COST-EFFECTIVE COMPOSITE BUILDING PANELS FOR WALLS AND CEILINGS IN NIGERIA

Y.M.D ADEDEJI AND B. AJAYI

Department of Architecture, Federal University of Technology, Akure, Nigeria

and

Department of Forestry and Wood Technology, Federal University of Technology, Akure, Nigeria

ABSTRACT

This paper explores the possibility of using cement-fibres composite panels made of cement reinforced with palm kernel shaft, a by-product of oil palm for cost-efficient and low-cost building panels for walls and ceilings. Empirical surveys carried out among some practising professionals in the building industry (Architects, Engineers, Quantity Surveyors, Builders and Contractors) from selected cities in Nigeria with a view to measure time, labour and cost expended on the two types of masonries investigated were analysed. Besides, moisture absorption, thickness swelling, linear expansion and aesthetical satisfaction of the material were tested. Data from the field survey on 10 buildings shows that cement-bonded composite panels are comparatively cheaper, sound-proof, durable, lighter-weight and environmentally friendly than the conventional sandcrete blocks and asbestos ceiling board.

KEYWORDS

Cost-effective; composite; building panels; walls; ceilings.

INTRODUCTION

Construction industry is one of the most in important sector in a developing economy like that of Nigeria. The construction industry has real and potential adverse effects on the environment in many developing nations. The construction industry in general and the building sector in particular contribute to the degradation of the environment through the deforestation of the natural resources, energy consumption, atmospheric pollution and wastes generation. Globally, building construction is responsible for the current consumption of 25% of wood and 40% of aggregates, 16% of water and 40% of the energy annually spent (Braganca *et al.,* 2002). To this end no nation of the world can be indifferent to this challenge and allow the housing sector of its economy to develop haphazardly. It is however observed also that the rising cost of building construction in Nigeria can be attributed to some other factors, which include high transportation cost, devaluation of national currency (Naira), uncontrollable prices of building materials and particularly, the inability of production companies to meet high demand for building materials and the over dependency on the importation of building materials (Fasakin and Ogunsemi, 2003). Locally sourced building materials in Nigeria, which would have facilitated sustainable development, remain underdeveloped to a socially and economically acceptable level owing to the low level of development of the economy (Adedeji, 2007).

Recently, in the most developed countries, it has been verified that the traditional and conventional technologies used for construction and maintenance of buildings are inefficient and resource wasteful due to enormous amount of resources consumed. This situation leads to an increasing demand for further development of their technologies (Ghosh, 2002). More rational constructive processes can be implemented with the introduction of new production technologies that allow reduction of labour, materials, mass, time and fund. Such reduction becomes possible through the use of composite panels technology (CPT) initiative. Such initiative allows the reduction of mass in construction through the use of lightweight and heavy insulated envelope wall and ceiling panels. The CPT explores the possibility of developing alternative walling and ceiling materials from agricultural waste with cement as binder. Thus, the CPT concept can be classified as a better rationalisation of resources in construction.

OVERVIEW OF CONSTRUCTION INDUSTRY IN DEVELOPING NATIONS

A review of the numerous studies carried out on construction industry in developing economies reflects inadequate analysis as found in other sectors. Several authors attempted to solve these problems to a level. Crosswaite (2000) analysed the industry from the perspective of the share of the construction spending in gross domestic product (GDP), Drewer (2001) studied the international trade of construction resources, Bon and Crosswaite (2001) proposed future development and trends in international construction industry. While Ofori (2003) evaluated performance of construction companies to find more environmentally-sustained companies in developing countries, Ngowi *et al.,* (2005) examined the globalisation of the construction industry and proposed strategies that could benefit small companies in developing countries. In recent past, several rational constructive systems are gaining momentum in the building industry in many developing nations including Nigeria. In the quest to find solutions to the ever rising cost of housing, the gained results often require expensive advanced technology and an establishment of standardized community system, which are not expedient to these developing countries (Adedeji, 2008). This phenomenon led to the increase in the use of dry masonry and panel walls in the construction industry. In Nigeria, the first documented usage of the interlocking masonry was that of a 60-unit housing experimented in 1991 at the University of Lagos, Lagos. In this system housing, a prototype design representing a marriage of architecture design, materials and technology was developed into a commercial level where the product and the process were conceived as an integrated whole. It has evolved into an urban housing prototype as a strategic approach to housing delivery as an engine of growth in a developing Nigerian economy. This was followed by public patronage in an industrial scale where a 60-unit housing estate for Home Ownership Scheme of Lagos State Government Staff Housing Board, in Alausa was constructed (Olusanya, 2003). Besides, the Nigerian Building and Road Research Institute (NBRRI) demonstrated the use of the material in major cities in Nigeria such as Lagos and Abuja.

Wall Panels

Wall panels are vertical elements within a building that serve the function of walls. They can be produced in different ways and with various materials. In most cases, wall panels are pre-fabricated, factory-built units produced in an indoor environment. Panels can be made from various materials which include; timber, veneer, concrete, glass, polystyrene, polyurethane, aluminium, acrylics and composite materials among others. Wall panels serve many functions, from providing descriptions of exhibits in museums and galleries to hiding away electronics such as stereo speakers. As a decor element, wall panels are an excellent way to break up wall space. This can be achieved by panelling the upper or lower half of the wall, installing wainscoting, creating a faux finish, or one of several other methods. In the business setting, there are portable or temporary wall panels that can be used to divide a space into cubicles. Modular wall panels may be constructed of wood, metal or composite materials and are often covered with textured materials, fabrics, panelling or wallpaper to make them more aesthetically pleasing. There are also acoustical and sound absorbing wall panels that are good for studio spaces.

Other types of temporary wall panels are employed in homes. Many homeowners do not want or cannot afford modular panels, but may use fabric wall panels to quickly and inexpensively give a basement, attic or garage a finished look. This type of wall panel is made from heavy fabric such as canvas, and can be easily hung in a matter of hours to cover unfinished ceilings and walls, giving any space a clean, refined look. Wall panels are convenient and practical whether used for functional purposes or simply as an aesthetic element. Panels could be structural or non structural in their constructive use.

Cement-bonded Composite Materials

Cement-bonded board is an engineered particle composite product made from wood or other ligno-cellulosic raw materials bonded with inorganic binders such as cement, chemical additives and water and pressed under regulated pressure. Usually, cement-bonded wood are produced from strands, particles or fibres wood mixed together with cement and manufactured into panels, bricks, tiles and other products used in the construction

industry. In 1970s there was a major crush in the particle industries as a result of the global increase in price of crude oil, resulting to the increase in the price of organic binders and scarcity of the products. Consequent upon the high cost of machinery and synthetic resin in the production of particle boards, the need for alternative source of binder to meet the ever growing demands in the building industry become imperative. Thus, the introduction of cement as a binding agent in production of cement-bonded particleboard was adopted for commercial production. The need to use agricultural wastes for the cement-bonded particle board production has been motivated by the availability of cement binder and increase awareness for conversion of the country's wood waste for value added panel products. Cement-bonded products can be classified into cement-bonded boards, wood-wool excelsior boards and gypsum- bonded boards. The excellent properties of cement-bonded made them useful for ceiling, walling, roofing, flooring, claddings, partitioning and shuttering. Uses of products depend on their reliability and resistance to fire, insect attack during natural disasters such as earthquakes and tropical storms (Ramirez-Coretti *et al.,* 1998).
The typical raw material used for this Composite Panel Technology (CPT) is palm kernel fibre, a by-product of palm kernel, which is obtained from palm tree. A palm bunch is matured for harvesting when it has a few loose fruit. It is essential that each palm is inspected at least once a forth night for ripe bunches as overripe fruits produces lower quality palm produce. Usually, three methods of harvesting palm bunch are used: (1) the chisel, (2) the pole-knife and (3) climbing methods. It is essential in all cases that damage to leaves be restricted. The operations involved in the processing of the palm fruits to palm oil and kernels can be summarized as follows:

Sterilisation → Stripping → Milling → Separation → Pressing → Clarification → Storage or sale of palm oil.

Two main products obtainable from palm kernel in addition to the shells are palm kernel oil and the palm kernel cakes, which is extensively used in livestock feed. After the extraction of the oil, the fibre is washed out of the waste and becomes useful for other purposes including panels for buildings. CBN (2004) observed palm kernel as a supportive agent of economic growth in Nigeria as reflected in Table1.

Table 1: Pattern of Agricultural Outputs (Palm Kernel) in Nigeria (Amounts expressed in tonnes)

Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Palm kernel	543.0	548.0	555.0	572.0	600.0	629.0	620.0	645.0	690.0	745.0

Source: CBN (2004)

MATERIALS AND METHODOLOGY

Two research activities were undertaken for this study. First, was the experimental design method used for production of the cement-bonded boards. The laboratory research work on the palm kernel material was carried out in the Department of Forestry and Wood Technology, Federal University of Technology, Akure under the supervision of Dr. B. Ajayi. The second was an empirical survey method used to collect data on applications of CPT panels in housing construction from different locations in Nigeria for comparative analysis with the conventional sandcrete masonry used in the building industry. For the empirical survey method, data were collected through observations, structured questionnaire and interview schedules administered to key practising professionals in the building industry that are involved in the use of the material for building projects in the study area. Descriptive statistics analysis was used to analyse data collected. Cement-bonded boards were produced from mixture of palm kernel fibre and cement (Figure 1, Plate 3).

Plate 1: Palm tree

Plate 2: Palm Fruits

Plate 3: Palm kernel Fibre

Plate 4: Palm Kernel Processing

Figure 1: Preparation and Pre-treatment of Palm kernel

Source: Ajayi, 2008

The palm produce was harvested from Ikoya Oil Palm plantation located in Ikale Local Government Area, Ondo State, Nigeria (Figure 1, Plates 1 and 2). The material was sun-dried for two weeks and later transferred to the laboratory of Forestry Research Institute of Nigeria, Ibadan for processing. The palm kernel fibre was pre-heated with hot water at a temperature of 80^{0}C for 1 h to remove the inhibitory water soluble chemicals present in the material that are capable of poisoning the cement and thereby slow down the setting and curing of the cement binder (Ajayi, 2008). After 1 h, the water was drained off and the materials were dried to moisture content of approximately 12%. The raw materials were then packed to the laboratory for the production of cement-bonded boards.

Experimental Procedures

The experimental design used in this research is 2 x 2 x 3 factorial experiment in completely randomized design (CRD), the combination that gives 12 treatments. Raw materials include: palm kernel fibre, Portland cement, additives and water which was calculated based on this formula.

W_t = W (0.30-MC+0.60C). Where W_t= weight of water (g), W= wood drying weight (g); MC= moisture content (%); C= cement weight (g)

The following production variables were used:

1) Board density of 1000 kg/m^3, 1100 kg/m^3, 1200 kg/m^3
2) Additive concentration ($CaCl_2$): 1%, 2%
3) Mixing ratio of cement: palm kernel fibre (mass), 2.0:1, 2.5:1

   Constant factors are
4) Board thickness: 6 mm
5) Moisture content: approximately 12%
6) Board size: 350 mm x 350 mm x 6 mm
7) Pressing pressure: 1.23 N/mm^2

The amount of palm kernel fibre and quantity of cement ratio required were calculated, measured out and poured inside a plastic bowl and mixed thoroughly until well-bended with lump-free materials obtained. The quantity of additives required was dissolved in the measured quantity of water and mixed together. The water containing chemical additives, calcium chloride was then added and mixed with the material while the mixture is hand-formed into wooden mould. The furnish was formed into a uniform mat inside a wooden box of 350 mm x 350 mm, placed on metal plate and pre-pressed using wooden cauls plate. The steel plate was covered with polythene sheet before board formation to prevent the sticking of the board onto the plate. After board formation, the top wooden plate was removed; another polythene sheet was placed on the mat before placing metal cauls plate. The mat was then moved to the hydraulic press and pressed with the aid of hydraulic jack, under pressing pressure of 1.23 N/mm^2 and left for 24 h. The pressed mat under compression was released, the boards were removed from the cauls and wrapped with polythene sheet and kept in the laboratory environment for 28 days to ensure further curing of the cement. Loss of water from the boards was prevented through proper wrapping of the sheet. Thereafter, the board were stacked for 21 days at a relative humidity of 65 ±2 % while the edges of the boards were properly trimmed.
The water absorption, thickness, swelling and linear expansion were examined. Specimens were cut into size of 152 mm x 152 mm according to the ASTMD1037, (1978). The water absorption test samples were weighed first before soaking and the initial weight recorded. The tested samples were then placed horizontally in a large container of water at a temperature of 20^0C. These samples were soaked in water for 24 h, thereafter boards were weighed using weighing balance to determine water absorption, thickness and linear section were measured using Veneer Calliper to assess thickness swelling and linear expansion.
The water absorption, thickness swelling and water absorption were determined using the following formulae:

$$\text{Water Absorption \%} = \frac{\text{Final weight} - \text{Initial weight}}{\text{Initial weight}} \times 100 \quad \text{.............................. (1)}$$

$$\text{Thickness Swelling \%} = \frac{\text{Final thickness} - \text{Initial thickness}}{\text{Initial thickness}} \times 100 \quad \text{........................... (2)}$$

$$\text{Linear Expansion \%} = \frac{\text{Final length} - \text{Initial length}}{\text{Initial length}} \times 100 \quad \text{.............................. (3)}$$

The data obtained were analysed using SPSS computer software programmes. Duncan test was performed to determine if significant differences exist between samples means at 0.05 level of significance.

Description of CPT Initiative
The components of the CPT wall panel is made of lightweight sandwich panels, consisting of 12 mm thick layer of expanded polystyrene (EPS) fixed to boards (350 x 350 to1200 x 1200) mm ranges and 50 mm thickness of composite panel shaft at the centre, finished with two 6 mm thick plasterboard at the interior. The panels were factory-made. Installation is done with laminated steel profile. The floor is composed of cement, sand and kernel shaft of the ratio 1: 3: 6. The ceiling is of cement and 'koinkon' a material used for a local sponge. This can either be obtained from palm tree or any other plants that has similar property. The material which is of tensile property is used to reinforce the cement which is brittle and only good in compression.

RESULTS AND DISCUSSION

Effect of Board Density, Mixing Ratio and Additive Concentration on Water Absorption, Thickness Swelling and Linear Expansion
The mean values for water absorption, thickness swelling and linear expansion ranged between 14.8% and 19.72%, 0.12% and 0.86% and 0.20% and 0.99% respectively. Cement to palm kernel fibre ratio, additive concentration and board density showed the effect on the reaction of boards to water. It is observed that as

the board density, additive concentration and mixing ratio increased, water absorption, thickness swelling and linear expansion decreased. This shows that board produced at the highest levels of board density (1200 kg/m^3), additive concentration (2%) and mixing ratio of (2.5: 1) is most dimensionally stable board as the cement content in board is higher. The high concentration of calcium chloride caused retardation of inhibitory chemical substances and increased the exothermic reaction of cement binder to produce highly stable boards. It further shows a lower spring back tendency when the pressure was released from the press and after water immersion treatment. The high compression ratio of board, the presence of less void spaces, better inter-fibre surface contact area may be due to the reduction in water absorption, thickness swelling and linear expansion values and board's spring back (Ajayi, 2002 and Ajayi, 2006). The highest values for water absorption, thickness swelling and linear expansion at mixing ratio 2.0:1, additive concentration 1% and board density (1000 kg/m^3) may be due to the fact that additive concentration, board density and mixing ratio had strong influence on the boards' physical properties.

Applications of CPT in Housing Construction

CPT wall panels have been experimented in a number of projects in major cities in Nigeria and particularly for students' accommodation in Ambrose Alli University, Ekpoma, Nigeria. In the institution, the buildings were of modular design and limited to a single floor level. Dry construction method was adopted for the super structures while the sub structures followed the wet conventional type with strip foundations. The over site concrete floors were of the composition of cement, sand and palm kernel shells of 1: 3: 5 ratio. CPT wall panels were used for the framed masonry walls. The system is cost-efficient, less labour dependent and faster than the conventional as analysed in Table 2.

Comparative Analysis of the CPT Costs

The second data for the study were collected with the use of questionnaire administered to selected professionals in the building industry. The selected professionals (Architects, Engineers and Quantity Surveyors) distributed over four out the six geo-political zones in Nigeria expressed their opinion on the cost-effectiveness of this material as a replacement for the conventional types as shown in Table 2 below:

Table 2: Distribution of Questionnaires Type 'A' within the Study Area

S/No	Geopolitical zone	Town	No of Questionnaire	No of Responses
1	South West	Lagos	50	40
2	North	Abuja	50	32
3	South South	Port Harcourt	50	28
4	South East	Enugu	50	20
Total			**200**	**120**

Source: Field survey, 2007

The questionnaire collected information on unique projects executed by these professionals using the selected study materials namely: interlocking blocks and the conventional type. One hundred and twenty (120) respondents were randomly selected equally from the two hundred administered in the four geo-political zones. In the second set of data collected with the use of interview schedules, information on projects size, specification of materials used, gangs of labour engaged, and cost of interlocking and conventional blocks used, time expended for setting each of the materials and associated problems with their usage was collected.

Samples of ten (10) buildings constructed with CPT material were surveyed and compared with conventional buildings of similar sizes and subjected to the same construction conditions. While measurements of these drawings together with cost estimates were taken from the architectural drawings, estimates of masonry works of these buildings were based on data obtained from field for CPT panels and compared with estimates of the same building using the conventional masonry walls (Table 3). From the analysis, it is possible to have over 65% cost savings with CPT masonry. Since CPT panels are larger than the conventional block, shorter period was required for assemblage and wastages are also minimized (Figures 2-5). Besides, the cost of using CPT materials in construction is lower than that of conventional blocks as its operation does not require special skilled labour as it is in the case of conventional blocks. It was also observed that while a gang of 1mason + 1 labour could achieve a productive hours 6.5m^2/h with CPT masonry, a gang of 1mason + 1 labour could only achieve a productive hours 1.55m^2/h with conventional masonry. There is overall reduction in cost of masonry works (65% lesser) with the use of Composite Panel Technology for construction of a housing unit as compared with the use conventional sandcrete blocks for the same project.

Table 3: Comparison of Selected Data from Executed Project Sites

	CPT Masonry					Wet Masonry		
S/N	**Area (m^2)**	**Rate ($)**	**Cost $ (in 1000)**	**Labour (No per gang)**	**Pro. Hr. m^2/h**	**Cost $ (in 1000)**	**Labour (No per gang)**	**Pro. Hr. m^2/h**
1	286	23.0	1.68	3	6.50	4.15	12	1.55
2	242	16.5	1.57	5	7.24	3.06	20	1.44
3	410	18.0	2.67	3	4.71	5.95	12	1.71
4	550	14.5	3.57	5	6.5	8.51	18	1.50
5	460	16.5	3.00	4	6.14	6.69	16	1.47
6	837	17.0	5.45	7	5.65	12.25	24	1.65
7	575	17.5	3.73	5	4.78	8.39	16	1.78
8	930	16.5	6.05	6	6.61	13.50	27	1.61
9	280	17.5	1.83	3	5.52	3.89	14	1.52
10	480	16.5	3.12	6	5.72	6.96	26	1.72

Source: Field Survey, 2007.

There is overall reduction in cost of masonry works (65% lesser) with the use of Composite Panel Technology for construction of a housing unit as compared with the use conventional sandcrete blocks for the same project.

CONCLUSION

The study revealed that it is possible to produce dimensional stable cement-bonded particle boards using palm kernel fibre with Portland cement binder after hot water treatment. It shows that increase in cement/palm kernel fibre ratio, board density (1200 kg/m^3) and additive concentration caused decrease in water absorption (WA), thickness swelling (TS) and linear expansion (LE). Also, boards produced at the highest levels cement-palm kernel fibre ratio of 2.5: 1 additive concentration 2% and board density (1200 kg/m^3 showed the highest resistance to water intake and lowest spring back. The finding is capable of stimulating improved standardised cement-bonded particle boards production from palm kernel fibre for industrial and economic development. Boards produced could be used as alternative to sawn timber for construction works and furniture.

Accelerated dry masonry system using Composite Panel Technology (CPT) is advocated for in housing projects as an alternative method cheaper than the conventional wet type. It is also faster in operation with a potential of saving over 65% of time and cost of the masonry work. It reduces wastage of materials, and number of labour required for operation. The use of dry construction methods with appropriate standardised components to reflect the designer's specification would reduce or completely eliminate wastages, reduce labour force, cost and time for construction. Dry construction method is therefore cost-effective and preferred above the conventional method as confirmed by this research. Finally, CPT materials offer several advantages such as design flexibility, cost effectiveness, light-weight, reduced construction time, environmentally friendly and solution to space shortage. Thus, the result of this research provides information on the provision of affordable and sustainable housing materials.

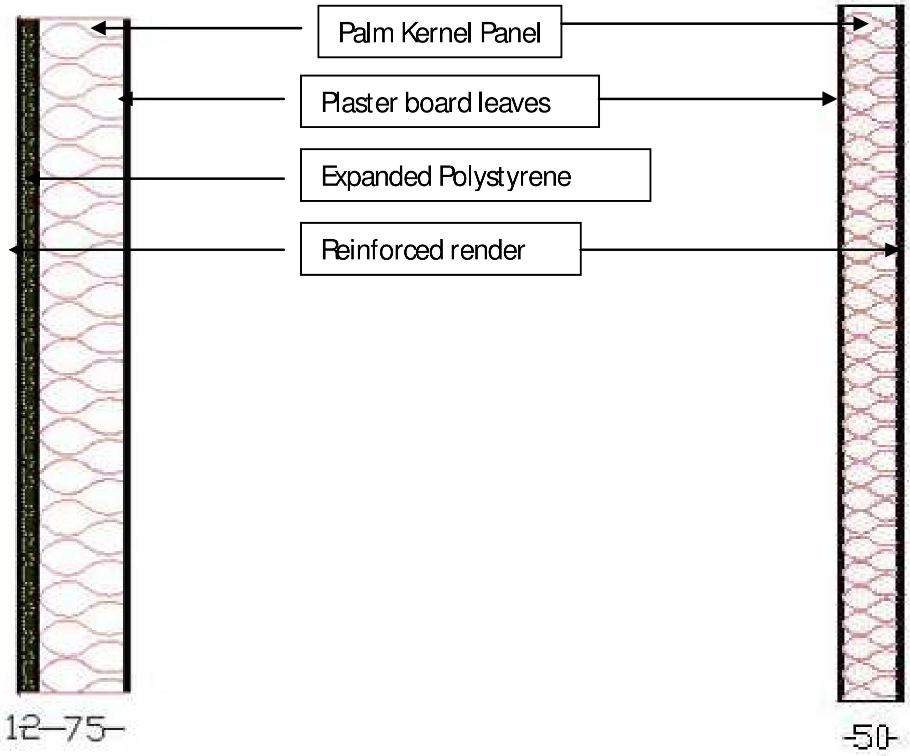

FIG. 2: EXTERNAL CONSTRUCTIVE WALL SECTION OF THE CPT

FIG. 3: INTERNAL CONSTRUCTIVE WALL SECTION OF THE CPT

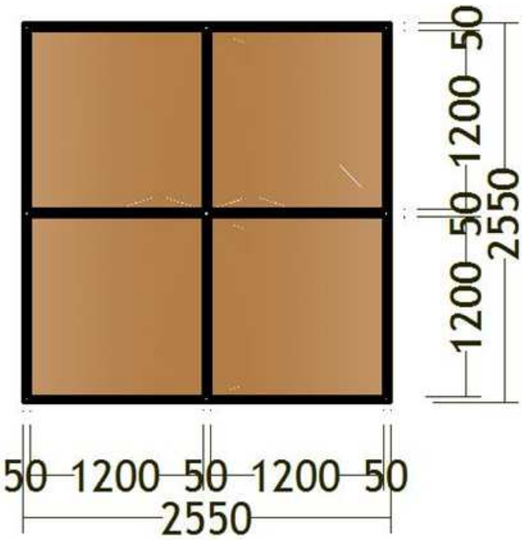

FIG. 4: EXTERNAL CONSTRUCTIVE ELEVATIONAL VIEW OF THE CPT WALL

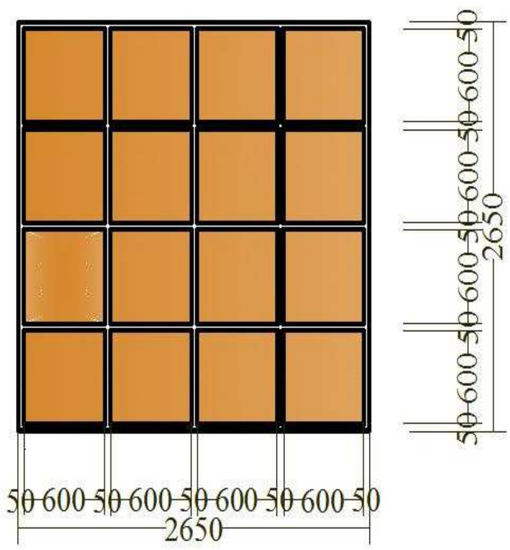

FIG. 5: EXTERNAL CONSTRUCTIVE ELEVATIONAL VIEW OF THE CPT CEILING

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