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COMPARATIVE STUDY OF SUSTAINABLE MATERIALS FOR REPLACEMENT OF STEEL REINFORCEMENT IN CONSTRUCTION

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Abstract *– The main aim of this paper is to summarize the current and emerging methods, techniques and alternatives by studying literature research, case studies and documents. According to new research about construction industry, the construction sector contributes to 23% of air pollution, 50% of the climatic change, 40% of drinking water pollution, and 50% of landfill wastes. And comparatively it was also seen that maximum number of harmful emissions and pollution was from steel industry and its ever-growing demand in construction is making it worse. This paper includes studying and analysing sustainable substitutes as the main structural member in reinforcement. Analysis is done by studying types of wood and alternatives for steel, techniques from historical buildings which has survived many earthquakes and other calamities, studying trending technologies now-a-days for using timber and bamboo in high rise structures which are under construction. Results includes study and analysis of most applicable materials for alternative for steel in reinforcement such as Recycled steel, bamboo, Cross laminated timber (CLT), Glulam, Carbon Fibre reinforced polymer (CFRP), Glass Fibre polymer reinforcement (GFPR).*

Keywords: *Air pollution, Climatic change, Water pollution, Sustainable substitutes, Recycled steel, bamboo, CLT, Glulam, CFRP, GFPR.*

1. INTRODUCTION:

Over the last years, present construction techniques have negatively affected the quality of environment and hence to us. Though present construction serves all the comfort and requirements as per our fast life styles, but these practices are causing harm public health and the environment.

According to new research about construction industry, the construction sector contributes to 23% of air pollution, 50% of the climatic change, 40% of drinking water pollution, and 50% of landfill wastes. In separate research by the U.S. Green Building Council (USGBC), the construction industry has 40% of worldwide energy usage, with estimated to grow the emissions from commercial buildings by 1.8% by 2030.

Additionally, another research by Kleiwerks says that building material, such as concrete, aluminium, and steel, are directly responsible for large quantities of carbon dioxide (CO2) emissions. And comparatively it was also seen that maximum number of harmful emissions and pollution was from steel industry and its ever-growing demand in construction is making it worse. This is due to the fact that it is estimated that demand of steel and steel industry will grow significantly in coming future.

The research also shows that current practices of reducing pollutants or emissions from construction industry, are massively ineffective and even it is generating high levels of greenhouse gas pollution. This fact needs to be studied carefully as construction activities consume half of all the resources extracted from nature. Also, $1/6^{th}$ of global freshwater consumption, $1/4^{th}$ of wood consumption, and $1/4^{th}$ of global waste is consumed by construction industry itself.

2. NEED OF THIS TOPIC:

- We know, from energy usage to emissions, the construction industry has a huge impact on the environment. Industrial Pollution caused by manufacturing companies is of major concern today.
- There are many barriers in making a building sustainable and we always prefer comfort, so it is important to study its elements in detail and provide the better alternative options for all those critical elements which are majorly causing harm to our lives and environment.
- By studying this in depth we can create buildings with less impact on the environment than many other materials, often yielding immediate and measurable results toward sustainability.

- If we can provide proper economic substitute for the materials which causing major harm to environment, their demand in construction market will decrease, which will then minimise the number of industries and making the construction sustainable conventionally.

3. BACKGROUND OF THIS TOPIC:

The continuous use of construction materials like concrete, steel, plastics, aluminium which are major environmental and economic concerns have negatively affected societal development strategies. The construction and building industry, architects, designers, and builders, are dealing with the issues of green building design and sustainability from a long time.

By this we can contribute to the national and global over-arching goals of high performance and sustainable development.

The purpose of this study is to estimate a relation between construction materials as they are used as compliments or substitutes to each other and to qualitatively assess the environmental consequences of extraction, manufacture, use, and disposal of wood products, steel, aluminium, and cement.

4. AIMS & OBJECTIVES:

AIM:

- Finding sustainable, energy-efficient, readily available alternatives for the Steel and steel reinforcement.
- Implementing Sustainability & Green Building Principles in Construction Industry.
- Resource conservation, cost efficiency, Recycle, Reduce, Reuse.
- Proposing materials as sustainable replacement for steel in reinforcement having similar properties without losing the quality.
- Appropriate balance between economic, social and environmental issues

OBJECTIVE:

- Analyse the ecological, green & sustainable properties for elements of construction, hence making the building eco-friendly or sustainable while keeping the comfort intact.
- Outline how construction decisions and choices can promote sustainable & green development.
- Changing the way construction practitioners think about the information they use when handling building projects, and including sustainable elements right at the stage of construction.
- Studying what materials can be the alternative for the steel, which will have similar properties, more advantages, easy accessibility and will be sustainable, eco-friendly, vernacular and affordable.

  - ✓ Discuss the substitutes for Steel and how it will be more profitable than using steel in reinforcement having similar properties and advantages.
  - ✓ Compare how substitutes materials will be more efficient, waste reducing alternative to steel in reinforcement and cost-efficient at the same time.
  - ✓ Select a product that is durable and corrosion resistant to avoid maintenance and life cycle costs.
  - ✓ Minimising the discharge of pollutants and setting emission reducing targets from the steel industries by proposing alternatives to steel, thereby reducing the ever-growing demand of steel and steel reinforcement.

5. RESEARCH QUESTIONS-

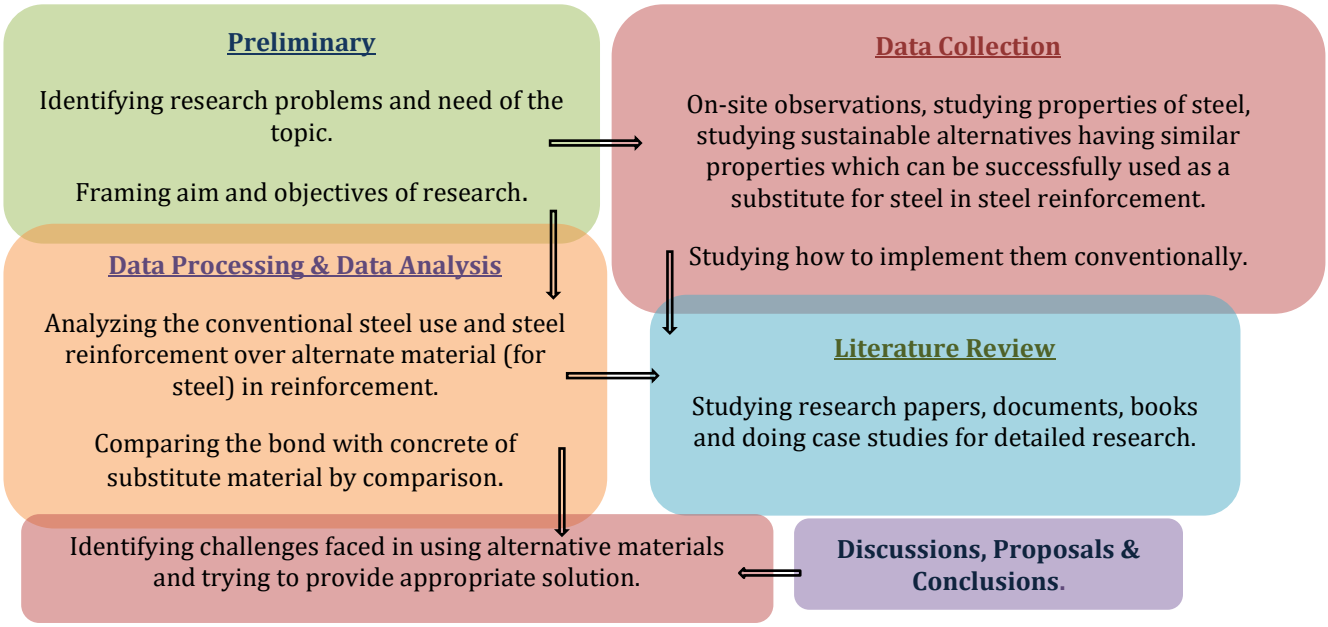
- Why people prefer conventional buildings over Sustainable and Green buildings?
- How can we make use of steel and steel reinforcement in construction more Sustainable or Ecofriendly?
- How steel reinforcement in construction adversely affects environment & human lives?
- Why 100% sustainable or ecofriendly building is impossible? What are hindrances in achieving it?
- What are the present elements and techniques in construction if steel that are harmful to environment and our lives?
- Up to how much percent we can reduce those by keeping our comfort and requirements intact?
- What is the role of architects, designers, construction managers & Government in achieving this?

6. FEIDS OF LITERATURE REVIEW & LITERATURE CASE STUDY:

- Studying the Critical elements of Construction and their harmful properties for environment.
- Finding better alternatives for those while keeping the comfort intact.
- Studying buildings which are most sustainable.
- Studying Green and eco-friendly buildings and factors making it suitable and eco-friendly.
- Find techniques and alternatives to the construction elements which are more sustainable comparatively, hence making it more acceptable.
- Studying every critical components & material of construction and proposing sustainable and ecofriendly alternatives to those.

7. METHODOLOGY-

This paper has study through research papers and case studies on overall sustainability of steel reinforcement in construction, with manufacturing, extraction and application processes, includes the detail note of sustainable substitutes for steel and steel construction. The term 'sustainable' mostly says safe and better practices which can benefit the society socially, financially and also environmentally, without depleting our natural resources. It does not mean using expensive materials techniques, but it actually implies proper selection of materials and right choices to be made at the construction phase only. I will try to include techniques and alternatives to the construction elements, especially steel, which are more sustainable comparatively. Literature reviews and case studies are also in the construction scenarios.



8. LITERATURE REVIEW-

8.1 Steel as a sustainable choice towards the green building concept

S. H. Taha[1], M. G. Ibrahim[1] & Ahmed Abdel Monteleb M. Ali[2]

In this paper, through life cycle assessment studies of various buildings, conclusion was drawn that green building construction is not a particular method, it is basically decision and choices of materials, techniques and technologies, and accordingly environmental performance of the building is checked. Thus, this paper highlights on how Steel as a construction material can fulfil the green building standards by making right choices.

As construction industry is the biggest to Green House gas emissions, it has become essential to fine alternate ways to current techniques by implementing green building designs, and make decisions of construction techniques appropriate to 'Green Building Rating Systems'. While trying to make steel sustainable two points were considered, first that steel was superior in energy consumption and another one was considering lifecycle inventory based on particular location.

One of strong points in making steel sustainable was that it was recyclable and reusable, making it an important material. Using recycled steel in all areas of construction can result to have an eco-friendly impact. Steel industry is the major contributor to the pollution and is the major problem, hence Cold-formed steel is the best option, as it meets the highest sustainability standards and is recognised as major green building materials by rating programs. This paper also suggests that further research like improvising the strengths, less maintenance factors including non-corrosion ability, pollution control, utilization in high rise buildings not only confining to mid-rise buildings and eco-friendly production is necessary.

8.2 Sustainability of buildings made of steel

Françoise Labory, Olivier Vassart, Louis-Guy Cajot

Modern steel construction is having some benefits like material efficiency, ultra-high recyclability, quality and durability, dry construction methods etc. But sustainability of construction is the major aspect which is decided as per the life cycle assessment of the building. This paper says that sustainable construction does not mean using new materials or making big investments, but it actually the right choices and decisions to be made regarding right materials and right combination of materials in right place.

The most common industry in the word i.e., steel industry is of major environmental concern today. In average18.6 mj/kg of energy is consumed for production of 1kg of finished steel. The strongest sustainability part of steel construction today is that it has 95% of recovery rate. But still main airborne pollution like CO2, NOX, SOX emissions is by steel industry only. In that, CO2 has about 98% contribution in pollution. Hence by using recycled steel, these emissions will not be there and they will not be combusted or deteriorated at a deposit. Steel can be recycled over and over again without quality loss. But more than 2 billion tonnes of steel out there is waiting to be recycled.

Hence steel can be highly sustainable due to high degree of recyclability, reusability and fabrication leading to less waste generation. And these wastes generated which are called by-products from steel production are used in many other applications such as road constructions. Even the sites from where the iron ore is extracted for steel production, which are situated underground, are refilled with those mineral wastes.

8.3 Comparative study on the amount of CO2 emission of building materials between reinforced concrete and steel structure buildings using the input-output analysis

Chang-U CHAE Ph.D.[1] Kang Hee LEE Ph. D[2]. Sung Cheol JUNG Ph.D.[3]

Throughout the life cycle of any building, it consumes energy, utilises resources and also emits large amount of carbon dioxide. In this paper two types of four public buildings were studied and analysed. For this, reinforced concrete and steel skeleton structures were selected. It was seen that the amount of CO2 emission of and amount of energy consumption in the building was similar. Further, it was seen that energy consumption and CO2 emission of steel bar and RCC was higher than any other materials in building.

In this paper analysis was done majorly during the construction phase and data was largely collected on site. Remaining data was obtained by using input-output analysis, to estimate amount of energy consumption and CO2 emission from product level to industry level. After analysis results shown that major building works contributing to CO2 emissions were RCC and Steel works with window and door works. In that, amount of CO2 emissions by steel work was around 2 kg-C/m^2 which was more than RCC work, concrete and steel skeleton work. Therefore, it was clear that RCC building (72 kg-C/m^2) emits less CO2 than steel skeleton building (103 kg-C/m^2). This result shown that Steel emits 40% more CO2 than the concrete.

8.4 Environmental Ramifications of Various Materials Used in Construction and Manufacture in the United States

Susan Alexander and Brian Greber

This paper specially studies the relation between different construction materials as many of the materials are used as an alternative to other, such as steel, timber, cement etc. This was done by checking environmental effect of these materials and by studying extraction, manufacture, use and disposal also. While studying steel industry, it includes mining of coal, mining of iron ore and finally shaping of steel products, making it one of a most complex industry.

Major problems in steel industry includes the pollution it makes at the large scale in the form of solid waste which mainly includes stream sedimentation, liquid waste particularly from coal mining and also the gaseous wastes. While production of steel, open system of production creates almost 40% more pollution as compared to the closed system. Ferrous and slag are the by-products created on large amount while steel production, and necessary efforts are needed to be taken to put these by-products in good use, while making them a waste material, hence reducing pollution.

8.5 Steel Slag as A Road Construction Material

Mohd. Rosli Hainina, Md. Maniruzzaman A. Aziza,b, Zulfiqar Alia, Ramadhansyah Putra Jayaa , Moetaz M. El-Sergany c, Haryati Yaacoba

In production of steel, many by-products are also created during the process. One of the important and useful by-products is steel slag as it is having many advantages with high engineering properties. It is basically the mixture of higher value of bitumen content. This study showed that steel slag has enough potential to be used as an important product in many areas such as roads, embankments etc. Also, steel slag is cheaper being a by-product. But if the transportation charges are added, it can be expensive for areas which not in vicinity in steel industry area. Paper also says that if geotechnical properties of steel are studied properly and other areas like shear strength, compaction characteristics are properly analysed, this product can be explored further.

8.6 Bamboo as an Alternative to Steel for Green Construction Towards Low-Cost Housing

Alvin Harison[1]*, Akash Agrawal[2], Ashhad Imam[3]

Amongst many advantages of using bamboo instead of steel one of the important advantages is it is cheap and is readily available making it beneficial for rural and unreachable areas. This makes it perfect for low- cost housing as well, thereby reducing high demand of steel and pollution. This was proved in this paper by various lab experiments of tensile, compressive, split tensile strength and flexural strength of bamboo reinforced concrete for green construction. After the analysis of all these tests for bamboo reinforcement with M20 grade off concrete, of various lengths, widths and sizes, it was resulted that replacement of bamboo with steel in reinforcement requires precise arrangements and also binding and bonding of bamboo with concrete should be taken proper care.

- Compressive strength of bamboo reinforcement – 28 days – 23.2 N/mm^2
  Compressive strength of bamboo reinforcement – 14 days – 21.5 N/mm^2
  Compressive strength of bamboo reinforcement – 7 days – 20.38 N/mm^2
- Compressive strength of PCC – 28 days – 20.9 N/mm^2
  Compressive strength of PCC – 14 days – 19.7 N/mm^2
  Compressive strength of PCC – 7 days – 18.5 N/mm^2

Therefore, 10 – 15% rise is seen in compressive strength of bamboo reinforcement.

- Split Tensile strength (Normal reinforcement) – 28 days – 1.69 N/mm^2
  Split Tensile strength of (Normal reinforcement) – 14 days – 1.59 N/mm^2
  Split Tensile strength of (Normal reinforcement) – 7 days – 1.53 N/mm^2
- Split Tensile strength of bamboo reinforcement – 28 days – 1.67 N/mm^2
  Split Tensile strength of bamboo reinforcement – 14 days – 1.59 N/mm^2
  Split Tensile strength of bamboo reinforcement – 7 days – 1.53 N/mm^2

Therefore, almost similar results were observed here, but to some extent magnitudes are different.

Thus, flexural strength and compressive strength of bamboo is as good as Steel. Split tensile strength on the other hand is almost similar to that of steel. This Paper also suggest that development of simple design code for application of bamboo in construction is needed.

8.6 Comparative study on replacement of steel reinforcement with bamboo reinforcement

NIKHIL. N

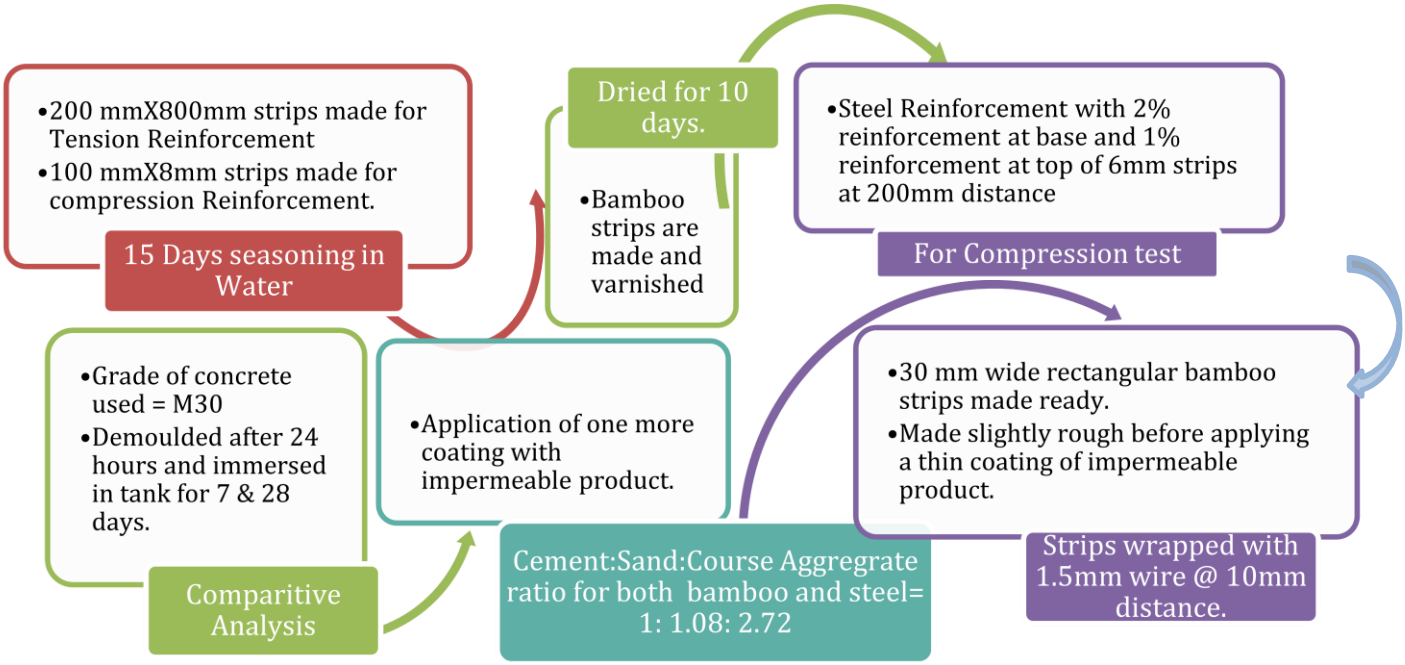
Bamboo being natural material, properties of steel are compared with bamboo in this paper and bamboo reinforcement is suggested to be used as substitute to steel reinforcement. Amongst 130 species of bamboo, commercially significant ones are-

Bambusa nutans, Bambusa pallida, Bambusa polymorpha, Bambusa balcooa, Dendrocalamus hamiltonii, Bambusa bambos, Dendrocalamus brandisi, Bambusa tulda, Dendrocalamus giganteus, Bambusa vulgaris.

But still use bamboo reinforcement is very limited due to some uncertainties. To eradicate this, tensile strength test was carried out and analysed in this paper.

- Tensile strength of bamboo reinforcement – 7 days – 9.25 kN
- Tensile strength of bamboo reinforcement – 28 days – 18.5 kN

Hence all such tests and comparative analysis of bamboo reinforcement and steel reinforcement showed that bamboo is a very good substitute and awareness is needed about the use of bamboo reinforcement.



8.8. Review of bamboo as reinforcement material in concrete structure

Ajinkya Kaware[1], Prof. U.R. Awari[2], Prof. M.R. Wakchaure[3]

Bamboo completes its growth within some months and is fully matured in 3 years. It has good tensile and compression strength. Dendrocalamus strictus, bambusa vulgaris schard are various species of bamboo which has highest value of tensile and compression strength. In this paper all problems of bamboo in using it as reinforcement for alternative for steel are focused by analysing mechanical, physical properties of it as well reviewing bamboo reinforced column & beams. In those problems, major problems noticed were water absorption and moisture content. For avoiding these issues, proper seasoning or treatment was given and analysed. It was also proved that dendrocalamus strictus and Bambusa vulgaris schard had highest compression value. But, bamboo ae per results bambbo was weak in shear and it failed to be used as shear reinforcement in R.C.C structure. As studies of researchers say that around next 60 years steel production can be reduced greatly, thus making natural and eco-friendly options like bamboo important. Treating bamboo with epoxy coating, tar coating etc. can eradicate the weakness of bamboo in bond stress.

8.9. Analysis of bamboo reinforced concrete column

Ajinkya Kaware[1], Prof. U.R. Awari[2], Prof. M.R. Wakchaure[3]

This paper proves how bamboo can be a successful substitute for steel in reinforcement by testing bamboo reinforced concrete column and compared with steel reinforced concrete column of similar dimensions, number and shape with

minimum steel reinforcement as per IS 456:2000. The results gave few rules to be followed for making bamboo reinforcement successful. Split bamboo reinforcement with width used 2-2.5 cm should be seasoned straight. Minimum width of column should be 230mm. Proper workmanship and skilled labour are needed for this work. Good water repellent products and good bond quality products are needed to be applied. Before using for reinforcement, bamboo should be seasoned for the period of 6 months. If exposed in environment the chances of swelling and decaying are increased. After all the results it was proved that bamboo can successfully be used as substitute for steel reinforcement.

8.10. Effect of moisture content on physical and mechanical properties of bamboo

M.R. Wakchaure* and S.Y. Kute Department of Civil Engineering, K.K. Wagh Institute of Engineering Education and Research, Nashik, India

Bamboo is a giant grass which grows within some months and if fully grown around 3 years and there is no secondary growth. For ideally replacing bamboo with steel in reinforcement, physical and mechanical properties of bamboo are needed to be studied, which are included in this paper. While addressing one of the important problems in bamboo reinforcement, it was seen that moisture in bamboo varies along the height location. According to height and age of bamboo its physical and mechanical properties also vary. Due to this high moisture content special care should be taken of insect attacks, levels of starch watering, humidity etc. But this rate of absorbing water id high in initial 72 hours only and it drops after that. Bamboo with less humidity is led prone to attacks of mould, especially with humidity less than 15%.

- Change in length < Change in width and height.
- % Of dimensional change due to water absorption while seasoning of bamboo (7 days).
  1 month – 7.59%
  6-12 months – 10%
- Tensile strength of middle portion of Bamboo < Top portion.

8.11. Study and Use of Bamboo Reinforcement in Concrete

MS. Pooja Dagade[1], MS. Laxmi Jakapure[2], MS. Nikita Khule[3], MR. Rushikesh Kuwar[4]

Bamboo is a type of grass which grows within some months and completely grows within 3 years. In Maharashtra it is also called as 'velu'. Bamboo has the highest value of tensile and compressive strength but some of its problem like water absorption and moisture content are the reason due to which it is not used as a construction material. In this paper bamboo was studied as a reinforcement in concrete. Bamboo concrete in reinforcement and construction follows same design and principles, same mix proportion and concrete techniques as we use for steel reinforcement. Also, properties of bamboo reinforcement are very similar to that of the steel reinforcement. This paper highlights the point of awareness about bamboo and it should be used as reinforcement instead of using steel as it is causing lot more pollution. It also gives conclusion that we should make software for bamboo to use it as reinforcement in concrete. This is due to the fact that it is cheaper then steel and is good option for economical construction.

8.12. Cross-laminated timber vs. concrete/steel: cost comparison using a case study.

Maria Fernanda Laguarda Mallo[1] and Omar Espinoza[2]

Cross laminated timber (CLT) is an innovative material having multi layered panels glued together at 90◦ . The main aim of this research paper was comparing CLT with concrete and steel in terms of traditional concrete systems. The main aim of CLT was using it as an alternative structural system and checking its feasibility and economic performance, and later comparing it with concrete and steel. Use of this material greatly depends on the type of building and type of the project we are working. CLT was capable of significantly reducing the cost by 21.7% in the cost of structure. But this cost competitiveness and feasibility varies greatly depending on the type and complexity of the project we are working with.

8.13. Sustainable Cross-Laminated Timber Structures in a Seismic Area: Overview and Future Trends

Antonio Sandoli *, Claudio D'Ambra, Carla Ceraldi, Bruno Calderoni and Andrea Prota

Now-a-days study of cross laminated timber is carried on a large scale because it is highly sustainable structures achieved from extraction from raw materials, manufacturing, use, disposal and also recycling. In order to study properties of cross laminated timber this paper studies the CLT buildings in seismic prone areas.Timber products such as Glulam, Cross

laminated timber, laminated veneer lumber are the species of timber used in construction and which can be replaceable for steel.

Also detailed study of cross laminated timber is studied through life cycle assessment reports of cross laminated timber. It is composed of number of layer of boards made with adjacent boards rotated around right angle and glued together. But depending on geographic area this board arrangement can be different. CLT have high load bearing capacity, high strength and stiffness, good dimensional stability, excellent energy efficiency, is eco-friendly, recyclable, renewable, have good vocabulary, Slenderness and is also available in different sizes. Hence high-rise buildings can also be constructed using this product with reduced masses. These aspects of CLT exhibit good seismic performance and also structural damage in timber components is comparatively less.

8.14. Steel Reinforced Glue Laminated Timber

By William M. Bulleit[1] Member, ASCE, L. Bogue Sandberg[2] Member, ASCE, and Greg J. Woods [3]

In this paper glulam beams are selected and examined as a replacement of steel in concrete reinforcement. 2/6 glue-laminated beams were successfully reinforced with a composite consisting of concrete and reinforcement steel embedded in flakeboard. Paper gives the result that dry beams exhibited stiffness of 24 to 32% over under reinforced control beams, whereas movement was seen to be increased by 30%. On the other hand, the moisture recycled beams where having this difference increased by 30% but there was no change in moment capacity.

8.15. Bond behaviour of steel and timber reinforcement in wood-cement compounds

Marco Maeder, Prof. Dr. Daia Zwicky

The previous studies on development, workability, mechanical properties and recyclability of wood-cement compound (WCC) show that this material can be used as main construction material and not just the finishing layers. This paper includes the study and comparison of steel reinforcement and timber wood-cement compound (TWCCC) by carrying out some tests. Steel reinforcement was formed by longitudinal and cross-bars. The timber reinforcement was formed only by timber battens. Timber battens showed similar behaviour to the steel bars considering the decrease of slip between loaded and unloaded ends. Results also showed, to increase the bond strength between timber and concrete, its surface was needed to be made slightly rough. Timber batten with the rougher surface was able to anchor a high tensile force.

8.16. Reinforcement of timber beams

Steffen Franke[1], Bettina Franke[2], Annette M. Harte[3]

This paper studies the emerging and available methods for repairing or enhancing the structural performance of timber beams. This is done by presenting main materials, cross sections, geometry of timber beams, general failure modes, typical reinforcement methods and other techniques. These reinforcement methods include wood to wood replacements, mechanical fasteners, use of rods and screws, and also adding strength to the material. This study shows how this type of material can be made stronger by using nano technologies. The additional strengths added through nanotechnology is self-cleaning, water resistance, fire resistance, scratch resistance, graffiti resistance and antibacterial coating. This study also suggests us to focus on reinforcement of historical timber structures and analysis should be done properly regarding it.

8.17. Reinforcement of timber columns and shear walls

Wen-Shao Chang[1]

This paper concentrates on repairing and reinforcing techniques on timber columns and shear walls. By reinforcing the timber shear walls we can increase its stiffness, strength, ductility and energy dissipation capacity. But with it repairing and strengthening through intervention of joints is very important. For this, there are various solutions for strengthening of timber shear walls like, using additional sheathing, reinforcing shear walls with steel diagonal elements, adding carbon or high tensile synthetic fibre, using hardwood inserts, post-tensioning the walls with prestressing wire etc. This paper shows reinforcement of columns with screws and composite materials like FRP for long-term performance.

8.18. Replacement of steel rebars by GFRP rebars in the concrete Structures

Shahad Abdul AdheemS JabbarSaad B.H. Farid

Glass fibre reinforced polymer (GFRP) is one of the important materials which can be a substitute for steel in concrete technology. GFRP rebars have diameter of 12.5 mm and are modified by inclusion of course aggregate and that will increase the bond strength between the concrete and GFRP. To prove the strength of GFRP bars, it is compared with steel rebars in this paper. It was also shown that GFRP rebars if coated with sand, its bond strength with concrete was increased. After the tests and analysis was done, results showed that glass fibre reinforced polymer was having light weight, non-corrosive properties, super tensile strength and was having high mechanical performance than the steel rebars. Also, the price comparative to steel was less. Analysis also showed that tensile strength of GFRP bar is 13% high then steel rebars, compressive strength of GFRP was 58% higher than steel, bend strength was also good, yield strength of GFRP rebars was 72%. The flexural strength and compressive strength were also noted good. Hence results showed that GFRP reinforcement was better than steel reinforcement.

8.19. Replacement of steel with GFRP for sustainable reinforced concrete

This paper includes the investigation of GFRP bars as internal reinforcement in concrete structures. GFRP bars has good performance in compression, tension, shear and cyclic loads. This is the main reason why we should study the behaviour of GFRP reinforcement under variety of loads. GFRP reinforced concrete was having low stiffness and deflection as compared to steel reinforcement. The overall strength and ductility of the columns reinforced with GFRP bars with combination of steel longitudinal bars was found to be almost similar or better than the columns confined with steel spirals. This paper also gives the conclusion that GFRP spirals can be used as lateral reinforcement in columns designed for non-seismic or seismic regions.

8.20. Experimental study of replacement of steel bars with FRP bars

[1]Vishwal Deshmukh, [2]Phadatare N. P

FRP is the composite cloth made from polymer matrix bolstered with fibres. FRP have good energy-to-weight ratio comparatively. GFRP reinforcement have better corrosion resistance property and higher tensile strength than steel bar. Yield tensile strength of GFRP rebar was 14% better than metallic rebar. Yield stress of GFRP is 60% higher than metal. GFRP is better than steel by almost 23%. But sand coated GFRP was seen to be more durable. Where flexural strength of clean GFRP was 66-71%, for sand coated GFRP it was 71-76%. Hence paper gives the final analysis that sand coated GFRP bars were having higher concrete adherence values than normal GFRP bars. Also, concrete bond between sand coated GFRP bars was twice as compared to normal GFRP bars.

8.21. Is GFRP Rebar a Potential Replacement for Steel Reinforcement in Concrete Structures?

P. Gandhi, D.M. Pukazhendhi, S. Vishnuvardhan, M. Saravanan and G. Raghava

GFRP has the good potential to be replaced as steel in steel reinforcement. In this paper tests were carried out by taking concrete beams with GFRP bars of dimensions 100mmX200mmX1500mm for study and then subjected to static monotonic loading to analyse flexural behaviour. This study was analysed under four-point loading of 70, 60, 50, and 40% of static ultimate loading. The cracks were seen very early in GFRP reinforcements. The average ultimate loading for GFRP reinforcement was 59.2kN, and accordingly its average deflection was 18.2mm. Paper shown that the use of GFRP bars subjected to fatigue loading seem to be undesirable. But when these GFRP reinforcement was modified for matching serviceability conditions with Thermo-Mechanical-Treated (TMT) bars, there was lot more improvement in the results.

8.22. Steel Versus GFRP Rebars?

Roger H. L. Chen, Jeong-Hoon Choi, Hota V. GangaRao, and Peter A. Kopac

GFPR is one of the trending materials in construction industry being lightweight, free of corrosion, durable, high tensile strength, and affordable. GFRP rebars are composed of calcium aluminosilicate glass fibres and urethane vinyl ester reason matrix of 70% minimum fibre content in it. In this paper the steel rebars replaced with GFPR rebars.
The results found where as follows-

Item	Steel-Reinforced CRCP	GFRP-Reinforced CRCP
Slab Width	7.32 meters (24 feet)	7.32 meters (24 feet)
Longitudinal Reinforcement	# 6 rebar at 6-inch spacing	# 7 rebar 6-inch spacing
Diameter of Longitudinal Rebars	0.75 inch	0.875 inch
Required Concrete Compressive Strength	40.7 MPa	40.7 MPa
Average Compressive Strength at 7 Days	19.7 MPa	19.7 MPa
Average Compressive Strength at 28 Days	26.9 MPa	26.9 MPa
Average Compressive Strength at 4 Months	37.6 MPa	37.9 MPa
Midsection Cracks at 3 Days	45	19
Midsection Cracks at 38 Days	75	40

Fig: Comparative analysis between Steel-Reinforced and GFRP-Reinforced

8.23. Fibre reinforced polymer and steel rebar comparative performance

Richardson A, Drew P

This paper includes comparative analysis of fibre reinforced polymer (FRP) and steel rebar, and the study of its tensile forces, bond strength, flexural strength etc. For this 6mm diameter steel and FRP rebars were compared. For bond strength 12 concrete cubes of 150mm were studied, of which 5 had steel rebar and other 6 had FRP rebar. For flexural strength, 3-point loading test was conducted by taking 28 concrete beams of 500X100X100 mm. It was seen that FRP rebars had surpassed steel in each test. Also, failure modes of FRP rebars had higher degrees of toughness as compared to steel. FRP rebars is about 2.5 times cost of steel, but in terms of corrosion prevention, coatings, or stainless steel, FRP can prove to be cheaper as well as durable.

8.24. Replacement of conventional steel stirrups by internal reinforcing CFRP grids in shear of concrete beams

Sirapong SUWANPANJASIL[1], Takuro NAKAMURA[2], Koji MATSUMOTO[3] and Junichiro NIWA[4]

In this paper the conventional steel stirrups are replaced with CFRP grides inside the concrete cover. Then these two grids are compared and analysed. Results show that the shear capacity carried by CFRP grids was improved when higher amount of grid strips were provided in it. The location of this internal grid also mattered a lot. However, the increment of internal grid is not proportional to the number of grid strips. This is due to the fact that each strip in the grid cannot equally resist the shear force.

8.25. Structural behaviour of CFRP reinforced concrete members under monotonic and cyclic long-term loading

Redouan El Ghadioui Dominik Hiesch. Lukas Bujotzek. Tilo Proske. Carl-Alexander Graubner

The corrosion of steel in reinforced concrete can cause a lot of damage to the structure. CFRP is having high strength, corrosion resistance and is made up of reinforced polymers and hence it is becoming more and more important in structural engineering. But for using it as an alternative for steel reinforcement deep knowledge of this material is required in order to ensure safe and economic design. This paper studies the long-term behaviour of CFRP reinforced concrete members and are compared with steel rainforest concrete to get the results. It was seen that concrete members with CFRP reinforcement have high resistance to monotonic and cyclic loading. Comparatively FRP reinforcement generally tends to creep.

8.26. Transient Thermal Analysis of Steel, CFRP & GFRP Reinforced Beams

Reshma Merin Roy[1], Jeena B Edayadiyil[2]

This paper presents an attempt to model the nonlinear behaviour of beams, which were reinforced with steel, CFRP & GFRP bars FRP are composite materials which consist of fibres in a polymer matrix. From some years FRP is used in reinforcement in concrete structures as an alternative to steel reinforcement in concrete structures. There are different types of FRP materials such as GFRP, CFRP, AFRP. FRP reinforcement can be used in bridges, multi-storey buildings, industrial structures or in some places to overcome the fire effects. In this paper various beams such as steel reinforced beams CFRP reinforced beams and GFRP reinforced beams were studied. after analysis it was seen that GFRP reinforcement was having lesser deformation than CFRP reinforcement and steel reinforcement. Paper also gives the conclusion of FRP can be used as a better alternative to steal reinforcement as both CFRP and GFRP bars.

From the transient thermal analysis, it is clear that GFRP reinforced beam has lesser deformation as compared with CFRP reinforced beam and steel reinforced beam. FRP can be used as a substitute to steel reinforcement as both CFRP & GFRP bars are noted nearly equal deformation results and this deformation is very small compared with steel bars.

8.27. Seismic performance of building reinforced with CFRP bars

Suriyati[1], Ridwan[1], Zulfikar Djauhari[1], and Iskandar Romey Sitompul[1]

The study of past few years shows that FRP bars can replace steel bars as internal reinforcement in concrete structures. This paper studies the behaviour of reinforces concrete, CFRP and steel bars. For this a building of 4.0 m height for ground floor and 3.6m height for remaining 6 floors, was studied and analysed. It was seen that number of bar areas for reinforcement of building with CFRP bars was reduced and maximum force demand of the building was enhanced 1.9 times as compared to reinforcement with steel bars. The use of CFRP bars in reinforcement did not change the frame behaviour to be the brittle one. The ductility of structure with CFRP bars was 4.1 and that of steel was 6.3.

9. LITERATURE REVIEW-

9.1. Sharma Springs INDONESIA

IBUKU Architects

Sharma Springs was designed a family which was built almost entirely of bamboo near Ayung river valley. It is a 6-level, 4-bedroom 750sqm home, completed in the year 2012. This is one of complex bamboo structures, with 6 levels, built with help of engineering team to confirm the organically shaped, safe and pleasant structure. The dramatic entry of this house is directly on 4th floor through a tunnel-bridge. This is a traditional as well as modern house of which the outer shell has an implicative image of traditional Bali house.

- Bamboo Engineer: AsharSaputra.
- MEP Engineer: CV Solusi Strategis
- Lighting Designer: Phil Wilson, CV Solusi Strategis.

It has a central tower and staircase surrounding it which connects all levels and spaces that are enclosed for air-conditioning purpose. The 6th-floor is designed as a semi-open space called as belvedere point with sit-outs overlooking Ayung river valley and Green Village. The interior, plumbing and other metal features are

custom-built and every detail is studied. The garden surrounding the structure follows design principles of permaculture.

Fig: Sharma Springs

Fig: Dramatic Tunnel-bridge

Fig: Staircase surrounding Central tower

Fig: Interior

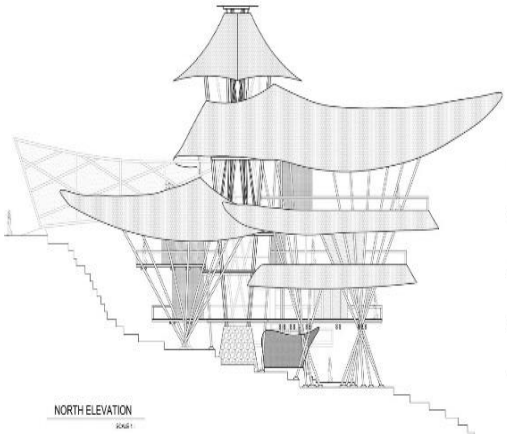


Fig: Side elevation

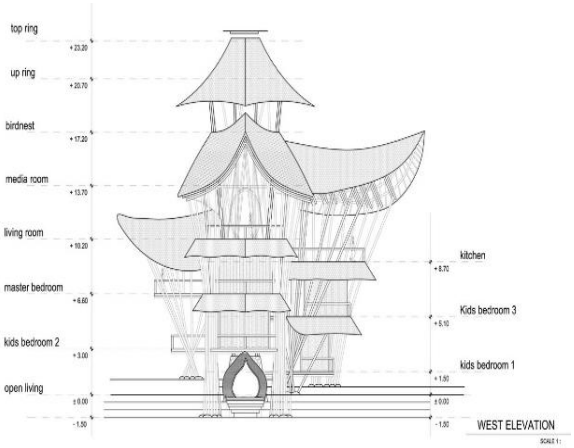


Fig: Side elevation 2

The repetitive pattern, contrast smooth surface of floors, use of soft pastel color spots makes this structure unique and powerful. Furniture is also of bamboo having combination of different shapes and patterns creating a relaxing work environment.

PLANNING DETAILS

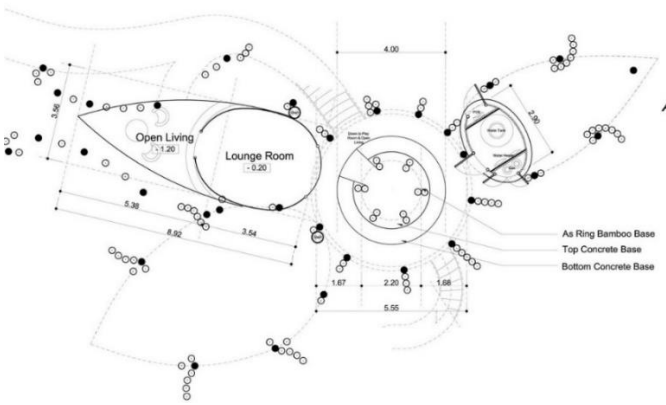


Fig: 1st Floor Plan

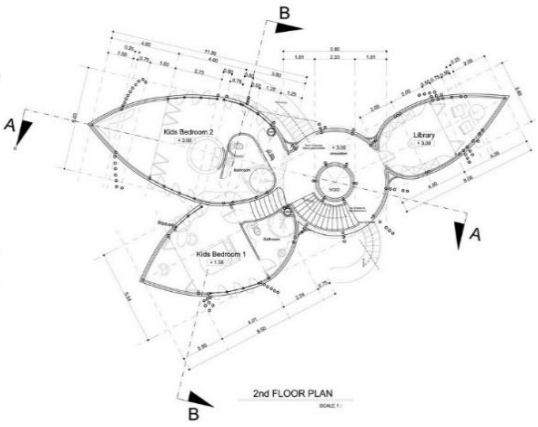


Fig: 2nd Floor Plan

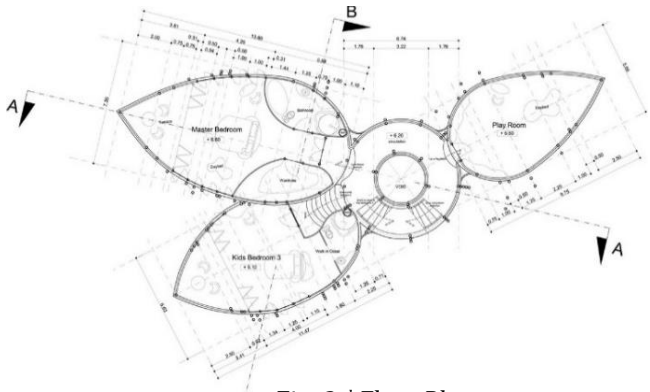


Fig: 3rd Floor Plan

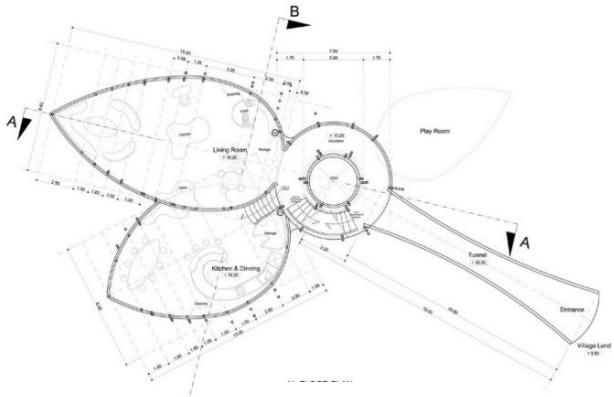


Fig: 4th Floor Plan

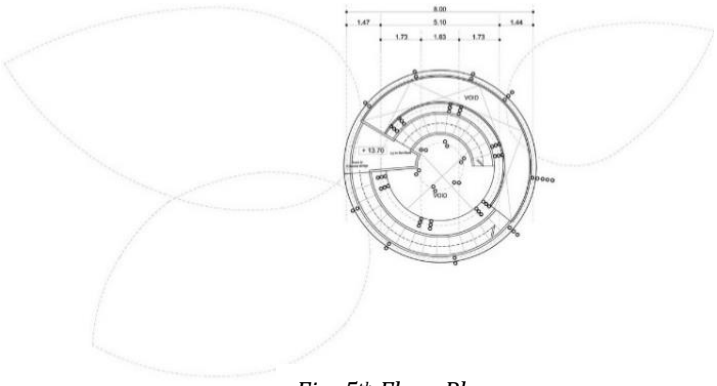


Fig: 5th Floor Plan

CONSTRUCTION DETAILS

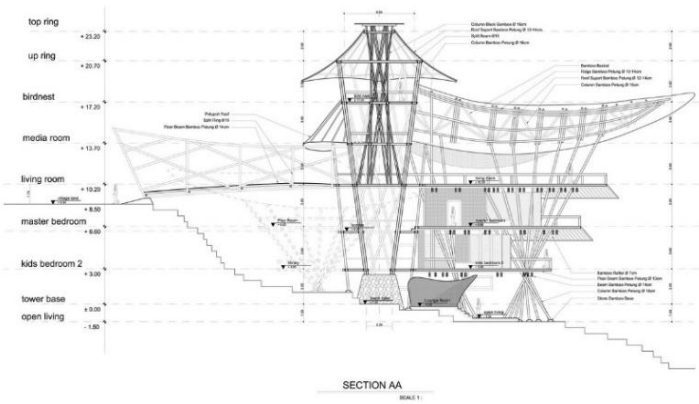


Fig: Side Elevation 3

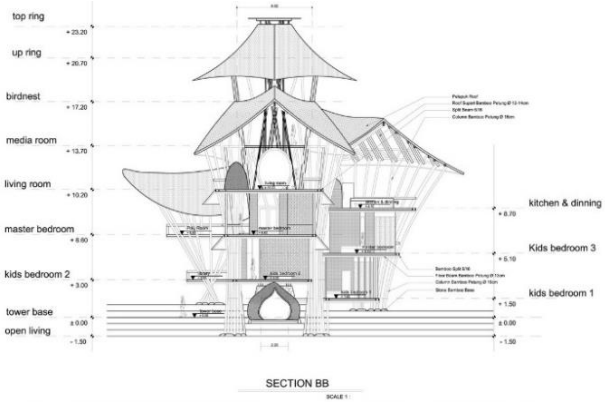


Fig: Side Elevation 4

9.2. Ancient 5 Storey Pagoda of Horyu-Ji Temple

Japan

In Japan even after many reports of earthquakes no serious damage was seen on to any of the ancient wooden pagodas. After the analysis of these pagodas, it was seen to have several factors of earthquake resistance like friction damping and sliding effect of the wooden joints, base isolation effects, balancing toy effects of deep eaves , bolt fastening effect of the center column etc.

Two more impressive features are the pliant impression suggestive of a flexible nature of its structure and deep eaves. Important Characteristic features of five-story pagoda of Horyuji are-

1. Height: Width = 5.1 (Main structure in the first story)
2. Width of top story: Width of first story = 0.51 (Of Main structure)
3. Lengths of eaves: Widths of the main structure =2.2 (first story), 3.0 (fifth story).
4. Sorin: total height = 1:3.4
5. Material = Wood
6. Contains many complex joints or connections between wood members. E.g.- `Kumimono`.
7. 1st storey columns are not tied down to foundation. Framework in each story is independent, no column ties them together.
8. One central continuous column supports the ornamental structure on the top. (This central column was buried in a deep hole in the ground in original structure but now it stands on a base stone in the podium.)

To study the construction techniques and based on this research some points were listed and illustrated like the base stone and column had a sliding effect during the earthquake which contributed in resistance i.e., base isolation, there were slipping and gaps in the wooden joint and hence friction damping effect was there between the wooden joints, balancing toy effect due to deep eaves was noted due to which building had a oscillation effect like a snake dance, eradicating any

damage on structure, central column had a TMD effect and this collision between this central column and main structure was making a bolt effect. Hence all these factors contributed to earthquake resistance of the pagoda for long time period of 1300 years.

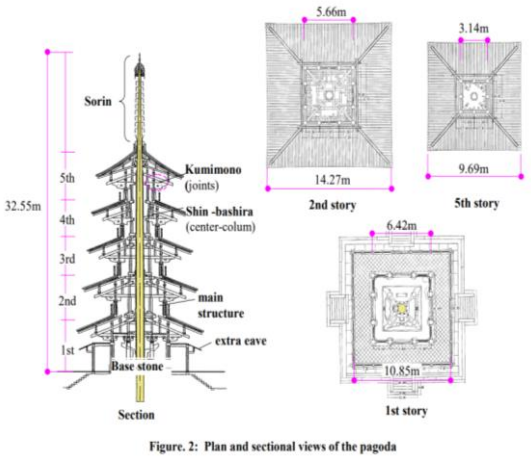


Fig: Plan & Section of Pagoda.

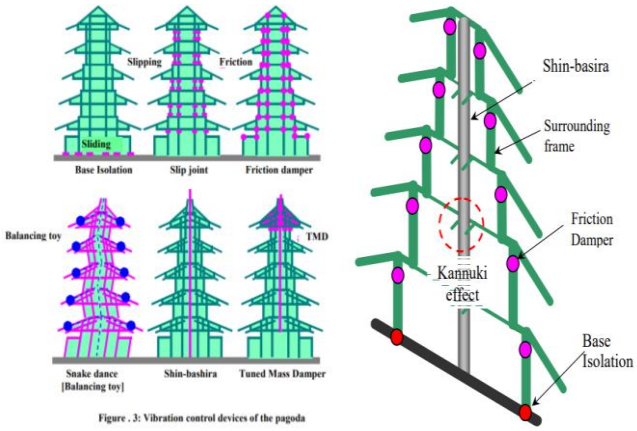


Fig: Vibration control devices of pagoda

3. The Netherlands' Tallest Timber Tower to be Built in Amsterdam

Team V Architectuur with Lingotto, Nicole Maarsen and ARUP

The municipality of Amsterdam has begun a construction of a 73-meter residential tower named `Haute Couture` and located in Netherland tower located along the Amstel River. When completed it is said be the tallest timber framed building or tallest wooden tower in the world depending on construction schedules. Building is 21-storeyed in which interior surfaces are also cladded in wood and the design of composition of cantilevered balconies, double height spaces, large windows etc, make this building unique. The building has a triangular plinth and an underground car park. The basic motif and idea behind this building was that over 3-million kilos of carbon dioxide will be stored in the cross laminated pieces used as a main material which was chosen considering the sustainable nature. There many other important features like energy generating facades, wastewater purification system, highest possible sustainability grade, outstanding rating by BREEAM etc.

Fig: HAUT residential tower

Fig: Triangular Plinth

Reuse Scenarios

Fig - SEGRO warehouse, Slough, UK (Relocation with the help of original designers)

Fig- S-Market, Finland (Deconstruction and reassembly of a steel structure in a new location

- The research and studies showed that the reuse of existing steel i.e., recycled steel in structure is always the best and feasible.
- The study of many case studies mainly included the use of recycled steel for the entire primary structure.
- The dismantling process is easier in the case of structures using bolted connections.
- But the reused steel structures also need to have some extra strength by the addition or change of some structural components and elements.
- The reuse process is easier when the original project and material certificates are available.

10. FINDINGS-

1. Using recycled steel is the best option in all areas which leads to eco-friendly development with safe and better help in future generations.

One of strong points of steel is that it is easily recyclable and reusable. Recycled steel is the best option in major construction areas which has an eco-friendly impact.

2. Sustainable construction does not just include using new materials or making huge investments, it is the right choices and decisions we make regarding the materials, techniques or combination of materials in right places, and at right phase of construction. By-products of steel production needs to be wisely used without any wastes and waste disposals. Even the sites situated underground, from where Steel is extracted are refilled with the mineral wastes.

3. Major CO2 emissions, throughout the life cycle of the building, main building works contributing to CO2 emissions were RCC and steel. But amount of emissions by steel work was around 103 kg-C/m^2 which was way more than RCC works that was 72 kg-C/m^2. Thus, this study shown that steel emits 40% more CO2 than the concrete.

4. The steel industry mainly includes mining of coal and iron creating many by-products and wastes, thus creating major problem of solid waste and pollution. In open system of production 40% more gas and waste produced as compared to the closed system. Efforts should be made in making good use of these by-products. For example, previously slag was been dumped near the steel mills creating serious air pollution problems. But now steel is effectively used in the road construction, making this by-product similarly useful.

5. The steel slag is now a use material having number of advantages with high engineering properties. Slag being a by-product can be cheaper if utilised in urban road, but its transportation charges make this product expensive for rural roads. Hence bamboo reinforcement is the good alternative for the steel reinforcement for concrete.

6. Today as there is a **need to replace the steel with alternative material** which is more non-polluting, consumes less energy, also should be readily available and sustainable in nature, after studying properties of bamboo, it is proved to be best alternative for the steel in reinforcement in concrete. As per various tests on bamboo were conducted, it was clear that it was having good tensile strength as steel.

7. As studies show that **demand of steel** is estimated to increase five times by 2050, the availability of steel, transportation demands, industrial growth, pollution, CO2 emissions is the important facts to consider in construction industry. Even today when 'Centre for Science and Environment' gave 19 out of 100 to Indian steel industry after studying its environmental profile. As bamboo matches the properties of steel reinforcement, awareness should there among us that bamboo reinforcement is a good alternative for steel reinforcement.

8. From last two decades **timber-based structures** are being studied, and products such as Glue-Lam, Cross-laminated timber (CLT), Laminated Veneer Lumber (LVL), are used. Cross-laminated timber buildings can be majorly used in seismic prone areas. Reinforcement of timber structures is thus important part to study. Many more techniques are still being studied and efforts are still made to make these products more suitable in reinforcement. For now, some products such as small glue laminated beams are successfully reinforced in tests carried out with concrete and later compared to the Steel reinforcement. But reinforcement effect is not as precise as compared to bamboo. The wood modulus elasticity still needs to studied and efforts are needed to made for bond strength of timber with the concrete. This is due to the fact that CLT can significantly reduce the cost by 21.7% in the cost of structure.

9. Depending on this **bond behaviour** is specially studied of timber reinforcement in wood and cement compounds and accordingly necessary tests were carried out. After analysis of timber reinforcement of several longitudinal timber battens having different surface roughness, bond strength of both steel and timber reinforcement was checked. It was seen that roughness of timber surface majorly made impact on the bond strength. But more tests are needed to study this behaviour of timber reinforcement system.

10. GFPR i.e., Glass fibre reinforced polymer is one of the major solutions as an alternative to the steel rebars. This is because GFRP reinforcement has higher tensile strength and ever more corrosion resistance as compared to the steel rebars. These studies make clear that GFRP has 58% higher yield strain, 13% higher yield strength than steel rebar. But for now, GFRP rebars have limited serviceability and hence efforts should be made for global acceptance of GFRP reinforcement bars. In addition, sand coated GFRP bars showed more strong bond strength as compared to normal GFPR rebars.

10. Fibre reinforced polymer is used as replacement for the steel reinforcement in concrete structures. The Carbon fibre reinforced polymer i.e., CFRP reinforcement can be used in construction of bridges, multistorey buildings, industrial structures, parking areas etc. as it is having enormous economic potential. (CFPR). Use of CFRP bars as internal reinforcement in RCC structures can increase maximum loading capacity. Also, CFRP reinforcement provide high resistance to monotonic and cyclic loading.

11. PROPOSALS-

- **Reclaimed or Recycled Steel**
- **Bamboo** is a dynamic emerging material in construction industry which has very high potential for bamboo reinforcement (as replacement for steel reinforcement), development in disaster prone areas, earthquake resistant structures, rural construction projects etc. as matches many properties of the steel and can be successfully used as substitute for replacement. This was proved by conducting several tests and results were passed bamboo to be in reinforcement in concrete. But standard building codes of bamboo are still not proposed, and bamboo reinforcement official methods of test are still not conducted, hence it is still to be officially passed as a building material in construction industry.
- **Failure-** In steel reinforcement concrete progressive cracks are developed, or continuing patterns of cracks are seen. But in bamboo reinforcement concrete, mostly brittle failure, or cracks at one particular area can be developed. This generally happens due to poor bonding between bamboo and concrete and this failure can be eradicated by properly using the bamboo dust in this process, which will eventually increase the bond strength with concrete.
- **Cross- laminated-timber (CLT) and Glue-laminated timber (glulam)** are increasingly used and are good substitutes in place of steel or concrete.
- **CFPR** carbon fibre-reinforced polymers
- **GFRP** Glass fibre-reinforced polymer rebar
- **LVL** Laminated Veneer Lumber

➢ OTHER ALTERNATIVE STEEL APPLICATION IN CONSTRUCTION-

- **Lumber & emerging wooden Skyscrapers**

  The introduction of new and trending technology of cross-laminated timber (CLT) makes wood an incredibly strong building material for skyscrapers. CLT is created by gluing together individual strips of wood due to which sturdy beams created. Hence, this shows that there is no need to harvest old-growth forests for wood either. Therefore, this also supports the sustainable practices for using as a construction material. CLT is originated from Switzerland and it is now being recognized as a regulatory sound building material in North America. Also, in other countries like Ontario, Canada invested $5 to build its first CLT plant.

- **Plant-based Polyurethane Rigid Foam**

  This material has been used as insulation material in building. It is also known as Rigid foam. Plant-based polyurethane rigid foam is coming from bamboo, kelp and hemp. In sustainable practices it is best option wherever we need insulation on materials. It also offers protection against mould and pests, is also heat resistant, can be perfect as sound insulation.

- **Recycled Plastic**

  Plastic from two-litre bottles can be spun into fibre for the production of carpets. We can also make products such as pipes, roofs, floors, PVC manholes, PVC windows etc. by the reused plastic.

12. CONCLUSION-

One of the strongest points of steel is it is completely recyclable and reusable. Unlike steel industry, recycling of steel does not include any pollution and harmful emissions, giving a complete impact. More than 2 billion of steel is still waiting to be recycled. Bamboo is 6 times stronger than steel reinforcement on comparison with the energy needed to produce steel is almost 50 times more than that of this natural product.

Property	Bamboo	Steel
Tensile Strength	28,000 per sq. inch	23,000 per sq. inch
Bending Strength	7.6-27.6 kN/sq.cm	14 kN/sq.cm
Compressive Strength	6.2-9.3 kN/sq.cm	14 kN/sq.cm
Shear Strength	2.0 kN/sq.cm	9.2 kN/sq.cm
Modulus of Elasticity	2000 kN/sq.cm	2100 kN/sq.cm
Failure	Brittle mode of failure	Progressive crack pattern

Fig: Comparative analysis of steel and bamboo

Fig: Bamboo Reinforcement 1

Fig: Bamboo Reinforcement 2

Fig: Steel Reinforcement Failure mode

Fig: Bamboo Reinforcement Failure mode

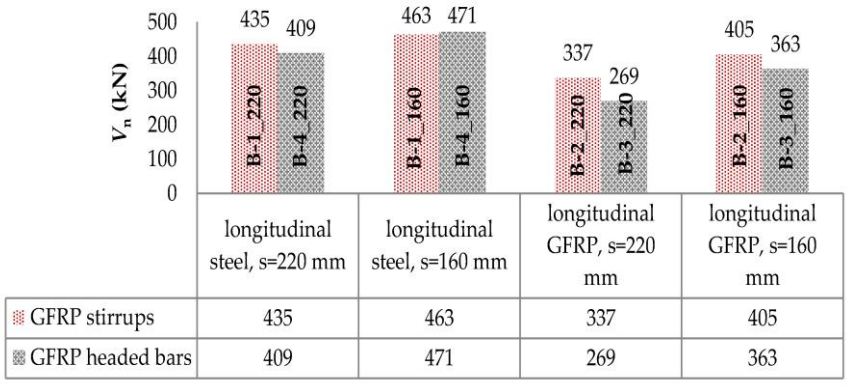
Fig: Bamboo Reinforcement 3

From the study, various disadvantages of bamboo in using it in reinforcement such as not having longer life, shrinking, seasoning time, attack by insects, low elasticity, brittle failure chances, are having the solutions such as-

- Making the surface of bamboo rough before using to increase the bonding strength with concrete.
- Split bamboo reinforcement needs to be straight and length should not exceed 2-2.5 cm.
- While using bamboo reinforcement minimum width of column should be 230mm.
- Bamboo reinforcement needs to be coated with Black Japan (lacquer/ varnish/ paint) to get water repellent and good bond qualities.

For getting high strength for big projects, bamboo can be used with the combination of recycled steel formwork. But, still after applying these things bamboo reinforcement has some limitations such as shear strength, cracks, seasoning time etc. To solve these limitations and to efficiency to replace the steel reinforcement, Professor Dirk E. Hebel has recently created a new bamboo composite material having high tensile capacity, highly flexible, long-term performance in concrete matrix and can efficiently used as substitute for steel reinforcement. This material is called Bamboo TECH and it can be tooled and given any desired shape. If this material is used with combination of thin rods, it can be used structural member in concrete in the same way as steel.

- The ultimate strength behaviour of reinforced timber makes it a good option to be replaced for steel reinforcement by working on its limitations.
- There are many solutions for strengthening the reinforced timber shear walls, e.g.-
    - Using additional sheathings
    - Using diagonal steel elements with timber reinforcement
    - Using it with combination of high-strength synthetic fibre
    - Reinforcing these beams with hardwood inserts
    - Post-tensioning the walls using prestressing wires.
- Failure type here is horizontal splitting and tensile fracture at extreme fibre in bending.
- Fibre reinforced polymers (FRP) are one of the strongest members to be replaced as steel in reinforcement. It weighs 75% less than steel. But study shows that to increase its strength and to use successfully in construction industry it is better to be in combination with recycled steel.



	longitudinal steel, s=220 mm	longitudinal steel, s=160 mm	longitudinal GFRP, s=220 mm	longitudinal GFRP, s=160 mm
GFRP stirrups	435	463	337	405
GFRP headed bars	409	471	269	363

Fig: GFRP strips and headed bars comparative analysis

The use of FRP (CFRP & GFRP) is limited only to a few structures due to limitation of serviceability, also its awareness and acceptability in construction industry.

13. ACKNOWLEDGEMENTS-

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