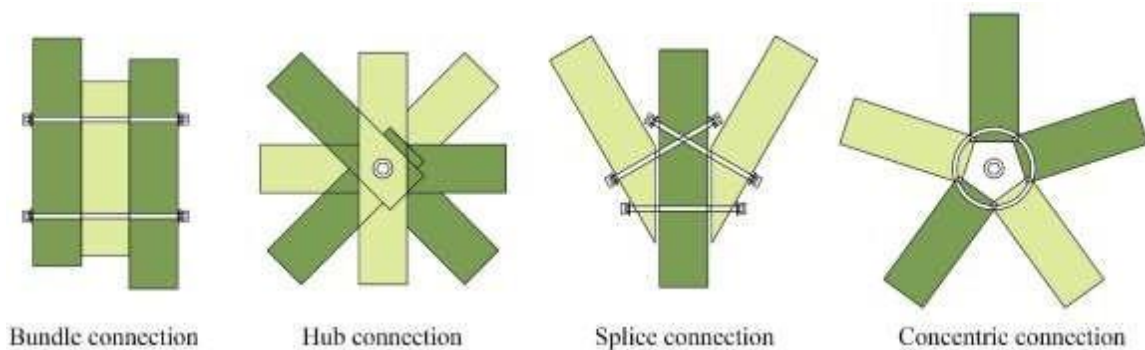
T Connection

X Connection

Fig. 2. Examples of Bamboo connections in basic geometrical forms of Joints.

Figure 2 shows basic joints that most bamboo structure should use in their applications. I connection is needed when bamboo culms need to connect in extended longitudinal direction. L,

T, and X or cross connections are typical ways to align bamboo culms in those letter shapes. However, there are more chances that the design of structure can get complex when more materials are used and the scale of structure gets extended, so connections are also designed to accommodate the complexity, see Figure 3. Bundle connections is to put many bamboo culms together to gain more strength than just few members. Cross bolt-thru or dowels are used to insert inside culms to make all culms working together in one system. Hub connection is happening when all bamboo members are summed up into one point. It can be at top of roof or any main nodes in structure. Splice connection is occurring when adding supporting members in one load-transferring direction. Mostly splice geometry will be triangular formation. Lastly, concentric connection is quite similar to hub connection, but only receiving compression. These are common examples. There are many more complicated connections seen in real construction



projects. The study decides to introduce new way to put different bamboo types and different joints together by designing the innovative connections.

Fig. 3. Bamboo connections are getting complicated when designed structure is complex. These samples show variations of more complex joints.

5. Connector Prototypes for Basic framing

One important concept about construction bamboo architecture is that the project will use local bamboo. This is to minimize the transportation service that leads to minimize the carbon production of material logistics. Using local bamboo can be advantageous, so bamboo can be immune to local threats, such as insects or climates. Condition in some project site might not be the most offering place for construction. The Pre-fabrication process then comes to consideration. When preparing materials in other place and assembling on site may offer the convenient process. The design experiment then starts with how to connect bamboo together off-site area. The study then designed three innovative connectors.



Fig. 4. (Left) The model of prototype design was created to study the potential way to design connectors. (Right) Model helps the understanding of the connector at the hub.

The study started the experimentation at the project in Nansha Bird Park in Guangzhou. This is the design & construction competition. Time offers to build this structure in only for ten days. The study then starts to focus on how the structure can be installed faster. That is why pre-fabricated connectors are invented and used at this structure project. The structure is designed to look a flying bird as a small pavilion. At main structure, it is designed to have vault made of two intersecting arches. Since the pavilion has tight-radius dimension, arches are made of split bamboo. The roof will be used bamboo culms connecting each other in multiple directions. So, there will be two bamboo types at base, culms and splits. The connectors then are designed to have two connecting nozzles; one for culms and one for splits. The nozzles then will be inserted into the receivers at foundation. The bases should be able to receive both type of nozzles.



Fig. 5. Images show different designs of nozzles and receiver for bamboo structural joints



Fig. 6. Nozzles for bamboo splits and culms after being installed, and ready to be fabricated. There are also the design of straps for bamboo split bundles, similar to nozzle for splits.



Fig. 7. Actual construction experiment where the pre-fabricated connectors are installed in the locations as they are designed.

The project site was offered to the specific location, on the pedestrian bridge in the bird park. The structure of pavilion is designed to build in 3 identical modules right next to each other, while each module is about 2x2 square meter. Total square area is about 12 square meters. The receiving plate is welded to the foundation piers, and the structural members are assembled in nearby location. The installation of pre-fabrication frame then started after every structural members were prepared. It is a result that preparation of materials took 5 days and another 5 days to put them together. The construction was quite effective. For a similar construction project, it can take up to 1-2 times longer. The introduction of pre-fabrication strongly became an efficient way.



Fig. 8. The complete pre-fabrication construction

6. Connector Prototypes for Truss framing

In different approach, when the bamboo architecture design process has finished, the construction traditionally will be planned to build according to the design has been made. The pre-fabrication process can be introduced to fit the design. However, to make bamboo structure more flexible in terms of structural design, if the connectors are pre-determined, structure can offer freedom to be put together in any forms. It is similar in creating truss frames by connecting steel joints together, and bamboo are members to transfer loads. This is the project by Muanjai Park Chiangmai, Thailand. The structure is designed to be an open pavilion for a recreation park. The study of bamboo connector is then looking into the process to make bamboo triangular trusses, and possible to do geodesic truss frames.

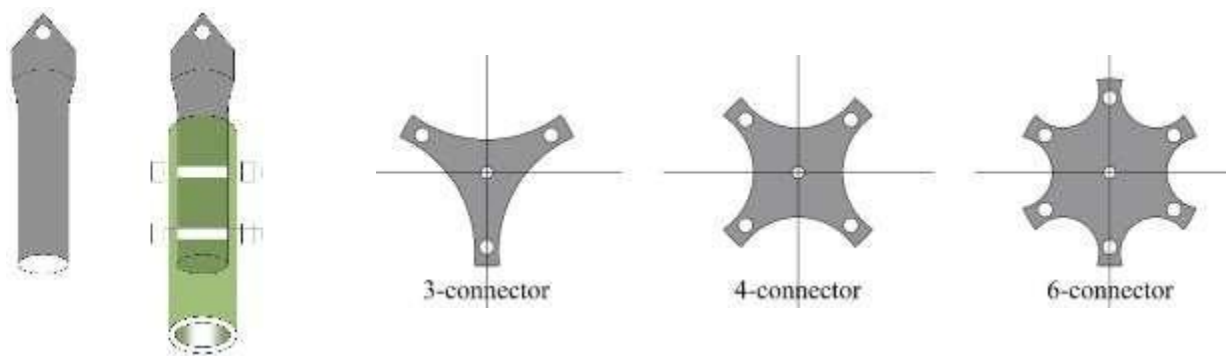


Fig. 9. (Left) Head nozzles showing how it is inserted into bamboo culms, (Right) Plan view of star plate, showing different configuration of nodes.

Truss frames are made of small structural members are put together. It is to design the head nozzles to connect to bamboo culm on either end. Bamboo culms are inserted to head nozzles, then secured with cross bolts through. The head nozzles will then will connect with star plates to

form the structural connection geometry.

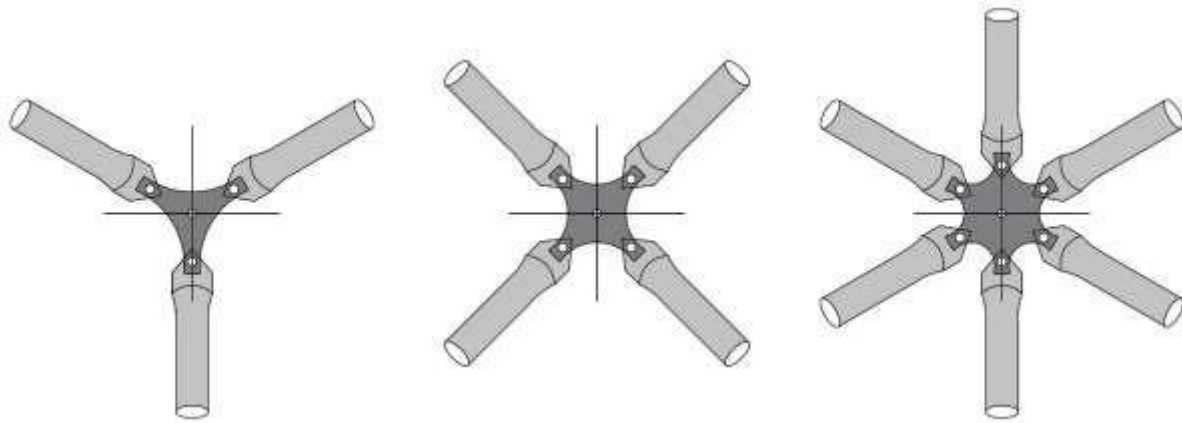


Fig. 10. The star plate different configuration at the nodes of 3, 4, and 6 bamboo culms

The star plates are designed to be nodes for connecting bamboo structural frame members together. This designed geometry is reminding the shape of Shuriken, a small metal weapon of Japanese Ninja, which the form is inspired by. The star plate is made of thin piece of steel, and cut into shapes desire for the formation. The star plate is design to offer many configurations depending on numbers of structural members at a node. The experiment is design to host 3-, 4-, and 6-member configuration, see figure 10. Another one is designed to receive at the ground connection as the foundation anchor, see figure 11. However, the design is not limited to these configurations, they can be designed to according the truss framing is arranged. This way, the innovative pre-fabricated connectors can offer so much flexibility.



Fig. 11. The star plate at node connecting to the ground or foundation.



Fig. 12. Head nozzles are produced mass production, since the truss frame will be made of

many structural members.

The head nozzles are simply made of steel pipes in multiple lengths, according to the needs. In this case, two lengths are made at 30 and 50 centimeters. The pipe is pinched at one end to make a flat plate and drill a hole for bolt-thru joint. Another end is cross-drilled through for the bamboo culm to be inserted. This will create the bamboo tip of each structural members to



connect with the star plate, in order to form the truss frame structure.



Fig. 13. Images show the real application when bamboo culms are installed with head nozzles, and formed with star plate to make truss frame structure.



Fig. 14. Star plates that are designed to connect super structure to the ground.



Fig. 15. With flexibility of connecting elements, the designed truss frame can offer variety of design. Creating gateway truss (Left) or Geodesic dome (right) are also possible, by simply putting together with simple tools.

7. Results and Discussion

The experiment result is found that after the fabrication process has been introduced, it can minimize by half of the construction time. For the first experiment, it took 10 days for material preparation and installation together, while conventional construction should take twice longer. For the second project, it is more interesting that the preparation of the material take longer than the process of putting structure together. However, the construction of putting all bamboo pieces together was really fast, depending on sizes of project. The systematic process of assembling the structures really helps expediting the construction time. These two experiments can be considered the success. However, the connectors still need to develop further in many aspects, such as, to receive more loads, to make an easy installation, to be more interesting with different

bamboo configurations, and lastly to look attractive.

8. More Pre-fabricated connectors in experimental projects

After the initial finding, it was found that was the only way to do the bamboo connection, while bamboo structure show craftsmanship and various configurations of possible geometry. Therefore, more experimental projects continue seek more potentials to utilize steel connectors in different other ways. The experiments are done via Bamboo studio, the researching and learning collaboration among architectural students at Thammasat University, Thailand. They are design-built experiments that put real construction together, yet the outcome from one to another stimulates to explore further in the future. Here are some projects by Thammasat Bamboo studio.



Fig. 16. Carrying on Experiment to re-design nozzles and star plates and build a simple structure by Thammasat Bamboo studio.



Fig.17. Experiment of Bamboo pavilion using connectors to put together bamboo splits, bundles, splices and at base by Thammasat Bamboo studio.



Fig. 18. Experiment of Bamboo pavilion using multiple connectors in one node at bases by Thammasat Bamboo studio.

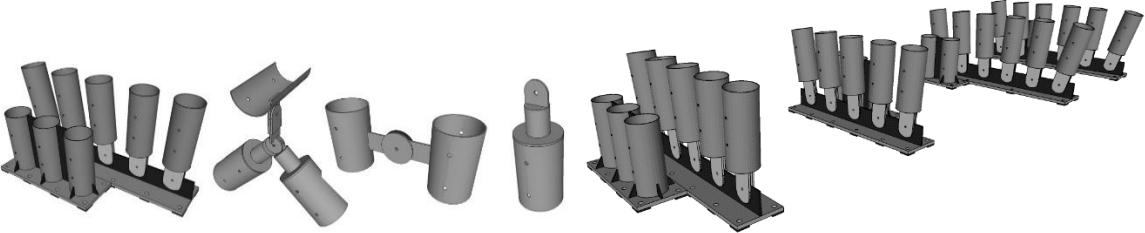


Figure 19. Design of bamboo connectors at base with multiple members and at roof ridges.



Figure 20. Installation of multiple-members connectors at base foundation



Figure 21. Experiment of pre-fabricated connectors at roof ridges for fast installation.



Figure 22. Experiment of using commercial connectors in industry by applying the use with bamboo to construct the prototype shelter.

Conclusion

These experiments are yet the pilot study and investigation. Though there have been many bamboo projects from around the world working on these similar methods. However, as previously mentioned, each culture offers their own bamboo architecture language, due to different local technology and perception of material. Bamboo architecture in Thailand have been gaining more popularity because people are interested in sustainable material and attracted to how the vernacular architecture looks. Therefore, the research and development are still on process to keep making a better design and construction. This study then has become the effort to share with the rest, especially to inspire and to promote the innovation and possibility. It can be said that the pre-fabrication connectors in this study provide effectiveness in terms of construction time, durability because of the material, and lastly the attractiveness. It is hoped that these experiments of this connectivity methods can inspire and promote local people, designers, or architects to gain more interest of making more interesting bamboo architecture in the future. Lastly, the benefit will gain in contribution to our world's sustainability.

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Conflict of Interest

The authors declare there is no conflict of interest.

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