Theme: 3. Economy; 3.5 Architecture, Engineering and Construction (Construction System and Methods)

Design, Development and Preliminary Evaluation of Bamboo Connectors

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Abstract

Bamboo connectors were designed, fabricated, and tested. Development objectives were for standardization of connectors for built-up pentagon structures and for ease in bamboo construction. Designed and developed were the starfish, top chord-purlin, post-top chord-beam, top chord-strut, top chord-rafter, and the rafter-beam connectors. These were fabricated locally from GI pipes using available metalworking skillsets and tools. Three houses were constructed for preliminary evaluation in a span of four years. The first utilized traditional joinery plus the starfish connector and took 10 days for 3 carpenters to finish the skeletal structure. The second one utilized all the developed connectors and was constructed in 2 days employing unskilled student labor. The third skeletal structure was constructed by the author and a helper in three days. Weathering tests showed climate resiliency for all structures. Versatility of the connectors was proven with the design and construction of single as well as double-storied structures. Preliminary cost evaluation proved that investment in the connectors may be offset by savings in labor, ease and timeliness in construction and resiliency of structure amidst natural disasters.

Introduction

Bamboo connectors that could be fabricated using locally available materials and skillsets have implications on the widespread use of bamboo as an engineering material. The non-uniform physical characteristics of bamboo pose difficulties in using available fasteners (Soriano 2000). Traditional connections are cumbersome to make owing to the cylindrical shape and dimensional variability of bamboo as a material. Nails, lashings, holes and dowels are the traditional practical joinery techniques used by local carpenters and craftsmen. In furniture production, bamboo connections are commonly used where small diameter culms are inserted into large ones and the connection secured by glue, dowel or both. In house construction, dowels are commonly used when two culms cross each other. At times, a notch is made in one culm to accommodate the other and the connection is then fastened by nails, dowels, ropes, tying wire, or a combination of these methods. These techniques are suitable but are cumbersome. The strength characteristics of the joints are also doubtful as the notching and doweling or nailing reduces the strength of the individual culms (Arce 1991). Schroder (2009) stressed the importance of the presence of node in the connection to provide strength and to prevent crushing where the load bears on the open culm.

Recent developments in bamboo connectors are being made and people keep finding ways to improve them. There are metal connectors fitted into the culm and their ends joined by welding or by bolts and nuts connections. Other materials used are wood and plastics. There are myriad different connectors developed but none is available in the Philippine market. The development of connectors that are adapted to bamboo poles of local species that vary in diameter, culm thickness and tapering, built for standard house shapes, and with a high potential for commercialization was the prime consideration for this research.

Rationale

Bamboo is a natural resource that has a short rotation cycle. Poles can be harvested from a three-year old clump, and then one can collect from the same clump every year thereafter. With proper cultural management of plantations, bamboo can provide materials for housing, furniture, paper production, agriculture and fishery production, and for industrial uses. Engineered-bamboo is finding commercial use nowadays as many tries to standardize the material into sizes like lumber. Thus, processes such as thickness standardization of strips and gluing them up to form boards, planks or dimension lumber have found their way in manufacturing this material. Veneering of bamboo and converting the veneers into ply materials are also being done. These processes entail a lot of capital to put up the machinery needed for production.

Bamboo in its natural state is widely used in the countryside especially for house construction as the material is strong and provides aesthetics in design. Beach resorts, bridges, convention centers, even transport terminals have recently found good use for this material in the local and international settings. A renowned Filipino architect, Mañosa, builds on bamboo and published a book devoted to designs of houses using this material. The structures designed and built from bamboo used traditional joinery techniques and some used bamboo connectors. Still, these designs are one of a kind as the connectors are fitted to the specific designs and are not standardized. Standard connectors could bode well for the construction industry and will make construction easy using bamboo poles as major structural material.

Significance of the Study

The development of bamboo connectors will provide the construction industry with a readily available material that could be easily utilized in construction. The connectors will provide a cut-and-paste-like construction process for bamboo structures with the connectors serving as the "paste." All the workers would have to do is to cut the culms into sizes and assemble the structure in a very short time with the use of the connectors. Instead of standardizing bamboo sizes through the engineered bamboo, the connectors will enable prompt use of the material without entailing additional processing costs. Thus, the connectors could find valuable applications in emergency response where rapid shelter construction is imperative such as in calamities like typhoons, earthquakes and conflagrations where houses are destroyed, and immediate replacements are necessary.

The Research Problem

This is a developmental research designed to develop standard connectors for bamboo for practical use in house construction utilizing culms of different diameter, thickness and taper. The connectors should enable "cut-and-paste" construction with the connectors serving as the paste. Moreover, the connectors should meet the requirements of ease in construction, durability and affordability.

Objectives of the Study

The main objective of the research is the design and development of standard bamboo connectors with practical applications in house construction. Specifically, the research seeks to:

1. design standard bamboo connectors for pentagon house structures;
2. fabricate the bamboo connectors as per specifications in the design;
3. test the connectors in actual house construction to determine ease of construction and costs;
4. test the constructed house in actual weather conditions in the locality;
5. propose modifications, if any, in the design based on actual construction experience and performance to weathering tests.

Scope and Limitations of the Study

The objectives earlier presented define the scope and limitations of the study. The study was limited to the design, development and actual utilization of bamboo connectors for house construction. The design and development were undertaken at the Romblon State University and in a local metalworking shop, respectively. Actual utilization of the bamboo connectors was conducted in Anahao, Odiongan, Romblon. Tests conducted were on the ease of construction and on the capability of the overall structure to weather storms and the elements. Preliminary cost comparison was made between traditional joinery construction and construction using the connectors.

Review of Related Literature

Much had been researched about bamboo connectors by foreign as well as local researchers. A local one conducted by the Forest Products Research and Development Institute (FPRDI) of the Department of Science and Technology (DOST) enabled construction of a space frame with triangular elements (Araral 2015). The connectors were made of metal inserted in the bamboo culm, secured with a dowel and concrete; their ends bolted together to form the connection. The jointing system can easily hold up to 1000 kilos. It is similar to existing connectors developed by other authors. No commercialization effort was made on the connector though.

Janssen (2000) classified bamboo joinery into groups: Group 1 – full cross section that utilizes lashings to keep the bamboos in position; Group 2 – joints from inside to an element parallel utilizes mortar and putting a steel bar in it, also wood fitting is used; Group 4 – joints from cross section to element perpendicular uses elements of steel or wood held in place with pins; Group 5 – joints from cross section to elements perpendicular uses pins, bolts and others; Group 6 – joints from outside to element parallel deviates from traditional lashings and uses steel wire around bamboo with the "Delft wire lacing tool;" and Group 8 – joints for split bamboo uses thin galvanized steel fastened with nails in prefabricated housing. Group 3 – from inside to an element perpendicular and Group 7 – from outside to element perpendicular hardly have any practical application.

Gernot Minke (2016) discussed different joints and connectors in his book - Designing with Bamboo. He stressed the most important aspect of bamboo construction which is the formation of joints that transfer forces from one element to another. He pointed out that transfer of forces is better made with the fishmouth in perpendicular connections. Further he discussed different joints and connectors for bamboo. One particular joint discussed was the Bambootix system by Waldemar Rothe. The system uses flat metal sheet that is cut according to the connection made (perpendicular, as pictured). The cut metal has wings that may be folded to accommodate different bamboo sizes. The connector is fastened to the bamboo with lashings. As discussed and pictured in the book, the connector is capable of connecting crossed members angled at 90 degrees.

Phanratanamala (2015) studied bamboo bolted systems with and without concrete infills. Bamboo bolted joints in parallel direction showed capacities of 1.66kN and 3.7kN for joints without concrete (NFB) and with concrete infills (CFB), respectively. For bamboo bolted joints in perpendicular directions the average tolerance stress levels were 0.715kN for NFB and 2.42kN for CFB. The author recommends bamboo bolted joints for frame truss systems to provide rigidity and to prevent bending and buckling in the middle of the culm.

Schroder (2009) discussed traditional joinery techniques that utilized nails, lashings, dowels, and bamboo-on-bamboo for connections. The traditional techniques developed through years of actual working on the material persisted for want of alternative connectors developed in the bamboo construction industry.

Recent trends in bamboo connectors enabled development of geodesic structures utilizing various bamboo connectors. The structures formed were globular with five to six members for each connection. The connectors utilized metal and even PVC parts. The connectors were placed inside or outside the culm and the protruding ends were joined together by welding, bolting and gluing. Other joinery configurations that utilized groves were also developed (Robinson 2016).

Joinery techniques for large structure developments were also made by several authors (Meckes 2001). These joinery techniques enable development of large structures such as greenhouses, cold frames, livestock enclosures and domelike structures for various applications. The joinery techniques enable end-to-end connections, multiple end connections, or end-to-culm connections using wood, U-shaped metal and cross bracketing, plastic or fiberglass molded components.

The foregoing bamboo connections have not found much commercial use as these were intended for research and single construction purposes only. Although some actual laboratory tests were made on the strength of the connections, there were no reports on the weathering capability of said structures.

Conceptual Framework

The conceptual framework used in the study was the Conceive, Design, Implement and Operate (CDIO) process which is recommended by the Philippine Commission on Higher Education (CHED). The conceptualization phase was already done and aided by the volume of literature reviews, test results and other available materials. The design was made based on the concepts and design parameters earlier established. The implementation phase was conducted by carefully following the design. Design specifications were strictly followed for replication and for preliminary tests. The Operation phase was made through actual use of the developed idea. For this research, actual bamboo housing units were constructed using the connectors and were subjected to weathering trials. Ease of construction, speed of construction, weathering observations and preliminary cost considerations were compared with those of traditional construction.

Materials and Methods

The Connectors

The connectors were designed and fabricated using 3-inch diameter, galvanized iron (GI) pipes. Short lengths of pipes, varying from 6 inches to 8 inches, were halved to make the connectors. The connectors were configured to clasp the bamboo on the surface of the perimeter of the culm. These short, halved GI pipes were then configured on the type of connection and on the shape of the structure. For this research, the pentagon structure was chosen as it was easy to make triangular configurations out of the members compared to square or rectangular structures which are common in the rural areas. The triangle is the strongest polygon and its use in building trusses and building parts is indispensable. Achieving a triangular pattern would provide stability by making the entire structure more rigid (Phantranamala 2015).

To strengthen the bamboo-connector bonds, dowels and lashings were employed. The dowels passed through the end holes of the connector elements and penetrated through the walls of the culms. To further strengthen the connection, GI tying wire was used for lashings. Although other lashings may be made for other purposes like rattan for aesthetics, tube fasteners and cable ties for ease of application and nylon strings for cost considerations, the tying wire was easy to apply as well as low in cost.

Fabrication of the connectors was done at a local welding shop. The 3-inch diameter GI pipes were cut, halved, notched, drilled, and welded. The different metalworking operations depended on the type of connectors made. The starfish connectors, for example, no longer needed splitting the pipes as whole, short-piece pipes were used. The different angles were followed as per design specifications to be able to create connectors fit for a pentagon structure.

The Bamboo Species

The bamboo species utilized for this development research was the Botong (*Gigantochloa levis*, local name, Patong). This species grows tall and straight with minimal taper. It is commonly used as scaffolding, fences, boat outriggers, fish cage stilts, bamboo houses and many others. The species grows to as big as 6 inches in diameter and as tall as 30 to 50 feet. It was the favored species as the culms were straight and the nodes do not protrude much making the connectors fit easily into the culm.

Construction Tests

Three structures were constructed as part of the trials. The first structure utilized the starfish connectors to gather the top chords together in a pentagon structure. The rest of the joints in the house utilized traditional joinery techniques. The triangular elements in house construction were widely used in this first structure as well as in all the other structures. The first structure was built by two (2) local carpenters and one (1) helper utilizing the traditional techniques. The structure was constructed in Romblon, Philippines.

The second structure was built utilizing the developed connectors. Students with no prior house construction experience performed the construction. They were briefed on the design of the structure, on how to conduct layout and staking for pentagon house construction, and on the use of construction equipment particularly the sliding compound miter saw and the electric drill. Speed and ease of construction utilizing the connectors were the parameters tested in the second construction.

The third structure was erected utilizing the same connectors employed in the second construction. No additional connectors were fabricated but a two-level house was constructed. The author and one (1) helper performed construction of the skeletal structure to compare the ease of construction with the two previous structures. Another purpose of the third construction was to showcase the versatility and the standardized nature of the connectors.

Weathering Tests

The constructed houses were never occupied for living. They were left to the elements to weather but were visited for inspection from time to time. Notes on their resistance to typhoons and other weathering elements as well as decay vectors were made. As of this writing, the first and third structures were still undergoing weathering tests.

Preliminary Cost Evaluation

As no data exists on costs of developed connectors by other authors, cost comparisons were roughly made between traditional house construction (with the starfish connector only) and construction utilizing all the developed connectors.

Results and Discussion

Design and Development of the Connectors

The study was able to generate bamboo connectors specifically designed for house construction. The developed connectors were found to be amenable to standardization of the construction of pentagon structures of any size.

The different connectors and their uses were:

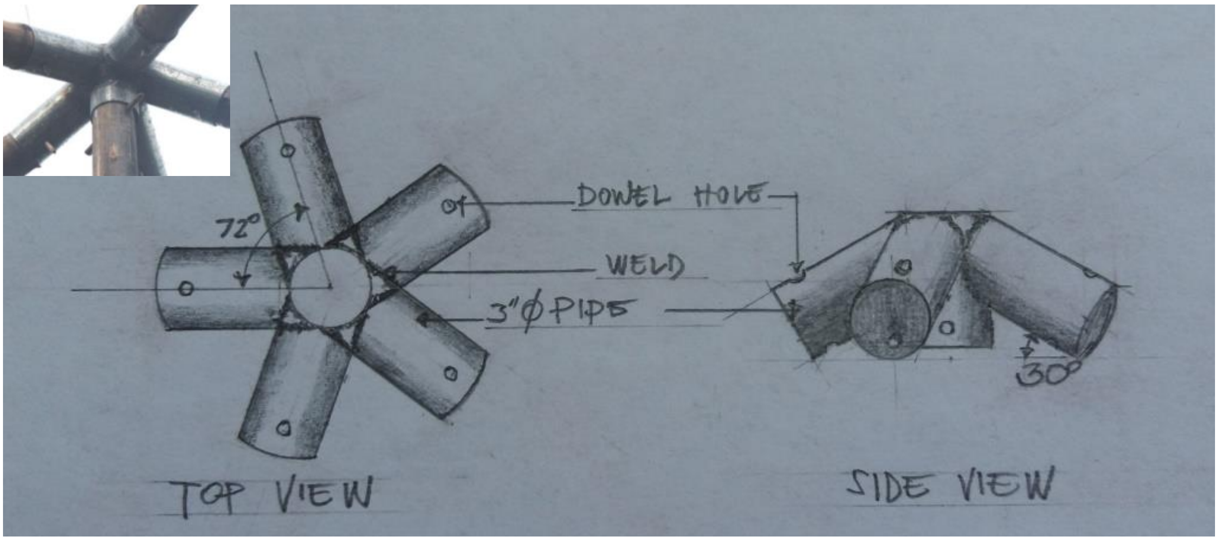

Figure 1.

a. Starfish connector (Figure 1). This connector joined the top chords of the pentagon together. It was made of whole, short-length GI pipes welded together in a five-point configuration with 72-degree separation from each pipe. The pipes were angled at 30 degrees from the horizontal to serve as the pitch of the roof. A central pipe joined all the pipes together. This central pipe served as the hole for accommodating a dowel which served as the topmost support of the roofing which is made of grass. It can also serve as a vent. Holes were drilled in the ends of starfish pipes to accommodate dowels that will hold the pipes and the top chords together.

b. Top chord – purlin connector (Figure 2). This connector was an important piece as it joined the top chord and the purlins in a manner that made the use of a central prop for the whole structure unnecessary. This was important as posts in the middle of a structure obstruct the floor area and divide it up to small pockets. A center-post-less structure will make it more spacious and airy. The connector pieces that rode on the top chord were angled 30 degrees for the roof pitch. On these were welded the pieces that connected to the purlins. The pieces that connected to the purlins were angled 108 degrees from each other and welded together. These were in turn, welded to the piece that rode the top chord in a manner that these purlin-hugging pieces straddled the former. Holes were also drilled in these half-pipe pieces to accommodate dowels for joining the bamboo and connectors. For this research, 25 pieces of this type of connectors were fabricated in a local welding shop.

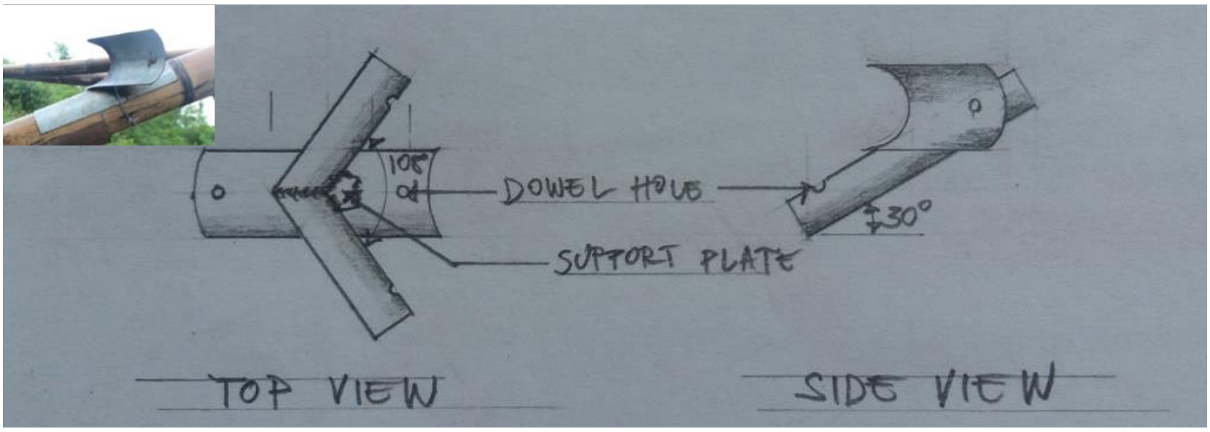

Figure 2.

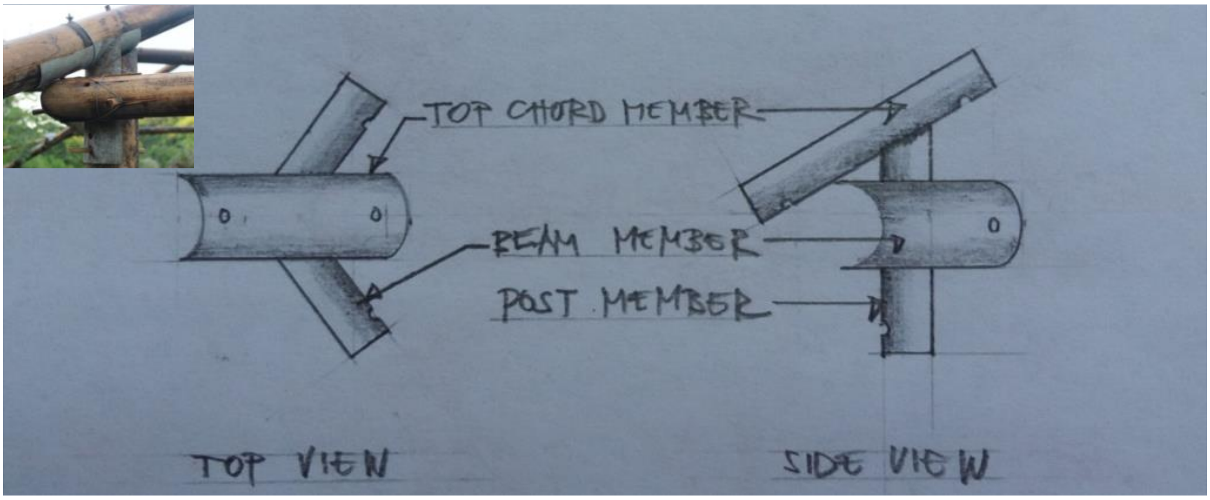

Figure 3.

c. Post – top chord – beam connector (Figure 3). This connector joined the three mentioned parts: post, top chord and two beams. The piece that half-embraced the post was oriented vertically and was concave towards the center; on top of this was welded the connector that served as seat for the top chord. This piece concaved upwards. The pieces that connected the beams were again welded at 108 degrees separation and in turn, welded to the post and top chord elements. These pieces were concaved towards the outside of the structure to give a snug fit to the connection. Holes were again drilled at the ends of the elements of the connectors to accommodate dowels for fastening bamboo and connectors. The pentagon structure necessitated five pieces of this connector.

d. Strut – top chord connector (Figure 4). To create a rigid structure, the posts were designed in a triangular fashion. Overall, the five posts of the pentagon structure configured this way plus the walls and braces gave rigidity to the overall structure. The triangular form comprised of the post, strut, and top chord elements. The connector joined only the two latter elements as the post and top chord were already joined in the previously described connector (c) and the post and strut were cemented together at the base (Figure 4). The connector was configured in a way that the two elements were joined at an angle of 100 degrees; the strut element concaved outside and was joined at its end to the middle of the top chord element that concaved upwards. The ends of the elements were again drilled to accommodate dowels. Five pieces of this connector were also made.

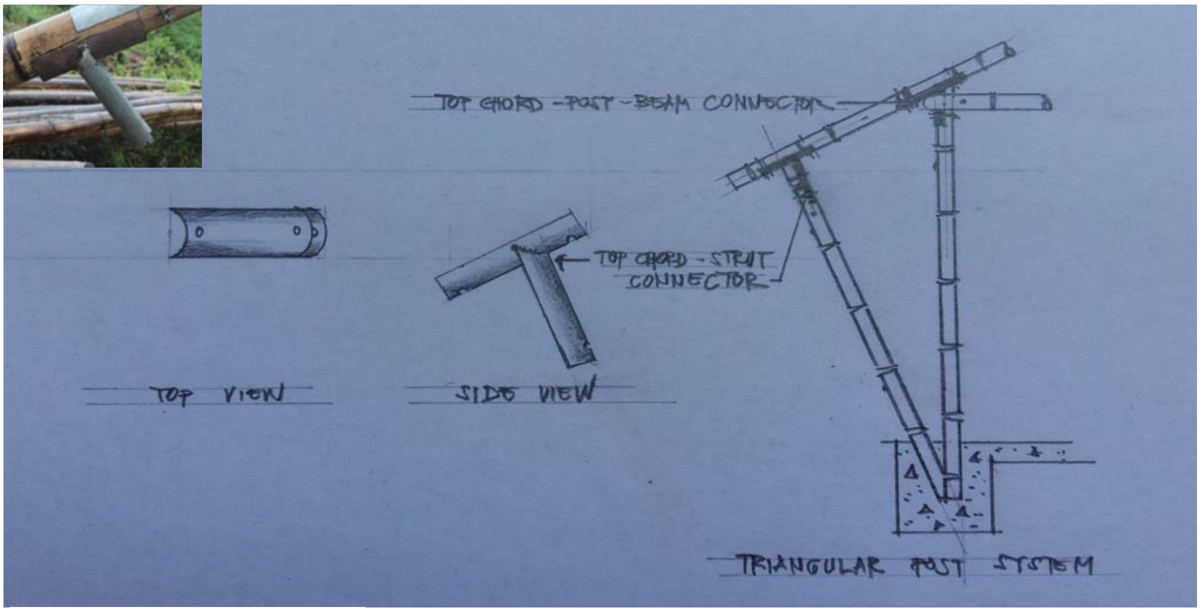

Figure 4.

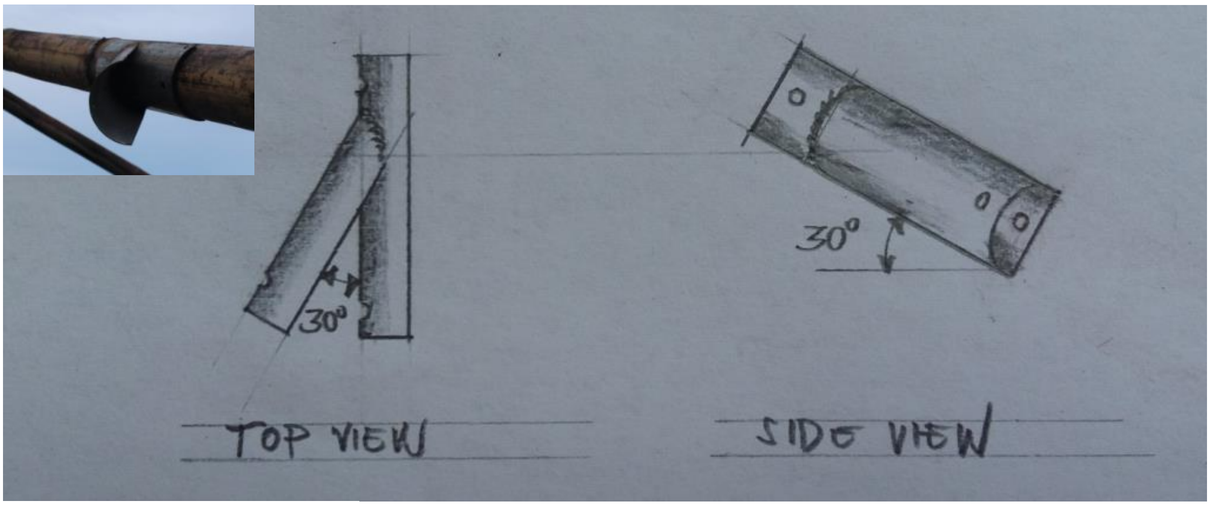

Figure 5.

e. Top chord – rafter connector (Figure 5). This connector was made of two pieces of the half-pipe elements joined at an angle of 30 degrees; the two elements concaved in the same direction. The joint was placed 1.5 inches below one element. To use this connector, one must taper the rafter 30 degrees to fit into the space between the connector elements. Again, holes were drilled in the ends of the elements to accommodate the securing dowels. Ten pieces of this connector were made.

f. Rafter - beam connector (Figure 6). This connector was made of perpendicular elements welded together at the middle convex parts. The connector rested on the beam and, in turn, carried the rafter. Holes were also drilled at the ends of the connector elements to secure the supported parts. The holes also accommodated the securing dowels. Ten pieces of this connector were also prepared for the study. This connector may be likened to the design of Waldemar Rothe of Bambootix discussed by Gernot (2016) in his book. The difference is that the Rothe design utilized a single flat metal plate that was stamped to shape and bent to fit the bamboo diameter whereas this connector utilized two halved pipe pieces; the pipes may either be hammered out or in to suit the bamboo diameter. Moreover, the Rothe design would require a different plate stamping pattern for angled connections, whereas this design would be easily adaptable for different angles. The fabricator would only adjust for the angle and weld the pieces together to suit the angle configuration. Furthermore, the Rothe design could only accommodate two bamboo components whereas the different connectors described above may carry 2, 3, 4, and 5 bamboo pieces. The starfish connector may be modified to an octopus connector and carry 8 top chords.

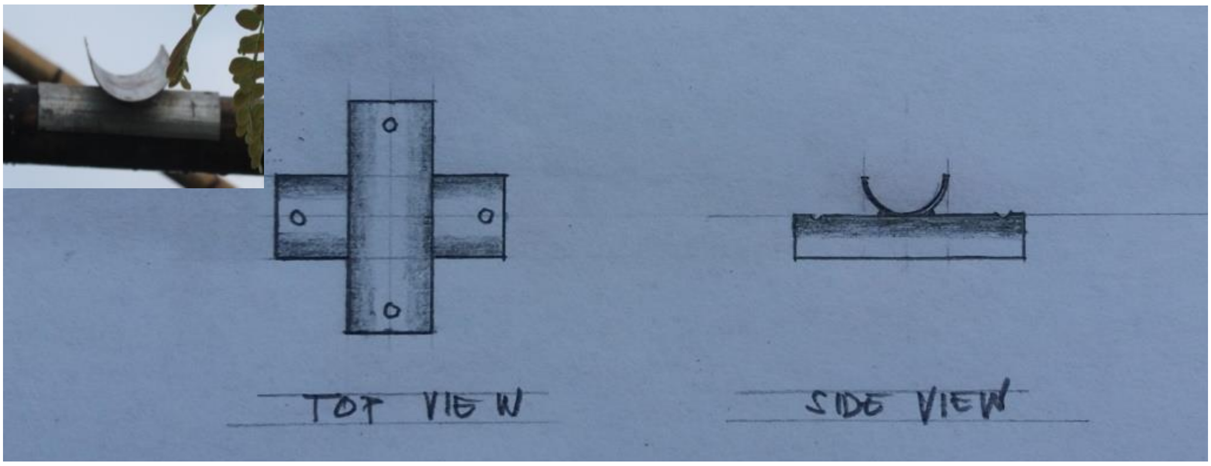

Figure 6.

Overall, the design of connectors was satisfactory and met design requirements for a pentagon structure like the pitch of the roof, the angles of the connector members and the number of connectors for the various joints identified.

Fabrication of the connectors was done locally. Local shops were found to have necessary equipment and skillsets to fabricate the connectors. Equipment used in fabrication of the connectors were cut-off metal saw, bench drill, angle grinder and welding machine. Metalworking skills like cutting, welding and grinding were also available in local shops. Materials for the connectors were also readily available and supplied by most hardware stores. GI pipes, angle grinding blades and welding rods were the consumables used during fabrication. The bamboo connectors can be made in any part of the country or outside where the raw materials, equipment and the mentioned skillsets are present.

Construction Tests

The connectors passed the test for ease of construction. Students without house building skills or experience were able to construct the pentagon skeletal structure in two days using the connectors. The author was also able to construct a two-story structure using the same connectors with only a single assistant in three days. Whereas two carpenters and a helper working on traditional joinery techniques were able to finish the same skeletal structure as the students did in 10 days. The key to speedy construction was the “cut-and-paste” method enabled by the connectors that served as the “paste”.

A review of the traditional joinery techniques employed by the workers and the joinery techniques using the connectors are shown in the figures below. The post - top chord - beam connection to the left (Figure 7) was prepared by the carpenters whereas the one on the right (Figure 8) was made by the students. The carpenter who made the joint took a day to measure and cut the bamboo pieces, assemble them together using tying wire, and tie them up using rattan. The students, on the other hand did the measuring and cutting, drilling holes and doweling, and assembling the elements together with the connectors and tying wire in less than an hour.

Figure 7.

Figure 8.

The figures below compare the ten-day output of the carpenters (Figure 9), the two-day output of the students (Figure 10), and the three-day output of the author (Figure 11).

Figure 9.

Figure 10.

Figure 11.

In construction, however, some observations were made on the snugness of fit of the connectors and the bamboo pieces being joined. As the bamboo tapers gradually, its butt diameter is different from the end diameter. This creates an issue when it comes to the tightness of fit. Where the bamboo diameter was larger than the connector diameter, the connector piece would be hammered out to widen its concavity; where the bamboo diameter was smaller, the connector needed to be hammered in to fit the bamboo being joined. Gaps occurred on some connections where the diameters of bamboo and connectors do not match. This issue needs to be addressed in refining the design.

Weathering Tests

The first structure built by the author using traditional construction techniques incorporated the starfish connector (Figure 12). This structure weathered Typhoon Haiyan that hit the province with storm warning number 4 in 2013. Where other similarly built structures around this house and banana plantations in the vicinity were toppled by the storm, this pentagon structure with the starfish connector survived gustiness of more than 185 km per hour. The structure also survived other storms that passed the province and remains standing to date. The success of the starfish connector and the pentagon configuration prompted the author to continue modification work on them. In 2014, the structure built by the students (Figure 13) weathered storms that hit Romblon up to 2016. If not for the weakening of the posts attacked by termites, the structure would have been standing to date. The roof structure that was not attacked by termites was still intact even if the structure toppled on its side. The second structure was set on fire to test if the connectors could withstand fire and remain useful. The connectors were recovered and reused to build the third structure. The third structure (Figure 14), built in January 2017, has not yet experienced a major storm. Nevertheless, it withstood gustiness of the Southwest monsoon in the June to October season in 2017.

Figure 12.

Figure 13.

Figure 14.

In cognizance of the minor issues encountered in construction of the structures, the connectors were found adequate for building pentagon houses with a minimum tools, skillsets and time. The implications would be myriad in that the connectors may be used for rapid house construction where immediate shelters are needed. The connectors may also be utilized for DIY construction where bamboo structures prefabricated in shops may be sold to hardware stores. A client may order a kit from the hardware store where it would be delivered in situ and the same client may start building the structure using a minimum of tools and or skillsets. This would mean a paradigm shift in the way structures are built in the countryside where one could only order a cottage from the hardware store and build one himself instead of hiring laborers to do it for him or buying an entirely built bamboo hut and delivering the finished structure to his yard.

Preliminary Cost Evaluation

Cost factored in, two workers using the connectors would save 18 skilled man-days and 8 unskilled man-days compared to carpenters working on similar structures using traditional methods. This could amount to a savings of PhP9,600.00. The connectors, however, were fabricated for PhP13,000.00 which made it a bit costlier option. Nevertheless, the difference in labor saved and the cost of connectors may be offset by the shorter construction duration and the resiliency of the structures. Moreover, as the connectors could be reused several times over, payback may be realized in less than two cycles of use. Further, the cost of the connectors may be further lowered with value engineering.

Commercially, the connectors have potential for use in bamboo houses that are still common in the countryside or in oriental-themed or native-style resorts. Home or resort owners may order units that are prefabricated using the connectors and have those delivered on site to be constructed with ease.

Disaster episodes may also require immediate shelters and prefabricated units could be delivered to disaster sites for immediate solution to shelter problems.

Comparison between traditional construction (with the starfish connector only) and construction using the developed connectors is shown in Table 1 below.

Table 1. Comparison between traditional house construction (with the starfish connector only) and construction utilizing all the developed bamboo connectors.

Parameters		
Ease of construction	Carpentry skills needed	DIY construction
Number of days to finish skeletal structure	Twenty (20) skilled man-days plus ten (10) unskilled man-days	Two (2) skilled man-days plus two (2) unskilled man days
Strength	May withstand strong typhoons	Survived typhoons that hit the area from 2013.
Fire resistance	Traditional joints will burn	All the developed connectors were recovered from fire
Versatility in construction	Limited by skilled artisans and carpenters	Unlimited pentagon house sizes and designs
Cost considerations for skeletal construction	30 man-days + materials	4 man-days + materials + plus cost of connectors. (Cost of connectors is offset by savings in labor cost, timeliness in construction and disaster resiliency.)
Acceptability potential	Low	High
Potential market	Low-end home owners	Resorts, hardware stores, DIY shops, LGUs, DSWD, Disaster Relief Organizations

Summary and Conclusion

The objectives of the research were met albeit some issues need further consideration.

Connector designs for various joints of a pentagon structure were made. The designs were made in such a way that half pipe pieces, cut to length, hugged the bamboo and was the main component for joining bamboo pieces together through welded joints. This design enabled the connectors to be attached to the bamboo secured by dowels and lashings.

Fabrication of the designed connectors was done locally utilizing available raw materials, minimal equipment and local skillsets. The fabricated connectors, although not tested in the laboratory, were strong enough to handle the loads imposed. With only local fabrication employed, the design may be replicated in other parts of the country or even abroad given the same fabrication conditions.

Construction tests using all connectors were done twice and referenced with construction techniques using traditional joinery. It was found that the "cut-and-paste" method with the connectors serving as paste enabled easier and faster construction of comparable structures. Novice carpenters and even home owners with little carpentry skills may be able to construct pentagon structures using the connectors. For faster construction, power tools like a sliding compound miter saw and electric drill may come in handy.

The test for actual weathering was conducted in a span of four years. The traditionally built structure that incorporated the starfish connector survived Typhoon Haiyan in 2013. Another structure built with all designed connectors lasted for 2 years until it was toppled by termites that gnawed on its posts. The roof structure where most of the connectors were found was still intact even if the structure was toppled on its sides. This structure was burned to give way to another structure and the connectors used which were left attached to the bamboo survived the fire and had no deformities. A third structure was built using the same bamboo connectors and is currently undergoing weathering tests.

The connectors, although somewhat costlier may be utilized many times over if the bamboo culms it connected have deteriorated in use. The cost of fabrication may be offset by savings in labor due to shortened construction. Timeliness in construction and occupancy may further offset costs of connectors. Costs may be reduced further with value engineering.

Implications and Recommendations

The study opens opportunities commercialization of the developed connectors as components of housing units that may be sold as DIY kits to home owners, resorts operators, or even to disaster management organizations. Setting up shop to produce DIY kits for pentagon structures or any other regularly-shaped structures can be the next move. The shop will fabricate the connectors as well as actual structures on the shop. These prefabricated structures will be knocked down until somebody orders a unit where it will be delivered on site to the customer who will personally oversee or perform the actual construction. A manual for construction should go with the set of connectors.

The issue on snugness of fit between bamboo and connector should be addressed. This would be easy if prefabrication would be done in a shop. A tool for either widening the concave or narrowing it down may well do the job in adjusting for the bamboo diameter. Another option in value engineering is to use one-fourth of the pipe instead of one-half. The arc would be narrower in the former and would allow snug fit to various bamboo diameters. The strength consideration for this latter solution may be investigated as this means reduction in the amount of material used.

The lashing for the bamboo and connector joint may also be improved by devising lashing techniques that are strong, easy to apply and economical. Moreover, comparison between the developed connectors and other previously developed connectors may also be done in future studies.

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Acknowledgment

The author is indebted to the following: the management of the Romblon State University for engaging the author in part-time teaching job at the RSU while in the initial stages of the research, for the current full-time service to the University, and for providing institutional funds for the second phase of the research; the Agricultural Engineering Students of the CET-RSU, the carpenters and helpers for the labor in constructing the structures for the research; and, to my wife and daughter for the inspiration and valuable insights.

To God be the glory!

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