# Preliminary Study on the Manufacture of Bamboo Panel Components for Prefabricated House

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# 1. Introduction

Bamboo is a fast growing renewable resource. Compared with wood, bamboo has higher strength/ weight ratio and can be a good substitute for wood.

Bamboo has long been used as building materials for both structural and decorative uses, mainly in culm forms .

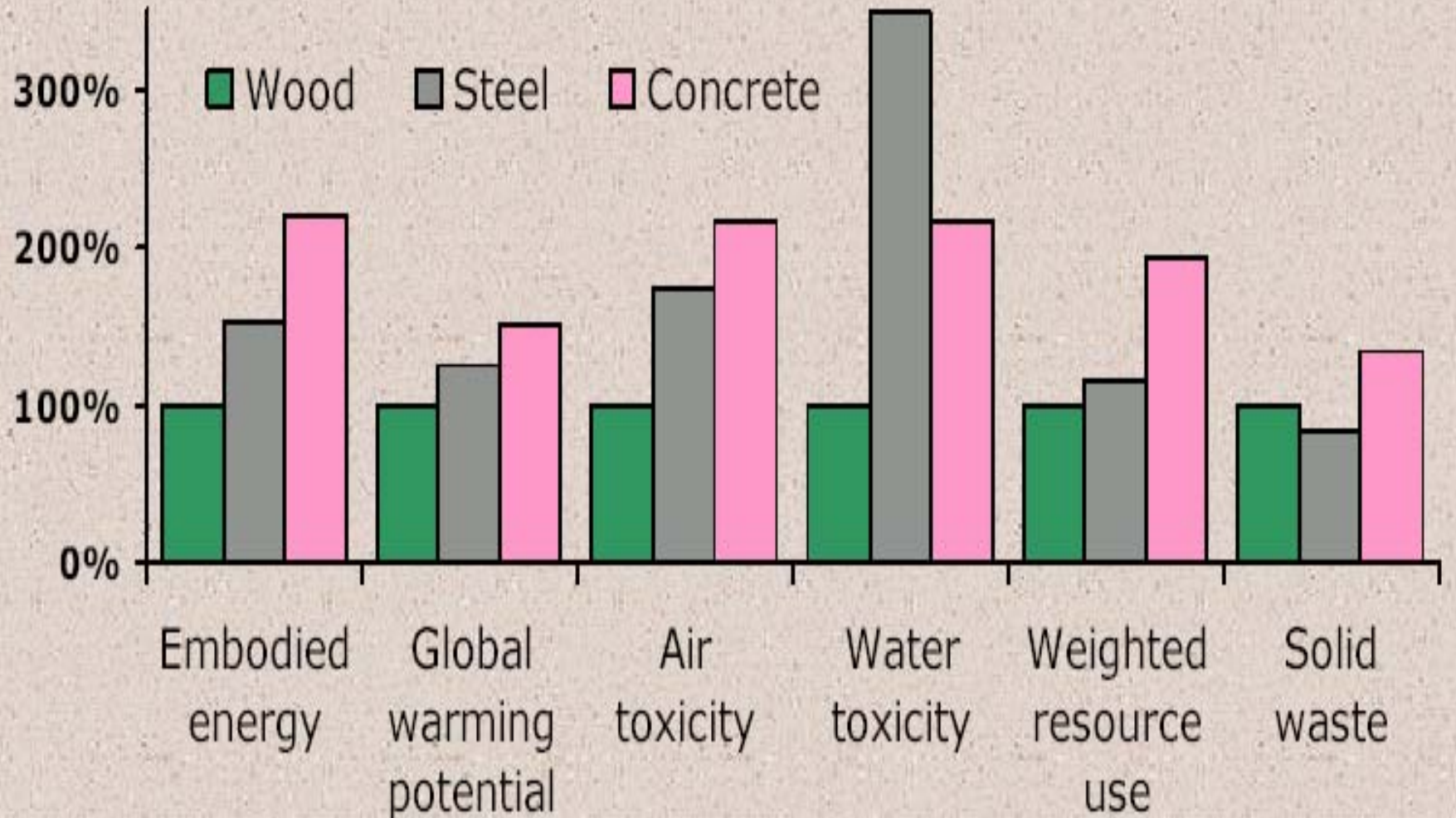
- There is a big potential for bamboo based panels to be used as engineered building materials with good and stable strength and structural properties from a renewable resources.

- In addition, using bamboo in construction may not only contribute to a more sustainable construction industry and environment, but also benefit local farmers and economy.

# Advantages of wood /bamboo materials

- 木材质轻、高强、美观，加工容易，加工能耗小，是当今世界四大材（钢材、水泥、木材、塑料）中唯一可再生、再循环利用和可自然降解的绿色材料和生物资源。
- 生产类似产品，木材产品的能耗为钢产品的１／９；铝产品的１／４；混凝土产品的１／２２

# Environmental impact relative to a typical wood frame house. *Wood outperforms other materials in most cases.*



- The role of use in wood/bamboo products in the mitigation of climate change is a case in point as they serve as carbon sinks during their entire service life.

- It has been estimated that if wood consumption in Europe annually increases by 4% , an additional 150 million tones of $CO_2$ would be sequestered in wood products per year, and the market value of this environmental service would be about EUR 1.8 billion/year.

- INBAR and WWF China jointly launched a Green Building Project in 2002 to integrate energy efficient building design with the use of bamboo panels as engineered building materials.

  With technical support of BEAR Architecten (Holland), Yunan Urban & Rural Planning & Design Institute and CAF, the Pingbian Primary School building was constructed in 2004, where bamboo plywood panels and bamboo laminated beams were used for roof trusses, sheathing boards and wall panels. This is the first time bamboo-based panels used for structural applications in China.

Bamboo plywood panels /laminated beams used for roof trusses, sheathing boards and wall panels at Pingbian Primary School

In late 2004 INBAR and The Nature Conservancy (TNC) signed a MOU on Project *"Promotion and Commercialization of Bamboo Building Materials"* **to** enhance the use of bamboo as an alternative to building/structural materials such as wood and steel by business demonstrations.

It was decided under the project to organize this Workshop to :

- explore potential of use of bamboo panels as a valuable construction material both for developing and developed construction markets
- demonstrate a module house from bamboo-based panels primarily for the relief from the global emergency situations and other urgent uses & identify R & D needs for future improvement
- develop partnership and draft a program focus on the pack-flat bamboo panel module housing

This presentation summarizes the major outcomes of the study on the manufacture of bamboo panel wall/roof components for pack-flat prefabricated module houses for the emergency relief and temporary use targeting mostly disastrous areas and developing markets.

- In July 2005,INBAR singed a MOU with CAF, Fustar Co., and Beijing Chengdong Co. on the construction of a demonstration pack-flat bamboo panel prefabricated module houses and the house was completed in late Oct 2005.

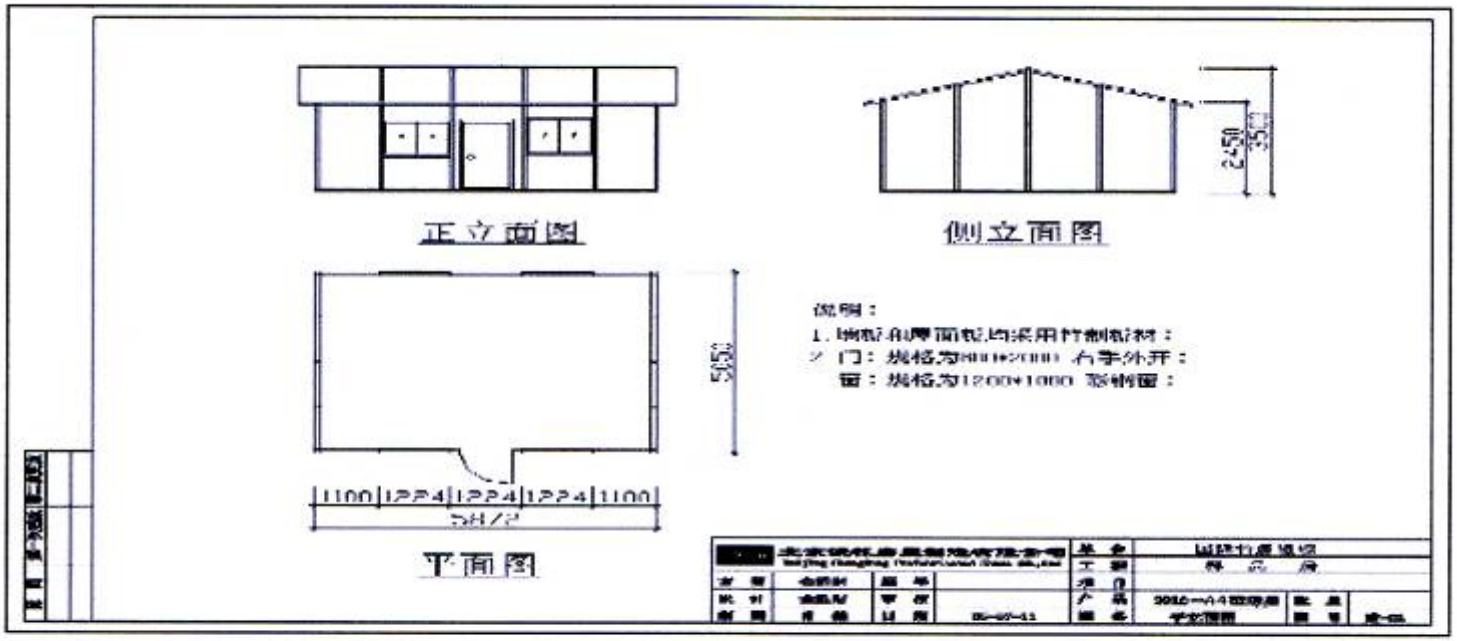



Fig.2 Demonstration bamboo panel module prefabricated house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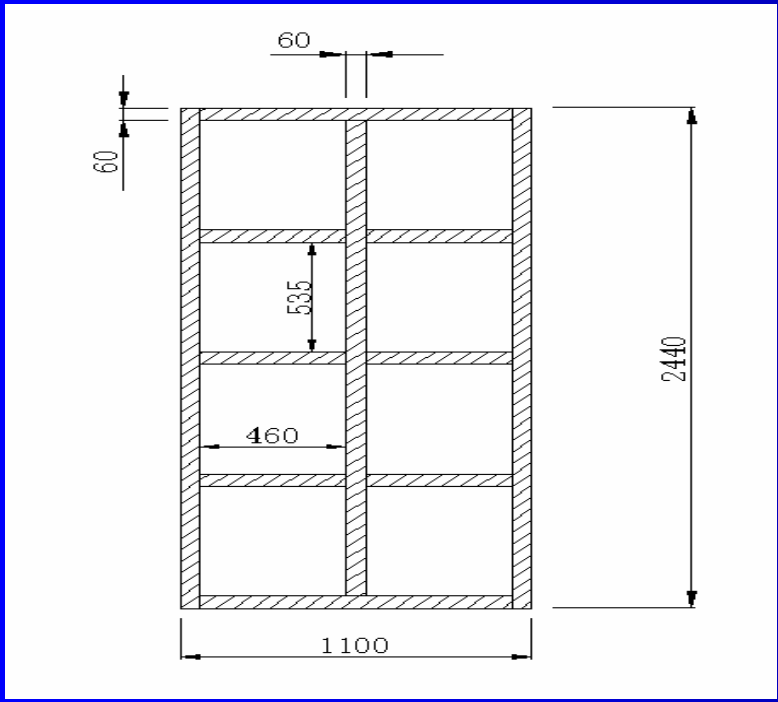
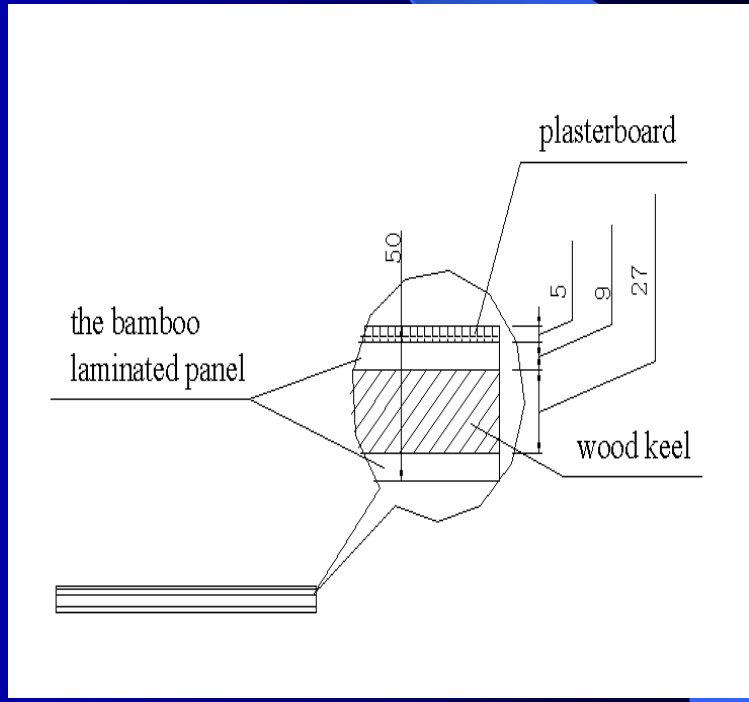
# 2. Manufacture of bamboo panel components

The structure of bamboo panel components for walls and roof are basic the same, as shown below. All bamboo panel wall and roof components in this study were made at Fustar Company.



## 2.1 Manufacture of bamboo plywood panel

The major process include:

- Cross cutting bamboo culms to desired length
- Cutting into long pieces and scraping nodes and removing both outer surface and inner surface and converting into slivers of 0.5~0.8 mm thickness and 20~30 mm width;
- Weaving slivers into curtains/mats;
- Air drying curtains/mats to 10~12% moisture content (m.c.);
- Dipping into 37% PF glue at a rate about 200 g/$m^2$;

- Drying the glued curtains/mats to 10-15% m.c;
- Assembling the curtains crossed with the adjacent layers, and the whole assembly is faced with one mat each at the top and bottom.
- Hot pressing at 130～140 ℃, for 1.5~2 min/mm, under 3-3.5 MPa.
- Trimming.

The final dimension of bamboo plywood panel is 122 cm×244 cm× 0.9cm.

cross cutting

splitting / nodes removing

Converting into slivers

(0.5~0.8 mm thick & 20~30mm in width, with outer/inner surfaces removed

Weaving slivers into curtains

Pre-drying curtains to 10~12% moisture content

Dipping into 37% PF glue (about 200 g/m$^2$ )

| | |
|---|---|
| 1 | 2 |
| | 3 |

1. glued curtain drying
2. Dried glued curtains
3. Curtain Assembling

| | |
|---|---|
| 1 | 2 |
| | 3 |

1. Hot pressing
2. Bamboo plywood
3. Trimming

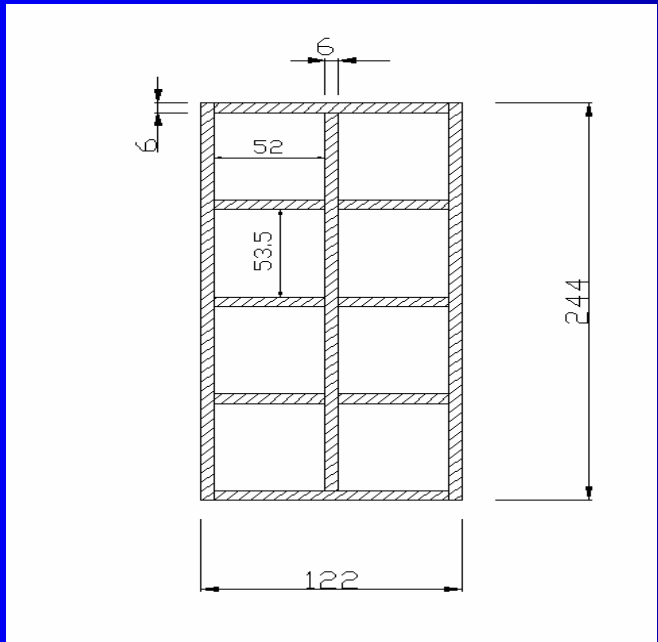
**Table 1 Physical and mechanical properties of bamboo plywood panel**

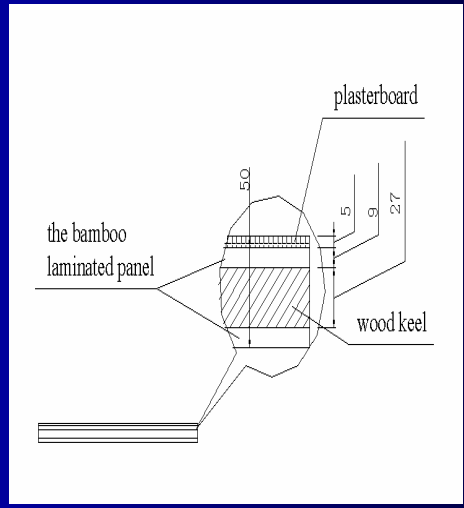
| Density g/cm3 | Thickness swelling (%) | | MOR MPa | MOE GPa | Compression Strength MPa |
|---|---|---|---|---|---|
| | 24h Cold water | 2h Boiling water | | | |
| 1.00 | 2.5 | 17.1 | 135.78 | 10.50 | 71.99 |

- Table 1 shows that MOR / MOE of the panel are higher than that of OSB (22Mpa/3.5 Gpa) (BS EN 300:1997, Load bearing boards for use in humid conditions)

# 2.2 Assembling bamboo panel components

- Preparing wooden frame(122×244X 2.7cm) by sawing/planning/cutting nailing, as indicated below.
- Assembling two bamboo plywood panels with one wooden frame as a core by gluing and nailing.
- Surfacing a gypsum board (122×244×0.5cm)by gluing and nailing.
- The final dimension of the bamboo panel component is 122×244×5 cm.



Assembling two bamboo plywood panels with a wooden frame by /nailing

| | |
|---|---|
| 1 | 2 |
| | 3 |

1-2 Surfacing a gypsum board (by gluing / nailing

3. Bamboo wall panel component

# 3 Testing properties of bamboo panel components

According to relevant Chinese National standards, the following properties are tested at the National Center for Quality Supervision and Test of Building Engineering

- Sound insulation
- Thermal transmission
- Fire-resistance

# 3.1 Sound insulation

- Chinese National Standard GBJ75-84“Code for measurement of building sound insulation” is used.
- The size of the testing sample of panel component is 2.44m × 4m × 5cm, composed with one wooden frame in same size and 4 pieces of bamboo based wall panels of 2.44m × 1m.
- The testing result of sound insulation of the panel component is 32db.

| | |
|---|---|
| 1 | 2 |
| | 3 |

1. testing sample

2. Sound wave receiving device

3. Sound insulation meter

## 3.2 Thermal transmission

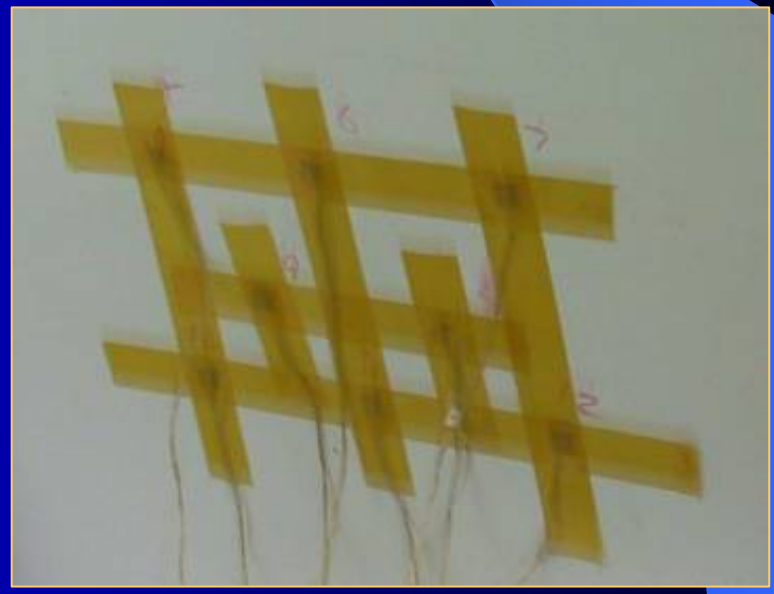
- Chinese National Standard GB/T 13475-92 “Building element-Determination of steady-state thermal transmission properties-Calibrated and guarded hot box” is used.
- The sample size of panel component is 1m × 1m.
- Testing results: thermal resistance 0.29$m^2$.K/W, thermal transmission coefficient 2.3W/$m^2$.K.

**Thermal transmission Device**

L: front view

R: side view

| | |
|---|---|
| 1 | 2 |
| | 3 |



# Thermal transmission Testing

## 3. 3 Fire resistance

- Chinese National Standard GB/T9978-1999 “Fire-resistance tests- Elements of building construction” is used.
- Composed with three pieces of panel components of 2.50m × 1.1m, the size of the testing sample of panel component is 2.5m × 3.3m × 5cm.
- The Fire-resistance limit tested is20 min.

左上图：垂直构件耐火试验炉

右上图：耐火试验炉喷火装置

右下图：试件安装

左上图：墙体开始燃烧

右上图：墙体燃烧中

右下图：墙体最终状况

## 3.4 Assessment of properties of bamboo panel component

According to Chinese National Standard GB/T15225-94“Graduation of physical performance for building curtain walls”, the testing results show that the sound insulation of the bamboo panel component reaches Class III, and the thermal insulation reaches Class IV, and both have met the requirements of performance for building wall materials.

- According to GBJ16-2001Chinese Building Industry Standard “Code for fire protection design of buildings", fire resistance performance of the bamboo panel component is higher than Class IV for non loading wall, partitions for escape passage and rooms.

- Further study and improvements may be needed, if the bamboo panel components are to be used for residential applications.

# 4 Erection of bamboo panel prefabricated house.

By using screws and steel connectors, the bamboo panel components were fixed with light steel frames and assembled into panel prefabricated house at Beijing Chang Dong Prefabricated House Co in late October 2005.

| | |
|---|---|
| 1 | 2 |
| | 3 |

1. Light steel frame parts

2.Bamboo panel components

3. screws, metal connectors, glue tapes

左上图：将轻钢骨架
固定在地面上

右上图：螺栓固定

右下图：墙体门窗安装

左上图：墙体的工字槽对接

右上图：屋梁与墙体连接

右下图：檩条安装

左上图：屋顶板安装

右上图：屋顶板的固定和密封

右下图：室内情况

# 5. Cost analysis of bamboo panel components

Building area of house : 30 m2

total bamboo panels used for roof and walls : 220 m2.

**Table 2 Cost of bamboo panel components**

| Items | Unite price (Yuan/$m^2$) | Subtotal (Yuan) | Remarks |
|---|---|---|---|
| Bamboo panels (9 mm) | 40 | 8800 | Double faces |
| Wooden frame (40×60mm) | 4 | 880 | 5 meters is used for per $m^2$ panel wall |
| Adhesives, coatings | 22 | 4840 | Including fire resistant coating for inner wall, water resistant coating for exterior wall, etc. |
| Gypsum board | 10 | 100 | |
| Wood processing | 5 | 1100 | |
| Painting | 18 | 3960 | |
| Total | 139 | 19680 | Including test specimens. Total net areas of roof/wall panel components is 91.75$m^2$ |

It is estimated that in future production, the unite price of bamboo panel components could be reduce to about 70 yuan/$m^2$, by

- reducing the thickness of bamboo plywood panel form 9mm to about 4 mm;
- improving processing efficiency.

# 6. Conclusions

- Bamboo panel wall & roof components can be used for pack-flat prefabricated module houses for the emergency relief and temporary use .They can be feasible in technical/economical/environmental aspects.
- Fast erection, easy for assembly/storage /transportation
- Further study is needed to further improve design/performance of the bamboo panel components.


Thank you !
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