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An Eco-Friendly New Construction Methodology Supporting High Market Feasibility

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Abstract: An Eco-Friendly new construction methodology supporting high market feasibility. A new construction methodology is developed by using wood and straw bale as the main raw material as an alternate to cement products. By doing so, anyone can own a building within a matter of hours since it facilitates lower cost estimation apart from being eco-friendly and possessing a longer lifetime. The thermal performance ranking is also very high. After subjecting straw bale into several tests including load bearing, thermal behaviour, life cycle assessment and energy performance, straw bale construction is found to be the best solution where wood provides additional strength to the building.

Key words: Wood, straw bale, cost estimation, load bearing, life cycle assessment, thermal performance

INTRODUCTION

Economy in the construction sector is considered to be the most emerging sector that is often significant in determining a country's development. Economic growth is said to be progressive if its construction pace is leading. Hence, more than an individual, a country itself take part in its growth where an active participation of dedicated architects does a crucial role. The term construction of a building indirectly means building up via concrete and its relative substances where wood has its role in interior and exterior decorations widely. Buildings can be made up of stone, steel, glass, wood, etc. where one prefers anyone, depending upon the circumstances and environment. On the whole, each type has its own merits and shortcomings. The rich can even build using gold or its variant but it is necessary to support all mankind in common. A country's wealth or development is comprised of every individual and relating to all these considerations, a new construction methodology is developed and validated to be technically reliable and feasible.

Although, straw bale buildings have started emerging world-wide they are not able to be accepted as an effective construction material due to the improper investigation over thermal performance. To the ones who do not agree with straw bale as a good construction material, straw bale and wood altogether would be an opt option. Hence by focussing on these two, this research has been attempted to satisfy the builders and the users. It is better to start up straw bale construction keeping in mind that straw is a waste from agriculture that paves way for sustainable buildings. Heravi *et al*. (2016) energy consumption during concrete and steel building manufacturing was analysed. It had been found out that the energy used up by steel construction is higher by around 27%. It is mandatory to develop complete structural model to examine the characteristics of performance over time whether it is steel or concrete construction (Shalabi *et al*., 2016). Construction industry often uses clay soils as building material. Since, they contain smectite or illite which are regarded as swelling minerals, these results in drastic damage to the buildings. To reduce this effect, steel slag is added to enhance stability. Rajapakse (2017) and Imbabi *et al*. (2012) the merit of using steel in construction is elaborated besides indicating that additional fire proof is required as it does not have the ability to with stand extreme temperatures.

Stone can be used as a productive, long lasting building substance. This type of construction gets declining these years as it is expensive and difficult to be gathered from quarries, brought into shape and transport (Klemm and Wiggins, 2016). It takes up huge labour research too. In structural behaviour point of view, glass delivers accurate designs to enable effective constructions (Achintha, 2016). Its difficulty lies in generating and managing the construction waste. By providing better utilization of glass wastes and decreasing carbon dioxide emission, its usage might get enhanced.

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Ordinary portland cement is comprised of limestone and clay that acts as a hydraulic binding substance in construction field (Adethya *et al*., 2016). Due to the emerging situations of population needs there arises, fossil fuel and raw materials depletion. This type of cement production results in enormous carbon emission and thus as a substitute to this, fly ash and silica fumes are used. Still, a condition persists that certain types can have negative impacts when used with concrete. It is important to remember that fly ash results from coal burning which leads to carbon emission. On the otherhand silica fumes are not suitable for strength development which is also expensive.

Straw bale construction was developed with steel as the insulating material along with straw clay and cement mortar as outer layer (Duan *et al*., 2010). This idea seems to be new and thermally safe but the energy can be saved only up to 55% (Chikhi *et al*., 2016). In order to minimise energy usage, polystyrene concrete was utilised and proved that it was better than ordinary cement due to its high hygro-thermal property. Certain kind of it would contain chlorofluorocarbon that is harmful to earth's protection layer.

A lean construction methodology (includes both research and development to go ahead with project based construction oriented towards product maximization by means of waste reduction) was employed to withstand the declining of the productivity (Aziz and Hafez, 2013). A set of features that applies for lean technique such as delivery mechanism, concurrent design and development strategies is listed for the successful completion of the project. It is said that maximum efforts are taken to reduce the total wastage as well. The study itself testifies that the methods adopted to fulfil the goals have limited ability to overcome systematic problems. It is in dilemma whether the research is to be focussed on the perspective of result basis or process basis (Kaczorek, 2016). A systematic analysis was formulated on the basis of minimising construction delay by featuring out the factors that hinders the production rate. So, this would be helpful to estimate the progressive effect of certain factors that is responsible for delaying.

Jankowski *et al*. (2015) and Diaz (2016) it is given that building information modelling is the present trend in construction due to its 3D Model structures usually comprised of mass, length and several phases of processing. To get use of this collaborative and interactive model, the design processes (plan, model, design, finishing) should be integrated as a single system and therefore, attaining sophistication is difficult due to cost factors and unavailability of credible software.

Franco *et al*. (2016) stated that straw bale construction method is suitable for housing system. Its mechanical properties are elaborated by means of simple linear model to generate functional characteristics of the devices used such as piston stroke, rod and crank and for power distribution; slider-crank approach is employed. At present, this project aids in constructing warehouses using straw bales (Lawrence *et al*., 2009). It is imperative to study the maximum durability that a straw bale construction would afford to confidently go with the plan. Along with it it is required to know the benefits that a straw bale building can provide based upon its low carbon and high insulation properties. These types of researches on moisture control help the builders to manage them accordingly since there is a need to clarify all the terms and conditions before stepping into construction (Ashour *et al*., 2011). A series of experiments to find out the compression factor and moisture level was conducted. Certain other criteria relating to that of stress-strain characteristics, humidity and thermal stability were also reported. The test results prove that straw bale constructions are secure and strong enough to proceed with.

Mattila *et al*. (2012) load bearing capability, hygrothermal (heat and moisture passage) characteristics, durability and the structural properties of straw are reviewed and favoured for straw bale constructions (Shalabi *et al*., 2016). It is also demonstrated that such buildings could store the carbon content of straw used, in-order to deliver energy efficient system. Based on the life cycle assessment, the study reveals that carbon storing ability of straw wall is better than the bio char systems.

A comparison was made on existing and developed compression field theories to validate how good the refined compression field theory is Palermo *et al*. (2014). By the results on shear strength and axial load bearing ability with that of compression field mechanism, it concludes that straw bale buildings could be well designed by means of plastering the outer walls (Walker *et al*., 2016). A renewable and defensible stream of buildings could be made which is also sustainable for thatched roofing. The successful built projects itself confirm how much a straw bale building could be trusted on the basis of their thermal insulation and long term durability. The study warns that the extremely high humidity content would damage the building unless it is coated with a suitable material.

So by carefully monitoring the non-invasive conditions of the straw bale and providing suitable coating, a straw bale building with the capacity to deal even with any uncertain circumstances can be constructed and this is what the proposed study does.

MATERIALS AND METHODS

As it is the urgent need to lower the fossil fuel consumption by substituting them with renewable

energies, one can go for straw bale buildings. To prove that straw is a good construction material, certain properties such as thermal behaviour, load bearing ability, life cycle assessment and energy performance are carried out.

Characteristics of straw: The physical and mechanical properties, strength and young's and rigidity modulus of the wheat straw are measured using separate apparatus. The stem internodes are subjected for measurement where the young's modulus is obtained by 4-point loading and the rigidity modulus by treating under torque. It has been investigated that the tensile and shear strength of wheat straw is found to be 21-31 and 4-7 MPa, respectively. Young's modulus ranges between 4 and 6 GPa and rigidity modulus is measured to be 265-545 MPa. If the growth of the plant is divided into four stages of maturity, each stage contributes differently for the above mentioned properties and elastic moduli. It should be noted that the shear strength would be higher in the initial stage of maturity where for the attainment of higher young's modulus fourth stage would be better. It is found that the rigidity modulus remains the same throughout the growth cycle but gets affected by the moisture content at the fourth stage. It influences the shear strength too. Internodes can be preserved by freezing which tend to have effect on young's and rigidity modulus.

Thermal behaviour of straw bale-wooden building: Generally, it is known that straw is of low weight and thickness and this brings defects while overheating. At this point, steady care has been taken by the addition of massive wall of wood at the centre and sides of the building and now the entire building is thermally secured. The wall does not possess any inertial effect and just the internal mass is responsible for heat capacity. It is calculated that the thickness of the straw would be 250 kg/m^3 and by adding the central lobe its thermal capacity raises from 220-300k/J/m^2. It confirms that the centre wall contributes more to the building where it takes 30% of its total heat capacity. Heat consumption is reduced due to high thermal insulation when moisture content is excess outside and the wood coating guarantees greater sustainability of the building by keeping away from water projections. The construction is also built in a way to limit solar radiation due to low solar factor and acts as a natural insulator because it is full of air pockets within its cellular composition. It is said that wood is multiple times better than steel or masonry or aluminium substance. It is the real cause that the thermal mass of wood is high and so it must be seen how much heat energy is passed into rather than how much is stored up. Expanding the wall density aids for more thermal resistance in turn in depletion of heat energy intake.

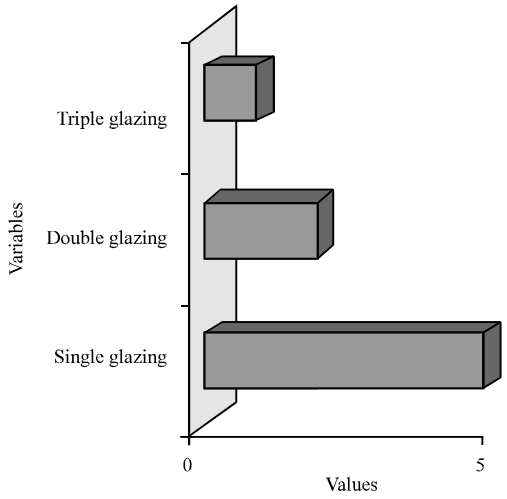

Fig. 1: Comparison: heat loss

Load tolerance/general structure: Feasibility studies are made to finalise whether straw bale could be put into practice. Since, the results are positive, straw was chosen as the good solution where its strength relatively relies on the thickness of bales used. This would take an extra man power or machine work. The walls of the building are made of straw bales where its outer layer and roofing are coated with wood insulation. Beams and structures are usually of solid timber and wood frame construction to provide additional load bearing potential. In these, beams are the structure that must be given top priority. Facilities to provide natural ventilation are also ensured where without any additional source for a heating system the internal temperature of the housing would be maintained. In certain cases, a pellet stove of low watt can be used that conveys heat via natural convection within the surrounding. Other features might include triple glazing system and flat proofing that favours to operate with solar panels. Even the lighting and other wares are managed to promote renewable environment. Triple glazing system is advantageous since it reduces heat loss and that is illustrated in Fig. 1.

Life Cycle Assessment (LCA): LCA is the assessment held from the very beginning of its lifetime analysing the total energy consumption (1970s-up to date). It is intended to value the importance of energy consumption when a construction is formed and destroyed where the proposed layout is compared to standard format. This analysis is made using a software program called SIMAPRO which takes upon the database Eco-Invent to

determine building up or decrease of energy consumption. Transportation charge, energy consumed in the transformation processing of raw to actual building materials are the factors involved in the assessment. Five set of classifications are made featuring the energy consumption. The first research is built using concrete provided with single glazing where the second one is the expansion of the former in where a polystyrene coating is additionally provided. Third, using straw as the construction material, though the energy consumption is largely reduced, relating to the production ratio, it is still lower. The next scenario is employing the straw bale and wood where the production and energy consumption rate is almost equal (Thomson and Walker, 2014). The innovative mode should be in the form that production rates out leads the other which is the proposed model. This is represented in Fig. 2 and the average lifespan is found to be 80 years.

The above factors are based on straw bale construction and when it comes for wood, its budgetary index is defined by open diffuse system. Four projects of wood based structure are illustrated with four variants. These are desk, gabled, hipped and tent. Wood frame ceiling is provided for the house with double deck and the construction cost is estimated individually.

Energy performance: To determine energy performance, cost estimation is a crucial factor, i.e., the cost of labour for brick-concrete housing is comparatively higher than straw-wood construction. Moreover, wooden coating is preferred due to its insulation property. Wirings and plumbing are made easy at any time (even after construction) in case of straw bale-wooden material. It is also eco-friendly and it assists in saving electricity, since it offers natural balancing effect. Wood framed apartments can withstand extreme natural calamities (heavy winds, earthquakes, fire) as well. These structures are economically feasible that it leaves only small portion of carbon in the atmosphere and it cuts down cost functions efficiently.

Analysis of hybrid construction system

Stick-frame construction: In stick frame construction, sheathing material that gets attached to sticks supports wind and wall bracing. This is normally put into practice where there is need for multi storey buildings as given in Fig. 3. The developed project widely uses wood panel construction as wood is generally used as a coating or protective material so as to support the straw bale material. Additional supporting is provided by means of internal or external pillars using solid timber, i.e., the project uses central wood column.

Wood panel construction: The walls in the building can be built using this sort of construction mode. Certain

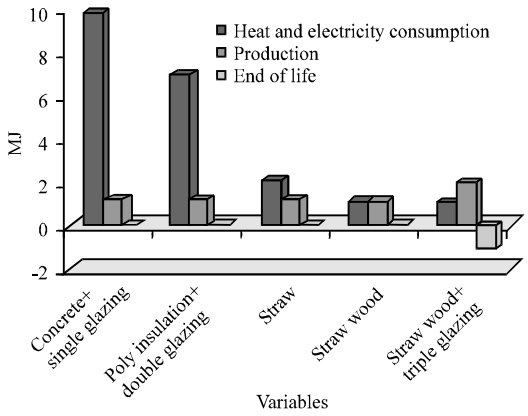

Fig. 2: Energy consumption: comparison

Fig. 3: Stick-frame construction

functions of the panels include fencing, dividing and bearing. Apart from strength providing, wood panel construction also aids in reduction of greenhouse gases. More than this, it is innovative and can be subjected to long term use. As this project primarily focus on eco-friendly rule thereby beats up other techniques that generates high emission and energy consumption, the proposed novel method relates to low carbon construction process. This could be possible by cross laminated wood panel construction which further progresses in design structure. It is preferred for urban infill and residential systems. The model of wood panel construction is shown in Fig. 4.

Wood frame construction: Wood frame construction is similar to that of stick frame construction which usually differs in frame thickness. This structure is efficient for building industrial premises as that it could hold number of equipment and things. This project makes use of this type in minimal portions.

Solid timber and assembled wood construction: Here, the buildings are assembled from prefabricated panels which often resemble concrete construction. It is necessary to

Fig. 4: Wood panel construction

analyse the static and bending behaviour as the wooden panel contributes only to the walls and central balancing structure and the remaining parts are filled with straw bales. Differences are noticed with the panels constructed under slot and tab design and with those which are not. The static and bending property of wooden panel is not variable to a greater extend but in the fatigue (tolerating repeated and constant loads) result sector, the panel that are built with slot and tab method gave better performance.

Labour requirement and construction delay: Both the wood and straw bale approach significantly reduces labour service. Even self-building can be promoted as no technical skills are actually needed for building up using straw bale material and for wood researches too, a little labour would do. Thus, the construction would be completed within a shorter time period. On building with brick/stone-cement-mortar, it takes a while to assemble the materials itself to the construction site and again, transportation charges consumes larger financial ratio. Hence to deal with market feasibility, this project impacts more besides it is technically simple and reliable factor.

Nutshell/benefits of wood-straw bale structure:

- Wood and straw act as good insulators
- Since they are of low weight, it could be easily researched with
- Less transportation, erection time
- Have the capacity to balance heat transfer, therefore saves power
- Easier/quicker modification
- Less maintenance
- Pollution free-less carbon emission
- More comfortable, flexible, cheaper
- Eco-friendly, recyclable, sustainable

RESULTS AND DISCUSSION

The proposed project looks alike to Fig. 5. The roofing is partly made of wooden material and the

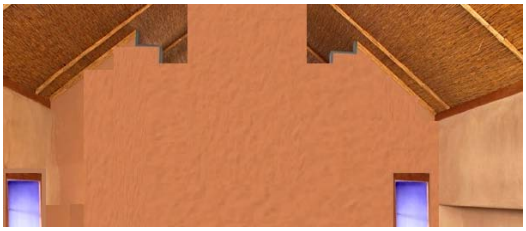

Fig. 5: Straw bale and wooden framework

Table 1: Waste generation

Materials	Initial weight (kg)	Used material (kg)	Loss rate (%)	Waste genera-tion rate (kg/m^3)
Concrete	10000	8500	8.5	2.0
Steel	100	90	3.5	1.1
Stone	1000	950	3.0	1.5
Glass	1000	900	5.5	3.2
Aluminium	10	8	6.0	3.4
Wood	500	490	2.5	0.5
Straw bale	750	750	1.0	0.2

research is purely based on wood and straw bale with a few optional supplementary mechanisms for the benefit of users.

Waste generation: By analysing the literature references and the present research, the following results are made. The generated waste can be determined as in Table 1, where the loss and waste generation rate is generally high comparing to wood and straw materials. This assessment is obligatory since in many of the construction departments, managing the industrial wastes itself is a difficult task. In these, recycling or regulating them is often a tedious job that the possibility is very low or one should have the capability or tendency to spend more in this area. The proposed system totally differs from the existing shortcomings related to waste management too. Since both the building materials employed in the project is eco-friendly and naturally available they are recyclable and reusable.

By comparing the initial weight and the weight used up, the loss rate is determined as in Fig. 6. It shows that the loss rate for straw bale and wood are considerably lower than other construction materials. Since straw 'bale' is used in the process, the possibility of loss and waste generation rate is low as all the straw brought to the construction site is used up to in its bale conversion process and there is no leftover. The remaining shall be stored up for future usage. The corresponding waste generation ratio is represented in Fig. 7.

Energy consumption: In terms of carbon dioxide emission, electricity and heat takes up larger portion (~30%) followed by industrial process (15%) transportation (17%) combustion of fuels (7%) agriculture and related works (including conversion of forest and agriculture land to human settlements) (25%). Based on these facts, the

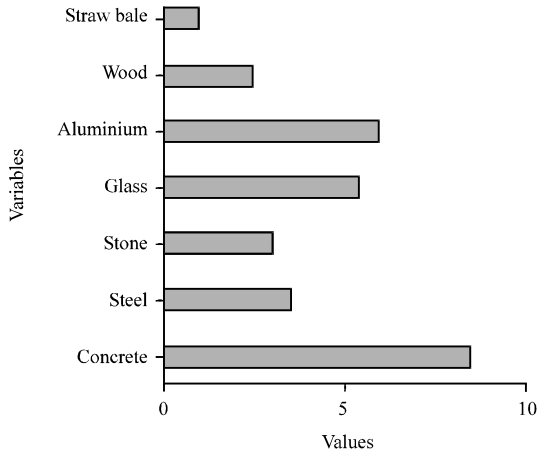

Fig. 6: Loss rate

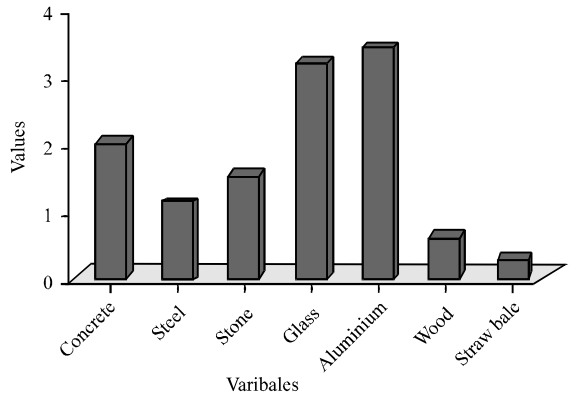

Fig. 7: Waste generation rate

Table 2: Energy consumption vs. CO_2 emission

Materials	Consumption of energy (MJ)	CO_2 emission ($kgCO_2/t$)
Concrete	40000	5245
Steel	37000	6430
Stone	47000	1410
Glass	500	1870
Aluminium	55	1600
Wood	30	Eco friendly
Straw bale	>10	Eco friendly

values are tabulated in Table 2. The carbon dioxide emission by burning of wood might be high but when used for construction purposes, carbon emission is considerably low and this is same for straw bale construction too. Before heading on to construction works, one must concern environmental safety also. So an analysis is made on that and by using the developed project, the carbon emission is lowered. The bar chart displaying the rate of CO_2 is shown in Fig. 8. When comparing the carbon emission and energy consumption by using concrete, the proportional gets varied to a higher degree. The same suits for steel and stone building

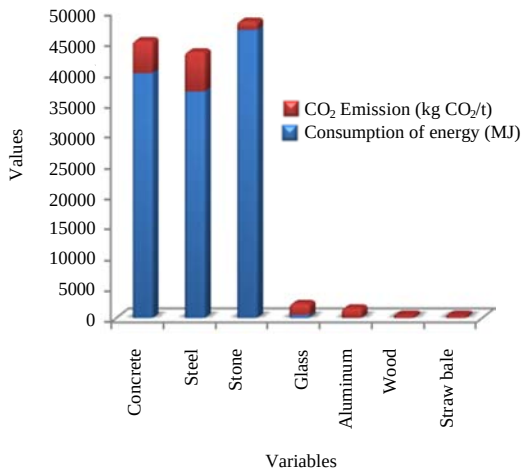

Fig. 8: Rate of CO_2 emission

materials. On analysing all the results, the bar chart clearly proves that the straw bale and wooden construction is economically and environmentally safer.

Cost estimation: Three set of experiments are done:

- Straw bale construction
- Wood construction
- Straw bale and wooden building

Total cost includes finishing researches also with that of other researches and materials. The equation for building volume has been calculated by:

$$BV = Vf + Vu + Vt + Vr\,m^3 \quad (1)$$

where, Vf, Vu, Vt and Vr refer to volume of foundation, under portion, top structure and roofing correspondingly and the budgetary index is given by:

$$BI = \frac{CCt}{BV}\left[EUR / m^3\right] \quad (2)$$

where, CCt represents the total construction cost of a single house. The results are plotted in Table 3 where the average budgetary index is found to be 135 EUR/m^3. From this, it is concluded that the building volume of all the houses tends to vary a lot but the budgetary index results to be almost similar as in Fig. 9. This validates that the BI of the house does not get affected by the size of the building. The total cost when constructed if only with straw bale would be negligible or very less but for long lasting of the building, constructions are built with both of these material. The figure relating to the budgetary

Table 3: BI determination and cost function: wood

Construction type			CCt (EUR)						
No. of floors	Base	Roof	Foundation	Bearing construction	Roofing	Finishing	Total	BV (m^3)	BI EUR (m^3)
1	Strip	Gabled	7000	11000	14000	50000	82000	430	170
1	Plate	Desk	11000	12000	12000	40000	750000	460	150
1	Strip	Hipped	100000	13000	17000	60000	100000	570	155
2	Strip	Tent	5000	18000	13000	50000	860000	550	130

Table 4: Total cost reduction: wood and straw

Construction type		CCt (EUR)					
No. of floors	Base	Roof	Foundation	Bearing construction	Roofing	Finishing	Total
1	Strip	Gabled	5000	5000	9000	29000	48000
1	Plate	Desk	9000	6000	8000	20000	43000
1	Strip	Hipped	8000	8000	12000	30000	58000
2	Strip	Tent	3000	11000	10000	25000	49000

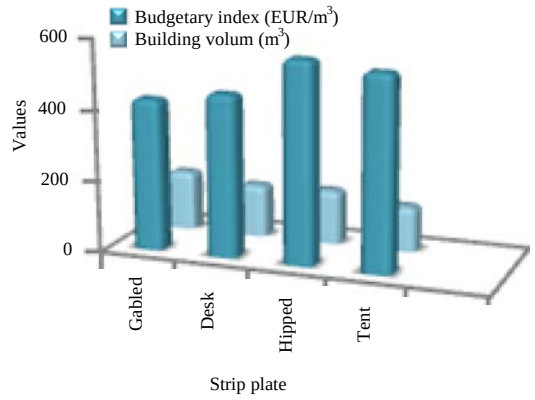

Fig. 9: Building volume vs. budgetary index

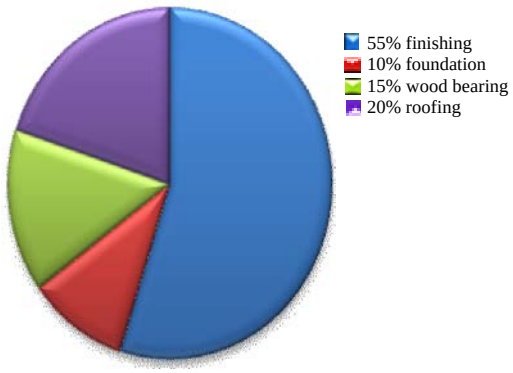

Fig. 10: Ratio of construction cost function

index and building volume could be clear when compared with Table 3. The base and the roofing tend to be strip, plate etc. and gabled, desk, hipped and tent accordingly and for each of the type its budgetary index and building volume are calculated. Table 3 is mainly intended for estimating cost function where the hipped roofing structure takes an extra amount. Furthermore, the bearing construction for tented roof and stripped base is also found to be higher and so gabled and desk framework is preferred on the basis of cost function. In terms of ratio, the finishing research takes greater percentage i.e., around 55% and the corresponding pie chart representation is given in Fig. 10.

This denotes the work of a wood based construction and its respective cost estimation. For the straw bale and wooden construction, cost function is reduced by half approximately. The corresponding table is referred in Table 4.

CONCLUSION

By straw bale and wood as the constructive material, a new construction methodology is emphasised which makes no room for inefficiency and deficiency. Always the human population aims for anything that favours low cost and durability and for such kind of people, this research would be well satisfactory and substantial. Any types of modifications such as double/triple glazing, extra fitting or any other is permissible without altering the entire structure. Though this method seems to be ancient, it is getting updated due to its better performance. Studies on straw bale are expected to get continued. As this article showcases the usage of straw bale with wood, steps are encouraged to be initiated to use some other alternatives instead of wood as well. Above all, generation of wood or active plantation therefore should be made compulsory at the other side in order to compete with the future needs.

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