MATEC Web of Conferences **258**, 01010 (2019) https://doi.org/10.1051/matecconf/201925801010
SCESCM 2018

A mockup unit of the an-eco budget bamboo chalet: design and cost estimation analysis

Hazrina Mansor[1,*], *Nursuzila M. A. A.* Wahab[2], *Yazmin* Sahol Hamid[1], and *Mohd Khairul* Kamarudin[1]

[1]Senior Lecturer, Faculty of Civil Engineering, Universiti Teknologi Mara (UiTM) Shah Alam, Selangor, Malaysia.
[2]MSc. Student, Faculty of Civil Engineering, Universiti Teknologi Mara (UiTM) Shah Alam, Selangor, Malaysia.

Abstract. To succeed by 2050, Malaysia visions would need to be ecologically sustainable. To align with this strategy, a mock-up unit of an-eco budget bamboo chalet is proposed and designed with the aim to provide an affordable and sustainable chalet using local sustainability features and expand the use of natural resources. A sustainable bamboo chalet requires proper initial treatments and preservation in maintaining its esthetic appearance and strength. Otherwise, it can be less durable and under certain circumstances would incur high maintenance cost to the owner. In this study, the proposed unit of an eco-budget bamboo chalet is designed and analyzed using the Staad Pro V8i software. The projection cost of the bamboo chalet in the next 25 years is studied comparatively in which involves a comparison of using a different material, i.e. concrete with the same built-up area. The bamboo chalet had a built-up land area of approximately 7.5 m x 7 m (53 m^2) and is made of 95% bamboo which comprises of two different species, i.e. Bambusa Vulgaris and Dendrocalamus Asper Bamboo. The results showed that construction material of the chalet saves up to 18% more when using bamboo compared to concrete. However, the total projected cost of the chalet for the next 25 years by using bamboo was 14% higher compared to concrete. Therefore, emphasis on the usage of bamboo for long-term strategy is required to maintain and control the gradual trend cost incurred if green building is to be built in Malaysia.

1 Introduction

Ever-since 1991, sustainable development, has been Malaysia's national focal point, with the aim to promote green growth technology and renewable energy by encouraging energy efficiencies in buildings, industries and households. Moreover, with the substantial spurs on the green business, demand from the industrial regulations and economic climate have indirectly caused tremendous progress towards its vision [1].

Issues on the environmental degradation and sophisticated recycling systems, that is caused by varieties of waste management that tumble into rivers, has won researchers attention and hence encourages more researchers to focus on eco-friendly construction materials [2-4].

In line with the Malaysia's vision, one of the objectives of this paper is to estimate the actual total cost of utilising a type of non-conventional material namely bamboo as the main construction material for a small structure (such as chalet). More importantly, the main purpose of this paper is to evaluate the cost effectiveness of using this material over the whole life cycle of the structure and compare it with conventional material, thus giving a better picture to designers and engineers in applying such material as the main construction material.

Therefore, in this project, the estimated construction cost, projected maintenance cost and overall life cycle cost of an eco-budget chalet with bamboo as the main construction material was compared with the same chalet design but different main construction material which is reinforced concrete. Beforehand, an investigation on the mechanical properties of the two different types of bamboo available in Malaysia was conducted to obtain its compression and bending strengths. These properties including others which were obtained through literature review (Young's Modulus and Poisson's ratio) were then used in conducting structural analysis of bamboo-based and reinforced concrete-based chalet structure using Staad Pro V8i. After both structures have been validated, the estimation cost of construction, cost of current annual maintenance practices, and the life cycle cost projection were calculated and compared.

* Corresponding author: hazrina.uitm@gmail.com

1.1 Bamboo as main construction material

Bamboo are the fastest growing woody plants in the world. There are over 1600 species of bamboo found in diverse climates from cold mountains to hot tropical regions mostly covered area in Asia about 40 million hectares [5]. Therefore, in Asia, bamboo has been intensively used as a structural element in construction especially during the era of pre-industrial architecture. This can be contributed to its prevalent availability in tropical climate region, fast growth and maturing rate and the combination of low specific weight with high mechanical strength. Despite its common use and huge potential, industry standardization and common construction practice are still lacking.

Bamboos are the perpetual form of structure, depends on species; their physical and mechanical properties are different into one and another. It has been reported that the diameter, the thickness of the bamboo culm is varying throughout the length of the bamboo culm. Also, the density of the bamboo fibres is higher when it approaches the external shell, and this is due to the high forces (i.e. wind) acting on the bamboo surface [6].

The durability of bamboo as a structural material is considered relatively low, as it is easily decomposed by microorganisms like a termite, fungi, bacteria, etc. Therefore, to extend the service life of the bamboo, the bamboo pole itself need to persevere. The most common practice is to soak the bamboo poles with a mixture of 10% of boron, 50% of borax and 10% of boric acid with a ratio of 1:5:1. It is reported that this technique can enhance the service life of bamboo up to more than 50 years as the bamboo fibres is being replaced with a significant amount of natural sugars with salts [7].

2 Physical and mechanical properties of bamboo

2.1 Types and sources of bamboo

There are two types of bamboo identified to be used in this project namely Bambusa Vulgaris and Dendrocalamus Asper. Bambusa Vulgaris or so called “Buluh Minyak” or “Buluh Aro” is one of the 45 species of bamboo found in Peninsular Malaysia. It is classified as perennial woody grass. It is quite common to be used in rural areas within Malaysia as it can grow in most places especially near river banks. Furthermore, this type of bamboo has a fast growth rate and mature very quickly when it is 6 months old culms. Due to its material and physical characteristics, it is widely used for lightweight construction such as window and door panels, furniture and louvres [8].

The second species of bamboo that was utilised in this study is Dendrocalamus Asper. Its species is native in South-East Asia and usually better known as giant bamboo in Malaysia. Like Bambusa Vulgaris, this bamboo species can grow on many soil types, especially if it is well drained. It is also considered as a clumping bamboo, therefore it does not grow laterally and considered to be not invasive. Due to its characteristics, it is mainly used for heavy construction as a building material for houses and bridges [9].

Several simple tests were also conducted to obtain specific mechanical properties of these bamboo species such as compression and bending tests. Furthermore, the average density and moisture content of the bamboo were also measured. In preparation for the tests, specimens of each type of bamboo were obtained from the northern Malaysia and supplied by a company in Malaysia. The specifications of the bamboo specimen used in the tests for each type are indicated in Table 1.

Table 1. Bamboo specimens for testing.

Type	Treatment	Parts of Bamboo Culm	No. of Specimens
Bambusa Vulgaris	Dry	Top	3
		Middle	3
		Bottom	3
	Dry and treated	Top	3
		Middle	3
		Bottom	3
Dendrocalamus Asper	Dry	Top	3
		Middle	3
		Bottom	3
	Dry and treated	Top	3
		Middle	3
		Bottom	3

2.2 Compression and bending strengths

In this compression test as shown in Figure 1, it has been found that the compression strength of the bamboo varied significantly with culm location (top, middle and bottom). Compression stress parallel to grain increased gradually towards the bottom of the bamboo culm. The test results show that compressive strength for the dry and treated Dendrocalamus Asper is higher followed by dry and treated Bambusa Vulgaris within range of 24.13 kN/m^2 to 32.57 kN/m^2 and 11.01 kN/m^2 to 21.06 kN/m^2 respectively. Figure 2 and Figure 3 show the strength trend pattern for both species respectively while Figure 4 shows the failure pattern of the specimen.

Fig. 1. The arrangement of compression test.

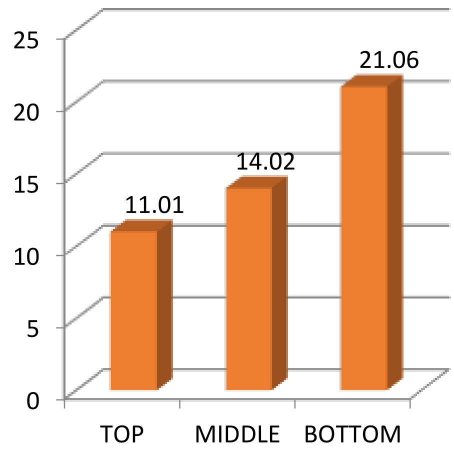


Fig. 2. Average compressive strength of Bambusa Vulgaris, kPa

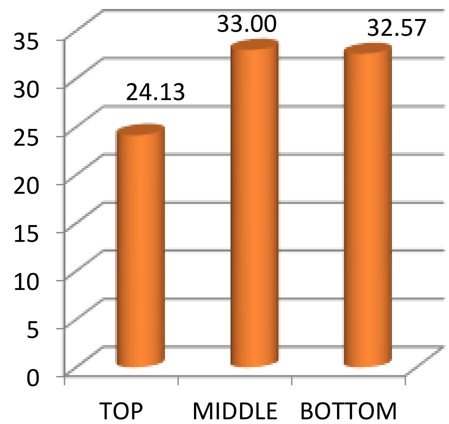


Fig. 3. Average compressive strength of Dendrocalamus Asper kPa

Fig. 4. The failure pattern of the specimens in compression test.

As shown in Figure 5, both types of bamboo (i.e. Bambusa Vulgaris and Dendrocalamus Asper) were prepared where their samples of 550 mm span length were loaded for three points bending test. Figure 6 and 7 show the results of the test for both species of bamboo under different moisture contents and thickness. It can be concluded from the charts that Dendrocalamus Asper has higher bending strength than Bambusa Vulgaris with the range of 30.07 kN/m^2 to 33.98 kN/m^2 and 15.64 kN/m^2 to 17.53 kN/m^2 respectively.

Fig. 5. The arrangement for bending test

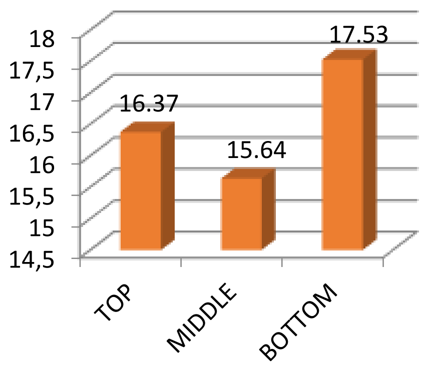


Fig. 6. Average bending strength of Bambusa Vulgaris, kPa

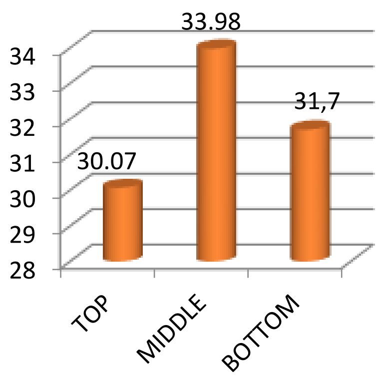


Fig. 7. Average bending strength of Dendrocalamus Asper, kPa

2.3 Density and moisture content

Table 2 shows the results of the density measurement for both types of bamboo at different culm locations. It can be concluded that Dendrocalamus Asper (DA) bamboo has in average higher density compared to Bambusa Vulgaris (BV) and in both cases, the bamboo density increases towards the bottom of the bamboo culm. Since treated bamboo is used in construction, it has been found that the density of dry and treated Dendrocalamus Asper is within the range of 821.23 kg/m^3 to 1299.78 kg/m^3 and for the dry and treated Bambusa Vulgaris is within 743.68 kg/m^3 to 1052.82 kg/m^3.

Table 3 provide the measurement results of the moisture content for both species of bamboo. From the results, there is an increase of moisture content towards the bottom of the bamboo culm. Results for the moisture content are given in Table 3 where the moisture content is constantly increased towards the bottom of the culm. For dry and treated Bambusa Vulgaris, the average moisture content was within 20.4% to 30.78% while for the dry and treated Dendrocalamus Asper was within 31.57% to 43.32%.

Table 2. Density of the bamboo specimens (kg/m^3).

Type of Bamboo	Top	Middle	Bottom
Dry BV	764.77	777.48	629.60
Dry And Treated BV	743.68	878.51	1052.82
Dry DA	785.85	815.75	1223.71
Dry And Treated DA	821.23	915.30	1299.78

Table 3. Moisture content of the bamboo specimens (%).

Type of Bamboo	Top	Middle	Bottom
Dry BV	24.01	30.05	33.40
Dry And Treated BV	20.40	24.10	30.78
Dry DA	31.27	35.90	38.20
Dry And Treated DA	31.57	36.12	43.32

3 Design of the mock-up unit of eco budget chalet

3.1 Structural design

The structural design of the eco budget chalet was based on the concepts of "Compact, Simple, Complete". Its main characteristic is an occupant controllable rotating platform that allows for a 360° view of the outside environment. Furthermore, the chalet offers an adequate circulation spaces for the occupant to perform all activities with minimum effect on the stability of the chalet structure.

This eco budget chalet is designed for an approximately total area of 7m x 7.5m. The floor view, front plan and side view of the model can be seen in Figure 8 (at the end of the paper). The proposed project is modelled by using Staad Pro V8i for the structure (bamboo and reinforced concrete) analysis. Any failures in the elements during the structural analysis are adjusted accordingly to ensure the chalet will be structurally stable. Shear forces, bending moment and stresses for both structures are identified and validated by using manual calculation.

It is well known that sizes for bamboo are slightly different and will not be the same for the same type. Bamboo has unequal inner and outer diameter of the culm as well as the thickness. Therefore, in this analysis the diameter for the bamboo material is assigned to an average value. Section properties details for bamboo and reinforced concrete structure are listed in Table 4 and Table 5.

Table 4. Section properties details for bamboo structure

No	Section		Materials
1	Floor and Verandah	12 mm thickness	Bambusa Vulgaris
2	Roof	10 mm thickness	Bambusa Vulgaris
3	Wall and Shear Wall	75 mm thickness	Bambusa Vulgaris
4	Column	125 mm diameter in tube	Dendrocalamus Asper
5	Roof Trusses	80 mm diameter in tube	Dendrocalamus Asper

Table 5. Section properties details for reinforced concrete structure

No	Section		Materials
1	Floor and Verandah	200 mm thickness	Concrete
2	Roof	5 mm thickness	Steel
3	Wall and Shear Wall	300 mm thickness	Concrete
4	Column	125 mm diameter	Concrete
5	Roof Trusses	TUB20202.0	Steel

3.2 Structural modelling

Both bamboo-based structure and reinforced concrete-based structure were modelled and analysed using Staad Pro V8i software. General steps of developing model in this software are as follows

1. Data preparation
2. Geometry input
3. Properties input
4. Specifications, constant and supports input
5. Loading system input
6. Analysis type selection
7. Analysis execution
8. Results

Any type of structure is subjected to basically two types of loadings. In this research, model is subjected to self-weight and imposed loading. The load shall be based on EN 1991-1-1 for the reinforced concrete structure and ISO 22157 for the bamboo structure. The imposed load will be assigned and distributed uniformly on top of the slab with plate pressure of 2 kN/m^2 and on top of roof with plate pressure of 1 kN/m^2.In Table 6, a summary of the analysis results in terms of maximum displacement, maximum shear force and maximum bending moment is presented for both bamboo-based and reinforced concrete-based chalets.

Table 6. Summary output from Staad Pro

Result	Bamboo	Reinforced concrete
Maximum displacement	0.0594m (Node 45)	0.024 mm (Node 45)
Maximum shear force	34.21 kN (Beam 65)	18.7 kN (Beam 49, 50)
Maximum bending moment	43 kNm (Beam 49)	43.59 kNm (Beam 49)

4 Estimation of life cycle cost

At this stage, an approximation of the total project cost (i.e. construction cost, maintenance cost and life-cycle cost) to build the bamboo chalet with two differences of construction materials (i.e. bamboo and concrete) were calculated. It is highlighted that; the cost estimation was calculated based on the supplier's quotations.

$$Life\ cycle\ cost = Construction\ cost + \sum_{1}^{n} Maintenance\ cost$$

4.1 Estimation of construction cost

Table 7 (given at the end of the paper) provides the detailed bill of quantity for both structures. From this detailed information, it is then possible to calculate the percentage difference in total construction cost and it can be concluded that the bamboo structure can be constructed with about 18% cheaper that reinforced concrete structure.

4.2 Estimation of annual rehabilitation and maintenance

Following are the maintenance cost covered under the periodical inspections for both structures;

Chalet constructed from bamboo structure

- Crack repair
- Replacement of rotting or damage parts
- Tightening of bamboo joint connection
- Surface treatment for fungus or termite attacks

Noted: Only 3% of the above total cost will be considered for annual overall construction cost.

Chalet constructed from reinforced concrete structure

- Cracking/ expansion joint (every 5 years)
- Exterior repainting (every 10 years)
- Re-roofing (concrete roof tiles to be fixed at 23^0 to on battens

It should be noted that the annual operation or rehabilitation and maintenance costs are increased based on average inflation rate of Malaysia. In this study, inflation rate of 3% is used to estimate the projected cost for cost life cycle.

4.3 Forecast of life cycle cost

The comparison of the projected life-cycle cost analysis on the annual maintenance practices for the proposed chalet if it were made up from bamboo and reinforced concrete structure is shown in Figure 9. From the Figure 9, the maintenance cost for the bamboo structure is exponentially increasing along the time while the chart pattern for the reinforced concrete structure is stagnant with significant peaks at the 10^{th} and the 20^{th} years of its service life. It is evident that the total projected cost (i.e. addition of the construction cost and maintenance cost) for bamboo and reinforced concrete are RM 69,855.37 and RM 59,712.90 respectively, hence in total resulted in 14% differences in the projection costs.

5 Conclusion

The main goal of this experimental study was to appraise the construction of cost-effective between bamboo and reinforced concrete by using life cycle cost method. The study also investigated the element that will be used in the proposed structure i.e. beam, column, flooring system, roofing system and wall. Investigation on the compression and bending strength of clear bamboo internode specimens taken from the bamboo culm was also conducted. Using Staad Pro V8i software for structural analysis, the designed chalets with the main material of bamboo or reinforced concrete were analyzed. The following conclusions are drawn from the results obtained:

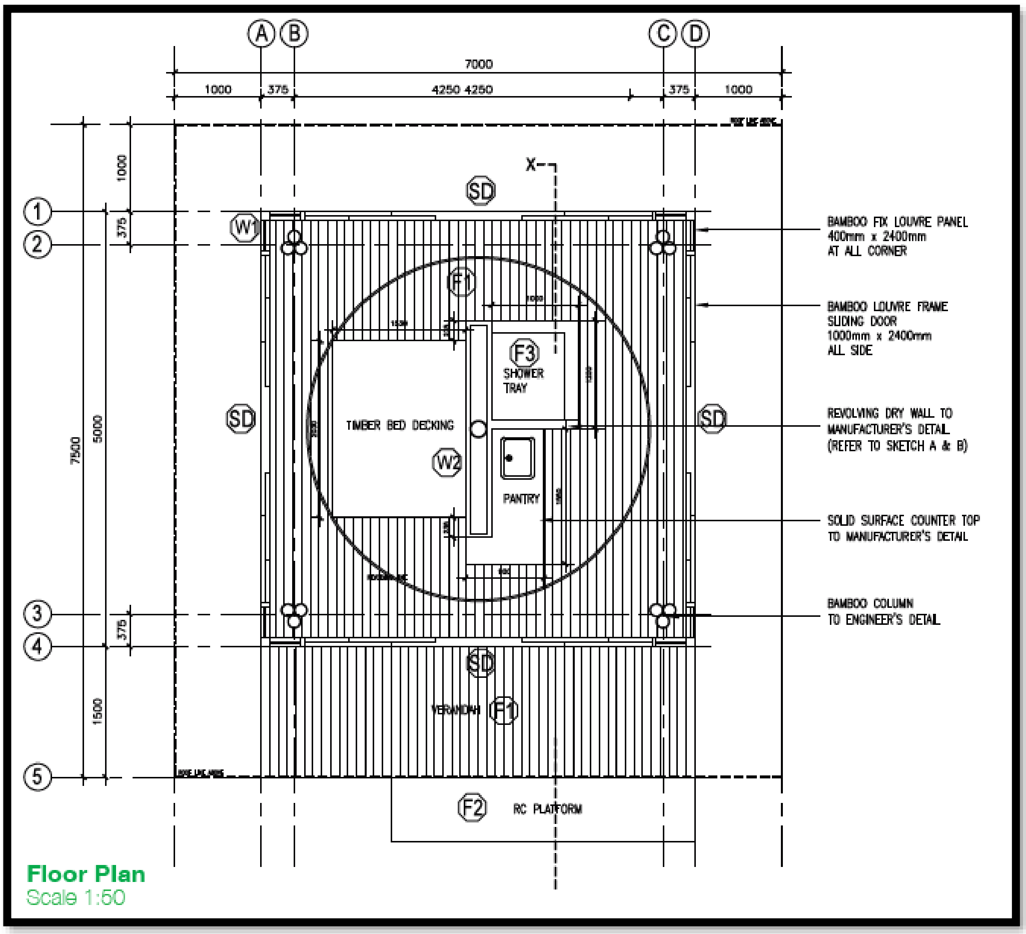
1. It can be concluded that the bending and compressive strengths of the Dendrocalamus Asper bamboo is higher when compared to the strength of the Bambusa Vulgaris respectively.
2. The bending and compressive strengths of both Dendrocalamus Asper bamboo and Bambusa Vulgaris are increases from top to the bottom culm.
3. The construction cost of the proposed chalet is 18% cheaper if bamboo is to be used as the primary construction materials compared to the reinforced concrete structure.
4. It was estimated that the projected cost for the chalet if it is build using bamboo, is 14% higher than reinforced concrete structure. This is due to the factor that bamboo is prone to biodegradation due to its service life.

A major question remains to be answered, i.e. whether the idea of increased utilization of bamboo as the construction material is warranted as it is highly degradable if not treated and its suitability in hot and humid weather in Malaysia. This study concludes that the construction cost of a chalet using bamboo is cheaper compared that using reinforced concrete as its main construction material. The main reasons are the cheap availability of bamboo, and the construction process does not require a high number of workers and technology. However, in term of maintenance cost, the use of bamboo will incur more cost compared to reinforced concrete. It also suggested that the future work in this area will look at the cost factor analysis that considering other techniques apart from maintenance such as rebuilding a new structure that may incur less cost compared that keep on maintaining the old structure.

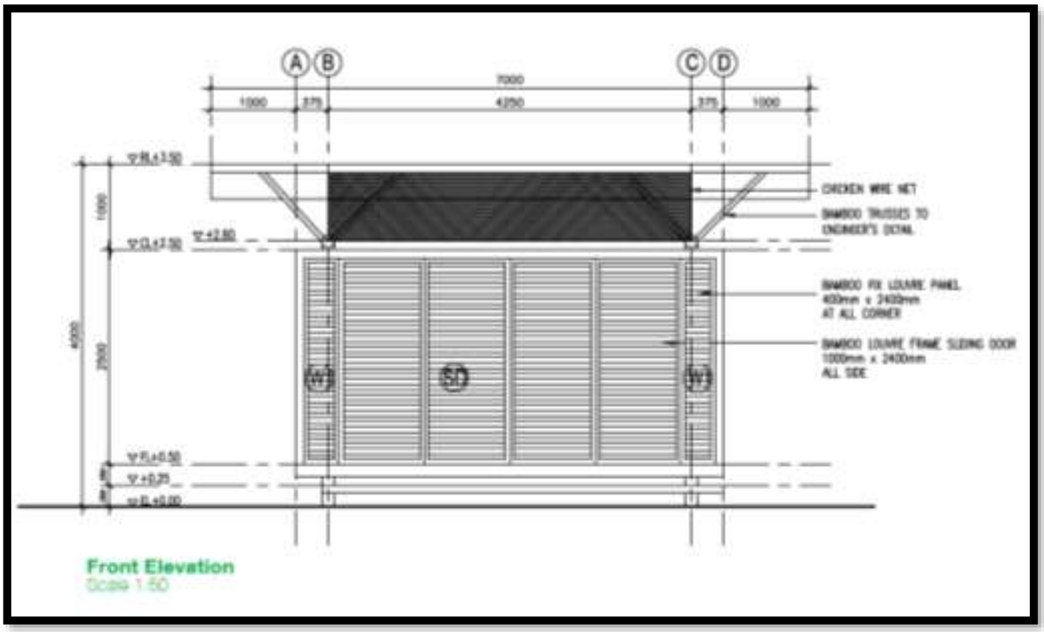
References

1. G. D. Soni, Social Issues and Environmental Problems, (2015)
2. D. O. Mbuge, Mechanical Properties of Bamboo (Balbusan Vulgaris) Grown in Muguga, Kenya. Nairobi: Bast Africana Collection, (2000).
3. A. Olufemi, Comparison of Bamboo and Conventional Building Materilas for Low-Cost Classroom Construction in Isarun, Nigeria. Federal University of Technology, Akure, 1-8 (2014).
4. B. Sompoh, Physical and Mechanical Properties of Some Thai Bamboos for House Constrcution. Bangkok Forest Research and Development Bureau, Royal Forest Department (2013).
5. Institute of Tropical Forestry and Forest Products. BAMBOO WORLD. Centre of R&D in Tropical Biocomposite and Forest Canopy Management (p. Issue 7 (2012).
6. K. Ghavami, Discussion 'Bamboo Structures in Colombia by David'. The Structural Engineer, 7-8 (2007).
7. S. Schroder, General Properties of Bamboo and Maintenance Tips. Available from Bamboo Import Europe:https://www.bambooimport.com/en/blog/properties-of-bamboo-and-maintenance-tips (Accessed on 2016).
8. J. Kasim, Bambusa Vulgaris for Urea and Cement-Bonded Particleboard Manufacture. Journal of Tropical Forest Science **4**, 249-256, (1991).
9. S. Schroder, Dendrocalamus Asper. Available from GUADUA BAMBOO: http://www.guaduabamboo.com/species/dendrocalamus-asper?format=amp (Accessed on 25 January 2010)

 https://doi.org/10.1051/matecconf/201925801010

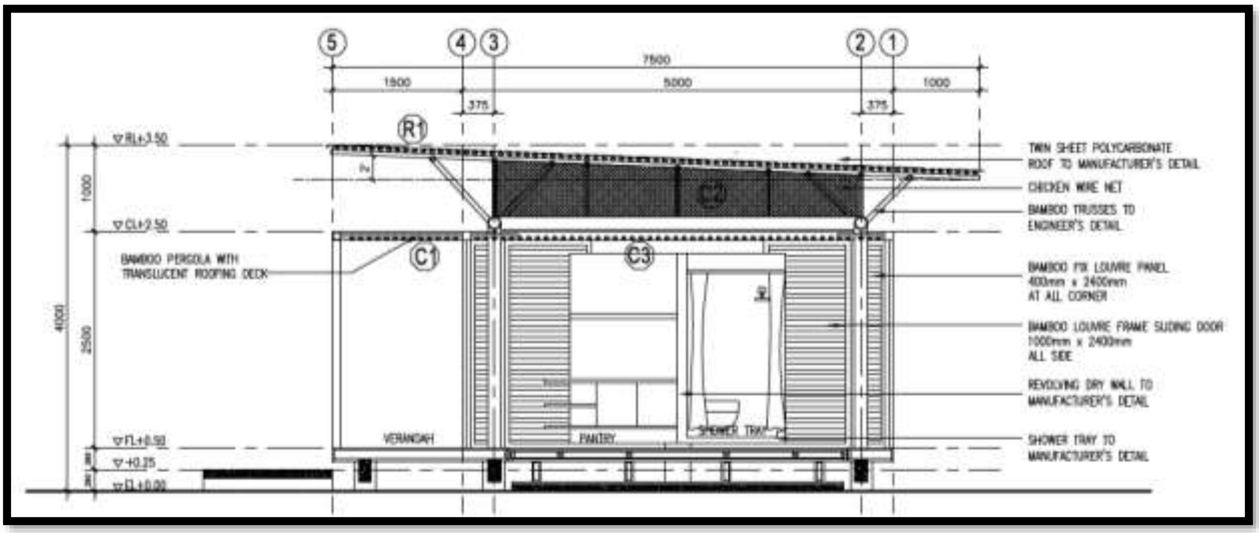


(a)



(b)

 https://doi.org/10.1051/matecconf/201925801010



(c)

Fig. 8 (a) Floor view (b) front plan (c) side view of the model.

Table 7. Bill of quantity for both structures

Description	Item	Amount (RM)	
		Bamboo	Reinforced concrete
1	WORK BELOW LOWEST FLOOR LEVEL	16054.22	12,040.99
2	EXTERNAL WALLS	5000.00	182.67
3	ROOF AND RAINWATER DOWN GOODS	8697.50	6,960.11
4	DOORS & WINDOWS	255.00	11,112.00
5	COLUMN	4815.00	462.00
6	WALL FINISHES	0.00	260.68
7	FLOOR FINISHES	0.00	3,913.38
8	CEILING FINISHES	0.00	233.75
9	COLD WATER AND SANITARY WARES, PIPES AND FITTINGS	9492.00	9,512.00
10	SANITARY PLUMBING INSTALLATION	0.00	3,525.00
11	PAINTING	0.00	45.47
12	ELECTRICAL WORKS	301.00	5,060.00
13	TRANSPORTATION	1450.00	2,900.00
14	MISCELLANEOUS	225.00	225.00
	Total Amount for 1 Unit:	**RM 46289.72**	**RM 56433.05**
	Difference in Construction Cost	**RM10143.33**	
	Percentage of Difference	**17.97%**	

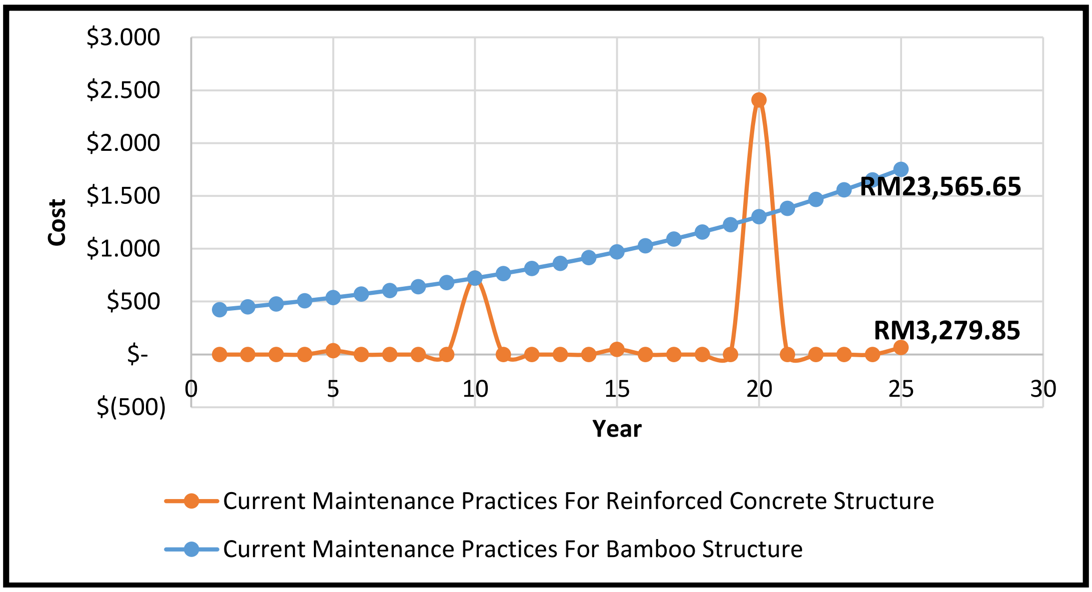


Fig. 9. Life cycle cost analysis of reinforced concrete structure and bamboo structure.