Bamboo Design and Construction in Thailand : Bamboo Art Gallery at Arsomsilp Institute of the Arts

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This paper talks about our lesson learnt from bamboo arts gallery project working with bamboo as natural material for construction which is our first experience. Bamboo Arts Gallery Project was a thesis for master degree of architecture program in community and environmental architecture this project demonstrates the visions of Arsomsilp Institute of the Arts which not only focuses on work-based learning and hands-on experience but also in promoting the alternative building technology and sustainable building materials. The project started in 2009 and the building was completed in 2013.

Due to the inadequate technical knowledge on design and construction of contemporary bamboo building, experienced builders are the key success for this operation. They could specify species of bamboo for construction, suggested design process and structural design. Through this paper, we intend to share lesson learnt from each process from designing to constructing process and want to be able to learn from others' experiences.

Introduction

From past to present, the demand for construction materials has increased far beyond the available supplies, especially from natural resources, which has caused the problem of exploitation of resources. At present, people are more aware of deforestation which takes decades to revive. The strength and renewable prospects of bamboo make them preferably alternative materials to substitute otherwood. Hence, bamboo are considered as the most perfect multipurpose plant species of the world.

Kurz (1876) emphasized that "No plant is known in the tropical zone which could supply to man so many technical advantages as the bamboo "which indicates the multipurpose use of bamboo. According to Hildalgo (2003), due to the low durability of most of giant bamboo species of Southeast Asia, at present most countries in this area do not use bamboo for the construction of main structure of their house.

In recent years, with the issue of sustainability the use of bamboo has gained a new value. This awareness is followed by many bamboo building built in recent years especially in the countries with plenty of indigenous bamboo species.

In Thailand there are 17 genera and 72 species recorded. The total area of bamboo forest in Thailand is approximately 454,486 hectares, consisting of a volume of 17.6 million m^3 and biodiversity index of 1.737 (Royal Forest Department 2009). But technical knowledge for architects and engineers is still not avilable.

Arsomsilp Institute of the Arts started Bamboo Arts Gallery Project in 2009 as a part of a work-based learning and hands-on experience of a master degree architecture student. Apart from that, the objectives of Bamboo Arts Gallery Project are a s follow

1. To experiment the natural potential of bamboo as well as to build people confidence of bamboo construction in contemporary context.
2. To construct a bamboo building for public uses.

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3. To publicize local wisdoms of bamboo construction in Thailand and subsequently develop and apply the knowledge to contemporary uses.
4. To gather available information and provide knowledge relating to bamboo construction.
5. To encourage and promote the uses of bamboo building in the future.

The design and construction process of the art gallery as a prototype bamboo building for public uses, was an opportunity for architects, engineers, bamboo carpenters and suppliers to share experience and knowledge. The gallery was also intended to inspire architectural and engineering students as well as social organizations for the usage of bamboo as construction materials for public building.

To accomplish this intention we gather and promote the knowledge and information on bamboo as well as to build up networks of educational institutions, communities, private sectors and lay people in order to encourage the use of bamboo as standardized construction materials.

Species of bamboo for construction

In Thailand, There are 28 bamboo species used in construction (Sarawood et. al 2011) Ten species were selected to test their physical and mechanical properties carried out by Royal Forest Department of Thailand and International Tropical Timber Organization (Thaipetch et al. 2004; Sompoh et al. 2013) as in Figure 1.

Bamboo Species	Culm part	Bending (Mpa)	MOE (x100 Mpa)	Compression (Mpa)	Shear (Mpa)		Tension (Mpa)	
					Internode	Node	Internode	Node
Dendrocalamus asper	Bottom	92	702	66	9.7	11.1	385	87
	Middle	59	564	70	10	8.4	348	101
	Top	100	520	70	8.4	9.9	342	100
	Average	84	595	68.5	9.4	9.8	359	96
Bambusa blumeana	Bottom	93	634	66.5	11.1	11.4	421	103
	Middle	104	878	68.0	12.2	12.3	353	134
	Top	79	221	65.0	13.5	12.7	389	123
	Average	92	578	66.5	12.3	12.1	388	122
Dendrocalamus strictus	Bottom	81	191	54.5	12.8	12.0	394	142
	Middle	78	177	57.5	15.1	13.0	322	124
	Top	90	197	56.0	11.5	13.4	33	53
	Average	83	189	56	13.1	12.8	349	106
Gigantohloa albociliata Munro	Bottom	130	280	41.0	10.1	9.4	358	164
	Middle	114	264	53.0	9.8	10.3	447	168
	Top	108	381	41.0	8.9	9.2	43	199
	Average	117	308	45	9.6	9.6	414	177
Bambusa sp.	Bottom	71	224	62.5	11.5	11.4	271	127
	Middle	79	210	68.5	13.1	12.7	-	-
	Top	94	257	72.5	13.6	13.6	-	-
	Average	81	234	68	12.7	12.6	271	127
Dendrocalamus hamiltonii	Bottom	104	86.3	31.1	6	4.9	-	96.3
	Middle	99.8	114	50.9	8.5	8.4	-	75.7
	Top	113	223	58.2	8.9	8.2	-	76.2
	Average	105.6	141.10	46.73	7.8	7.16	-	82.73
Bambusa Bambos	Bottom	156	301	49	8.69	8.28	-	103
	Middle	462	326	56.3	9.85	8.79	-	103
	Top	475	370	57.40	8.9	9.59	-	98.4
	Average	164.33	332.33	54.23	9.15	8.89	-	101.47
Thyrsostachys oliveri		120	197	57	4.30	7.03	-	-
Thyrsostachys siamensis		131	177	54.3	5.16	4.79	-	-
Dendrocalamus longisapathus		117	190	57.8	7.16	6.94	-	-

Figure 1 Mechanical properties of selected bamboo species carried out by Royal Forest Department of Thailand and International Tropical Timber Organization.

Three of these bamboo species, which are *Dendrocalamus asper, Dendrocalamus strictus* and *Thyrsostachys siamensis*, were selected to use in this project according to availability in the markets and suggestion by craftsmen

The common length of bamboo available is 6 metres. The longest bamboo available is limited to 9 metres due to the size of the truck.

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The Design

Bamboo Art Gallery is situated at the entrance into Arsomsilp Institute of the Arts with 360 m^2 usable area. The main purposes of this building are.

- To be an artistic lobby to welcome guest before entering into the institute.
- To signify the identity of the institute that emphasizes local wisdoms and values natural sustainable materials.
- To provide a multi-purpose space for Arsomsilp Institute's activities (Figure 2).

Figure 2 Graduation ceremony at Bamboo Art Gallery.

The building was designed to assimilate nearby buildings. Its design must reflect the attitudes of Arsomsilp Institute which views local culture and wisdom first priority. The gallery was designed with high pointed roof with slopes similar to a Thai monastery (Figure 3).

Figure 3 (1) Arsomsilp Institute of the Arts, (2) Traditional thai monastery (credit: http://www.art-in-sea.com/en/component/k2/item/467-prafang_art1.html) (3) Bamboo Art Gallery

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At preliminary design phase, the design was developed by focusing on functions and form (Figure 4). The problem that arose during the process is "How can we know that the structure that we are designing is strong enough?"

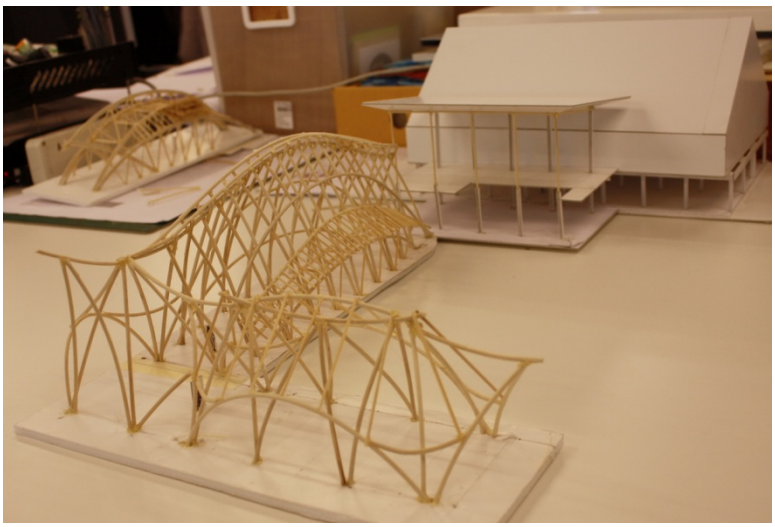

Figure 4 Preliminary design model.

During the design process, the researcher had a chance to join "BAMBOO FOR SUSTAINABLE COMMUNITIES: A training workshop on bamboo as alternative building technology and livelihood enterprise for poor communities" organized by Asian Coalition for Housing Right (ACHR), Homeless People's Federation Philippines, Inc. (HPFPI), Philippine Action for Community-led Shelter Initiatives (PACSII) and the Technical Assistance for Movement for People and Environment, Inc. (TAMPEI) and its local organisation, Mindanao Action Network of Technical Assistance Services (MANTAS). The benefit derived from this workshop was how to use a model as a learning medium for architect to see construction process by using bamboo sticks and pin (Figure 5). Then the design was again developed by using this method of making a model but since no engineers have available knowledge about bamboo structure, some engineers suggested that we needed to construct 1:1 mock-up model to test the structure we designed which would double the construction cost.

figure 5 Developed design model using bamboo stick and pin.

Due to the lack of engineering calculation, the huge size of this bamboo building depends on the competent skills of experienced craftsmen. The success of this project partly depends on the advice of the craftsman head and his assessment of the possibility of the construction.

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Figure 6 Developing structural design with Vichi Tawor and his team.

Vichai Tawor is a "Pakakyo" tribal craftsman head. He has had a lot of experiences in building many big bamboo structures in Thailand such as The Den, Panyaden School etc.. A three-day-design workshop with craftsmen was organized to develop building design together (Figure 6). At that time engineers who would be interested in bamboo building could not be found.

The structural system used in this project is similar to what the craftsman team had experienced with Panyaden School's construction. This structural system is rafter roof system, similar to what was suggested in IL 31 (Figure 7), developed by Olav Bruin and the craftsmen of Chiangmai Life Construction Co.Ltd. The advantage of this system is that long straight bamboos (Figure 8), which are difficult to find are not required.

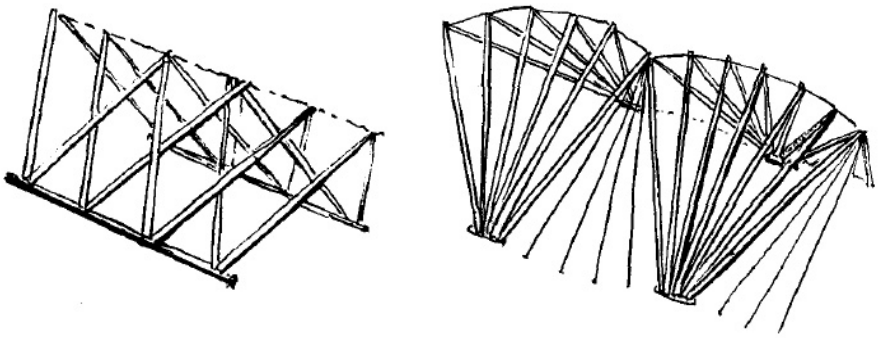

Figure 7 The example of suggested rafter roof for bamboo structure in IL31 book.

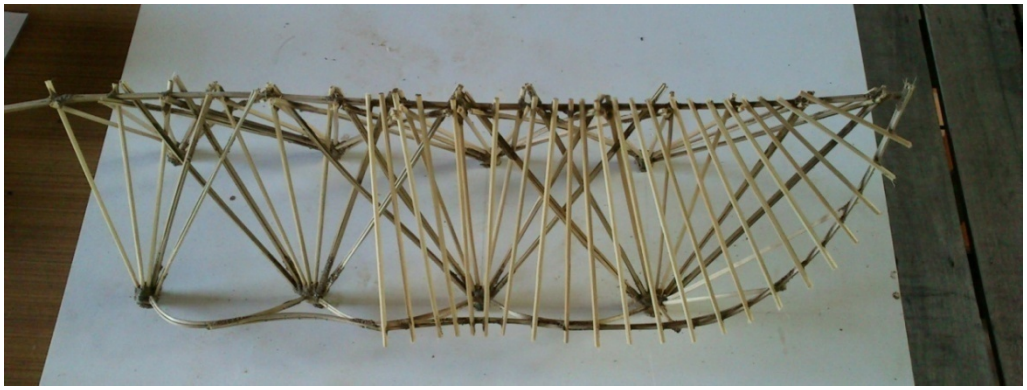

Figure 8 Roof structure of bamboo arts gallery model.

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From craftsman's experiences, each support should not be wider than 2.5 meters because bamboo is very flexible and easy to bend. The height of the building is 9 meters due to the bamboo size available in the market. The highest and longest rims are made from bundled bamboos to make them longer than 9 meters as an experiment.

Model making is an easy means to learn and communicate with craftsmen and facilitate mutual understanding.

Engineering Calculation

Arsomsilp Institute of the Arts collaborated with engineering students from the Faculty of Engineering King Mongkut's University of Technology Thonburi (KMUTT), under Assoc. Prof. Anek Siripanichgorn advisory, to prepare engineering database for Bamboo Art Gallery building. The specimens were randomly selected from the bamboo used for this building - 5 inches in diameter of *Dendocalamus asper* and 3, 4, 5 inches in diameter of *Dendrocalamus sericeus*.

To determine the allowable stress of bamboo used in this project we randomly pick bamboo examples from the bamboo we used and tested following the ISO 22157 recommendation, in order to put in the package analysis as model in commercial software SAP 2000. At the factor of safety of 2.25, it was found that the compressive allowable stress, tensile allowable and shear allowable of *Dendocalamus asper* and *Dendrocalamus sericeus* are as in Figure 9

Species	Diameter (inch)	Allowable stress (kg/cm2)		
		Compression	Tension	Shear
Dendocalamus asper	5	86	270	16
Dendrocalamus sericeus	3	60	288	12
	4	105		16
	5	119		20

Figure 9 Allowable stress of selected species

The building was modeled using analysis with SAP 2000. The roof loaded with a Live Load = 50 kg/m3, Dead Load = 50 kg/m3 and a Wind Load = 50 kg/m3 on the windward side. The result of maximum stress in each member compare with allowable stress of the bamboo used is in Figure 10.

Member		Compression	Tension	Shear
Ridgepole	Maximum Stress	11.33	38.54	58.396
	Allowable Stress	60.23	288.18	12.77
Column	Maximum Stress	121.95	36.36	0.72
	Allowable Stress	86.75	270.22	16.52
Rafter support	Maximum Stress	76.07	33.04	174.8
	Allowable Stress	60.23	288.18	12.77

Figure 10 Maximun stress occurs in the structure compared with allowable stress of bamboo used in each structural member.

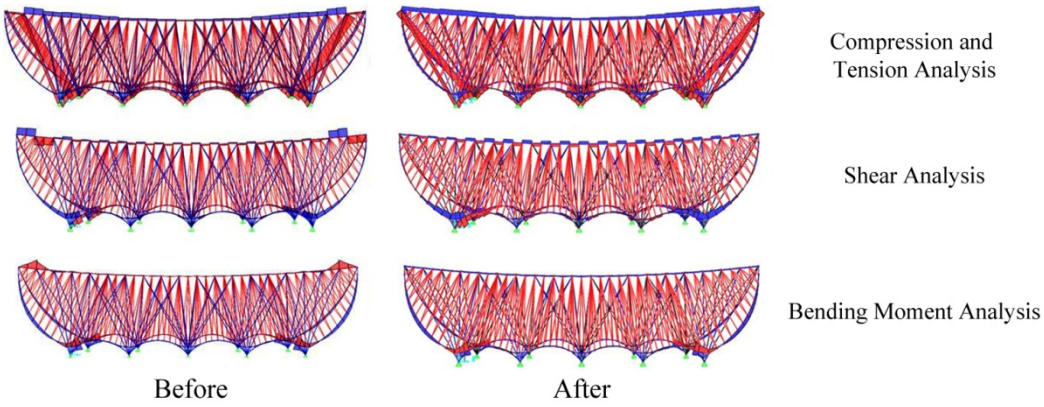
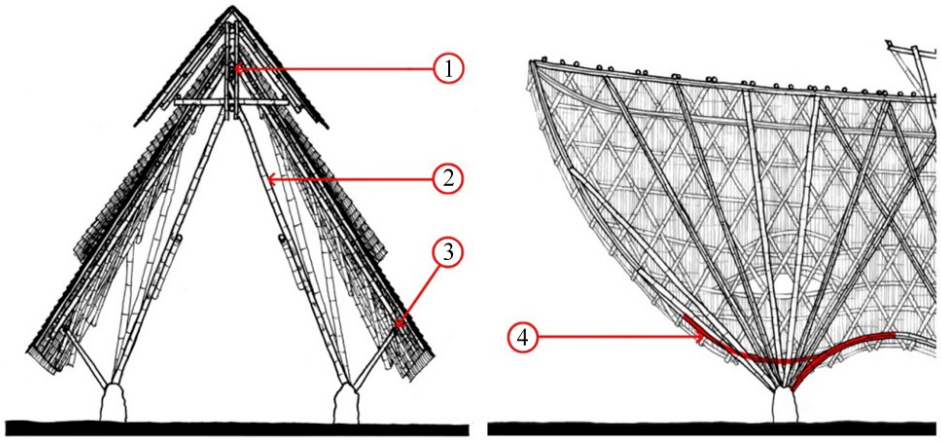


Figure 11 Comparison of structural analysis before and after adding columna at both rim

From the results of building, two more columns were added to each side to lessen the shear force of ridgepole and the compressive force of columns (Figure 11). Considering the sufficient of safety, the following appropriate sections were assigned (Figure 12).



No.	Member	Bamboo Species Diameter (inch)	Section
1.	Ridgepole	*Dendrocalamus strictus* 3	
2.	Column	*Dendrocalamus asper* 5	
3.	Rafter support	*Dendrocalamus strictus* 3	
4.	Rare rafter support	*Dendrocalamus strictus* 3	

Figure 12 Section of each member suggested by the engineer

Construction Process

Construction Process started from setting up scaffolding to form the shape of the building. We erected 9-meter-long *Dendrocalamus asper*, the longest bamboo poles we have, to temporary hold the ridgepole that would shape the form of the building (Figure 13-15).

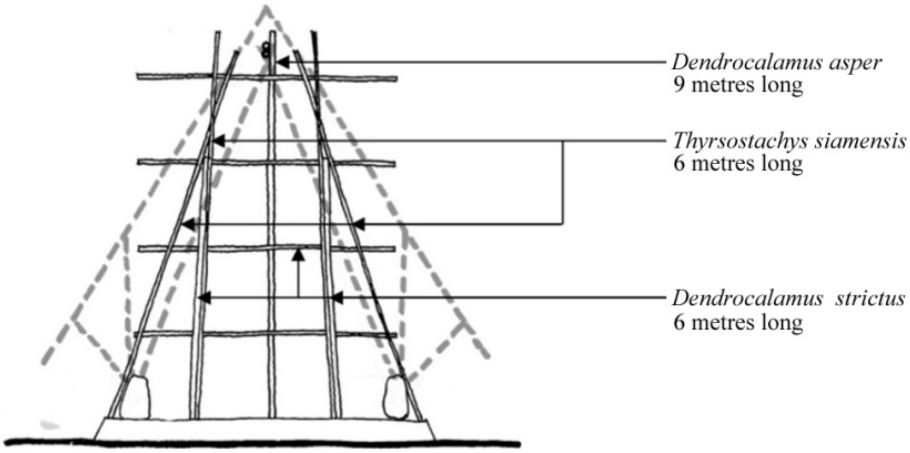


Figure 13 Bamboo Species used for scaffolding and the relation of its structure and the shape of Bamboo Art Gallery.

Figure 14 Scaffolding on the construction site

Figure 15 Ridgepole connected with 9-meter-long *Dendrocalamus asper* to shape the form of the building

From bamboo craftsmen's previous experience, *Dendrocalamus strictus* are not suitable for bolting and inserting concrete. Because *Dendrocalamus strictus* has a lot of moister so later on when it shrinks later on it will crack. Therefore most of the joints in this building are connected by bamboo pins (Figure 16). Just some important points of the structure use bolting.

Figure 16 Ridgepole bundles connected by bamboo pins.

The curving potential of each bamboo species varies. In this building, first we decide to use only *Dendrocalamus asper*, *Dendrocalamus strictus* but local craftsmen said that *Dendrocalamus strictus* couldn't be bent. They suggested *Thyrsostachys siamensis* for curving members that have short internode with thick wall. The form of the building, therefore, reflects the potential of flexibility the bamboo species we had.

Figure 17 Spilt bamboo as roof covers with felt paper in between.

0.9-meter-long split bamboo are used as roof covers with felt paper in between to prevent leakage (Figure 17).

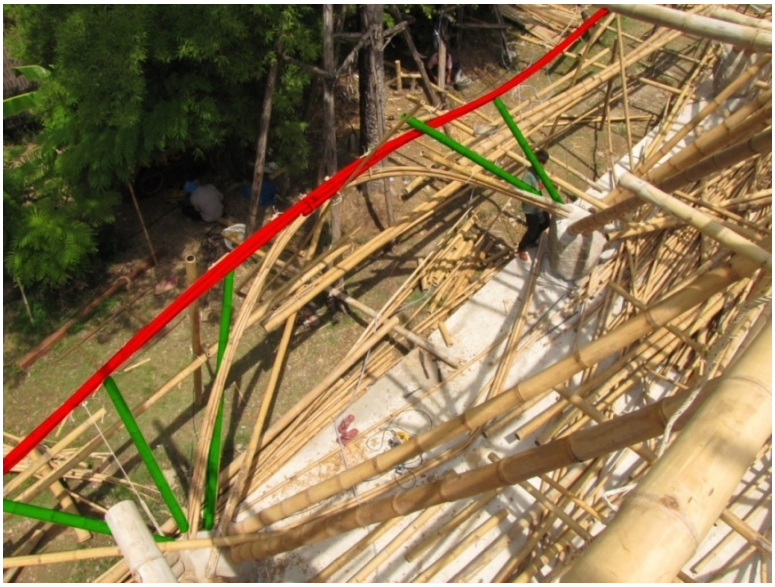


Figure 18 Rafter support (red) with added columns (green) to help bamboo arch hold the weight of the roof.

The construction of this building is a trial learning process. Many details were changed because of the problems we face during the construction such as adding more columns to support "rafter supports" that were first designed to be supported by bamboo arches but they are not strong enough. (Figure 18)

Cost, Time and Labor

The construction team consists of 7 – 8 person, 3 – 4 skilled labor. The bamboo construction phase took 45 working days. Bamboo structure construction cost is about 1,611,089.71 bath. The details of the total construction cost is as in Figure 19.

Catagory	Detail	Amonut (Bath)	Total (Bath)	%
Bamboo Treatment	Chemical	207,297.00	284,012.26	9
	Labor	48,000.00		
	Storage	18,965.26		
	Equipment	9,750.00		
Bamboo Pole	Untreated Bamboo	146,400.00	676,400.00	20
	Treated Bamboo	530,000.00		
Construction Labor Cost	Bamboo builder labor	480,000.00	480,000.00	14
Others	Natural Rock	54,800.00	170,677.45	5
	Manila rope for decoration	34,310.25		
	Felt Paper	23,304.00		
	Crane	16,000.00		
	Transpotation cost	23,900.00		
	Other Material	18,363.20		
Bamboo Structure Cost		1,611,089.71	1,611,089.71	48
Foundation		918,213.82	918,213.82	28
Floor covering and bench		623,995.00	623,995.00	19
Electricity		182,954.00	182,954.00	5
Total Construction Cost		3,336,252.53	3,336,252.53	100

Figure 19 Construction cost of Bamboo Art Gallery

Our Reflections

- To construct a secure, solid bamboo building in Thailand, one has to know 5 importance aspects: species of bamboo for construction, bamboo treatment, design process, construction process and engineering calculation.
- From this experiment, it is beneficial to have multidisciplinary action researches in the same project. In practice, an action research requires interrelating disciplines.
- To make bamboo building accepted by the society we need more research. Regulation are requires to support and backup. At global level, we already have bamboo building regulation such as in Columbia. Technical knowledge may be available elsewhere but not accessible due to language barrier or lack of sufficient information

Future Project

As a consequence of this project, Arsom Silp has found the Center for Bamboo Architectural Design and Construction with the main purpose to collect and promote the knowledge and information on bamboo as well as to build up networks of educational institutions, community, people groups and private sectors in order to encourage the use of bamboo as a standardized construction material.

The aim of Arsomsilp Institute of the Arts is on studying and researching to gain knowledge from experimenting concrete examples and acquire social acceptance. The following projects are going on:

- Bamboo Meeting Hall incollaboration with the Hill Area and Community Development Foundation (HADF) in Chiangrai (Figure 20) : The purpose of this project is to design and build an earthquake-resistant pilot building in Chiangrai which was affected by earthquakes in 2014. It consists of a meeting space for 30 persons and a dormitory to accommodate 20 persons. This project opens a chance for participatory design process in which traditional knowledge will be transferred.

Figure 20 Bamboo Meeting Hall for Hill Area and Community Development Foundation (HADF) in Chiangrai

- Orphan House in collaboration with the Mirror Foundation in Chiangrai (Figure 21) : Prefabricated bamboo house for orphan children was designed to experiment how to make a bamboo house cheap, fast and permanent.

Figure 21 Orphan House for the Mirror Foundation in Chiangrai

- Bamboo Hut at Arsomsilp Institute of the Arts in Bangkok (Figure 22) : This is a project-based learning project for first year bachelor-degree architecture students. A bamboo hut was designed, built and will be use by students themselves.

Figure 22 Bamboo Hut at Arsomsilp Institute of the Arts in Bangkok

- Bamboo architectural Office at Arsomsilp Institute of the Arts in Bangkok (Figure 23) : A two-stories architectural office building occupies 450 m^2. It consists of one studio office and three meeting rooms. The material used will be steel, wood, concrete and bamboo.

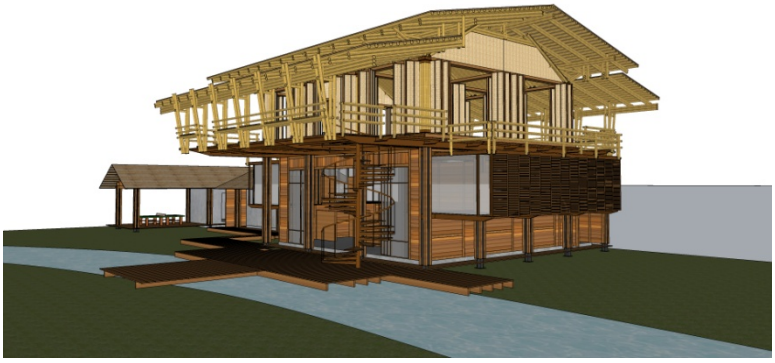


Figure 23 Bamboo architectural Office at Arsomsilp Institute of the Arts in Bangkok

- Baan Sam Saen (Three-hundred-thousand house) (Figure 24): A pilot project of an affordable family house with the estimated cost around 300,000 Bath or 160 U$ per square meters. The main structure will be bamboo with wattle and daub wall and concrete floor.

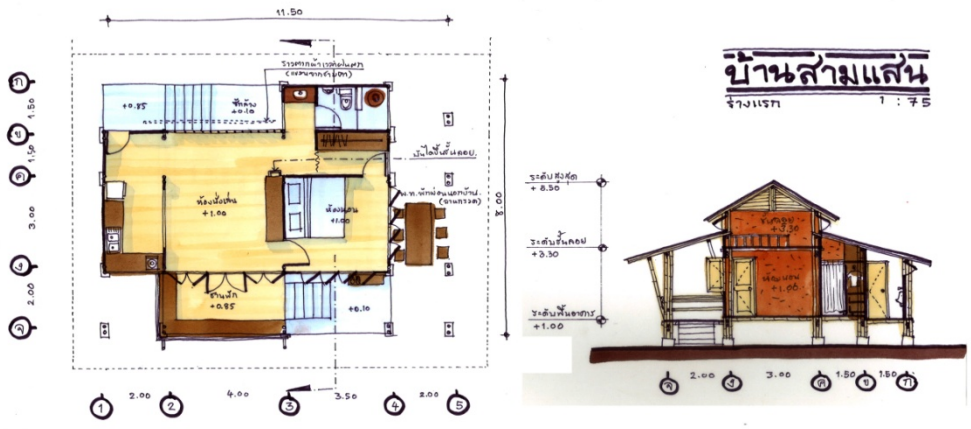


Figure 24 Barn Sam Saen (Three hundred thousand house) in Bangkok

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