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Construction with Bamboo: Building Carbon Negative Sustainability

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By designing and constructing with bamboo, we can form a living, breathing architecture that is rapidly renewable and that responds to the needs of the developing countries and the holistic habitation of mother earth. *"So, let us move together; let us interact together; and Save our Earth"*

Milieu

With the growing trends in environmental awareness, bamboo has cropped up as a green alternative to other woody raw materials. From soft bath towels, to sturdy buildings and homes, denotes the power of bamboo. Bamboo has been one of the oldest and most versatile building materials with many applications in the field of construction, particularly in developed countries. Lauded in environmental circles for its quick growth and the fact that it can be harvested without harming the plant, bamboo seems a perfect way for promoting green economy.

As wood becomes more scarce bamboo construction will hold more and more value where the benefits of its use have been known for millennia. Bamboo being extremely lightweight thus building with bamboo can be accomplished faster with simple tools than building with other materials. As such bamboo constructions are easy to build, resilient to wind and even earthquake forces. Thus, the major qualities which make bamboo an ideal material for green building include -Strength and Durability: *As it is heartier than oak and stronger than steel. It is flexible and water-resistant, minimizing the risk for warping, and* Affordability: *It is easily grown and harvested, making it one of the most cost effective – Economical, especially in areas where it is cultivated and is readily available. Transporting cost is also much lesser.*

Bamboo is quite common for bridges, scaffolding and housing, but it is usually used as a temporary exterior structural material. However, in order to fully exploit the power of bamboo, development efforts should be directed at the key areas of preservation, jointing, structural design, etc. Thus, efforts are needed to promote government institutional and policy support and integration with the private sector, integrating bamboo with local building materials and promote a broader range of bamboo construction projects, preparation of bamboo building codes and construction product standards, etc. Once these issues are successfully addressed, bamboo will be ideally placed to become a principal engineering and construction material for 21st century and beyond.

Unique features of bamboo as sustainable building material

Globally, there is a resurgence of interest in Bamboo in this age of information revolution and environmental consciousness. Bamboos are a diverse and primitive group of perennial plants in the true grass family. They are widely distributed throughout parts of the world, particularly in the Asia-Pacific region. It grows primarily in tropical and subtropical areas but several species grow in temperate areas. There are approximately 2000 species worldwide, of which around 100 are being used by humans. Bamboo species vary in height from 1 foot to over 100 feet tall and have stem diameters ranging from 1 mm to 30 cm.

Bamboo grows incredibly fast: Although it's heartier than many trees, bamboo is actually a grass. In fact, it's the fastest growing plant in the world. Bamboo's fast growth enables frequent harvesting without causing damage to the ecosystem of bamboo forests. It is one of the highest yielding renewable natural resource making it a good substitute to wood in mitigating pressure on natural forests. On average, bamboo can grow up to about 24 inches in a single day, while some species can grow nearly 48 inches. One can actually watch bamboo grow. The stalks, called "culms," can grow up to 0.039 inch (1 mm) per minute, and up to 47 inches (1.2 meters) per day, depending on the species. Some never grow more than about 7 inches tall and 0.07 inch in diameter, while others stretch to nine inches in diameter and 130 feet (39.6 meters) tall!

Bamboo has the potential to achieve its full height and thickness in a 3 to 4months growing season. it matures in as little as 4 to 6 years much faster than hardwood trees which can take 20 years and above to reach maturity. Bamboo provides 10 to 30% annual increase in biomass versus 2 to 5% for trees. Tree wood is a one-off building resource needing another 25 years to replace each tree. But one bamboo plant can produce nearly 33,000 feet (10,000 meters) of material in 20 years–at least 12 times more green building material than normal wood! The hardwood forests can take hundreds of years to recover after logging.

Bamboo is best harvested sustainably between the 3rd and 7th years of a growing cycle, versus 10 to 50 years for softwoods and hardwoods. After the second year, bamboo forests continue to harden and grow into more mature bamboo plants, although they will start to die and decay after 7 to 8 years. The plant roots, however, remain healthy, so after the older bamboo dies, new shoots take their place, growing even bigger and thicker than the previous generation. It sends out new shoots after each harvest and has unrivalled capacity to capture carbon.

Bamboo is better for the environment: Ecologically highly significant, bamboo is a sustainable resource that can grow under a range of climatic conditions, but preferably a tropical climate. Bamboo produces more oxygen and absorbs more carbon dioxide than trees, combating global warming with each bamboo shoot that is planted. It releases approximately 35% more oxygen and absorbs 40% more carbon dioxide than equivalent stands of trees, which results in a substantial improvement in the air quality purifying environment effectively. Some bamboos can sequester up to 12 tons of carbon dioxide from the air per hectare and the cumulative carbon sequestration value is estimated to be around 60% as compared to other species. Because the use of bamboo as a building material saves more hardwood trees from logging, the push for bamboo can help combat climate change. Diverse species make bamboo adaptable to many environments. Bamboo tolerates extremes of precipitation, from 30 to 250 inches of annual rainfall. Bamboo can also lower light intensity and protect against ultraviolet rays.

Bamboo helps control soil erosion: Bamboo prevents soil erosion and maintains watershed integrity and soil health. Bamboo has a widespread root system as well as an enveloping canopy, which makes it a great water barrier to control soil erosion. It is one of the best species for riparian management. Bamboo is widely used in a number of developing countries to protect crops and villages from washing away. Bamboo's high nitrogen consumption helps mitigate water pollution, and its roots are good for the soil.

Bamboo production creates livelihoods in impoverished countries: Bamboo grows best in tropical conditions and has the ability to provide economic sustenance to developing countries, improving stability for impoverished populations. It offers a sustainable way of making a living - all from a grass that grows like a weed. Bamboo has big income generating for people living in rural areas through bamboo cultivation. It is very easy, affordable, and profitable for low income communities to grow and use bamboo.

Bamboo is highly versatile: Bamboo can be used in a wide range of products, from paper to construction materials and flooring, bamboo furniture, bamboo sheets, bamboo yoga blocks and more. Some of the first paper products were made from bamboo, and today it is widely used to make a soft but durable bamboo clothing as well as to build fences, walls, bridges, bicycles, skateboards, helmets and computer keyboards. As bamboo's popularity increases, it's being used in more and more products, creating many beautiful ways for you to green your home and your lifestyle.

Bamboo has potential for sustainable building material: Renewable – can be harvested without damaging the plant and grows extremely quickly; Plentiful – there is great potential for timber-quality bamboo to be produced in the Local – can be grown locally in a small land area; Waste-reducing – sequesters carbon and leaves can be used as fodder or compost. Bamboo is a versatile, strong, renewable and environment friendly material. It is exceedingly strong for its weight and can be used both structurally and as a finish material. Bamboo is recognized as one of the most important non-timber forest resources because of the high socio-economic benefits from bamboo-based products. Bamboo can be recombined into useful products and elements such as flooring, ceiling, walls, partition walls, trusses, domes.

Suitability of Bamboo in Construction

Bamboo is a major building material in many countries, particularly in Asia, Africa and South America, because of its strong characteristics, light weight and flexible properties. It can be used for almost all parts of houses, including posts, roofs, walls, floors, beams and trusses.

Bamboo has the advantages of straight grain, beautiful colour, high strength and toughness, and excellent abrasion resistance. Bamboo composites have similar properties to wood composites. They have been widely used in the fields of vehicle, construction, ship building, furniture, and decoration to partly take the place of timber wood, steel, plastic, etc, being stronger than timber and steel, and aging resistance being superior to that of plastic. In addition, it is easy to process and acceptable in price. Then, bamboo-based composites will become a highly competitive alternative to wood-based composites and will become an important forest-based product in the future.

In Asian cultures, bamboo has been used as a building material for thousands of years. As the world becomes more environmentally conscious, however, many are in a sense going retro, abandoning modern construction materials for traditional bamboo. There are numerous reasons why so

many people are going green with bamboo products. Some are practical, while some are cost effective, while still others simply do so for the health of the earth and bamboo's many ecological benefits.

In Costa Rica, 1000 houses of bamboo are built annually with material coming only from a 60-hectare bamboo plantation. If an equivalent project used timber, it would require 500 hectares of threatened tropical rainforests. "Ply boo" is now being used for wall paneling and floor tiles; bamboo pulp for paper-making; briquettes for fuel, raw material for housing construction; and rebar for reinforced concrete beams. In Limon, Costa Rica, only bamboo houses stood after a violent earthquake in 1992. Because it is flexible and lightweight bamboo enables structures to "dance" in earthquakes.

Bamboo is useful for different things at different ages: <30 days it is good for eating; 6-9 months for baskets; 2-3 years for bamboo boards or laminations; 3-6 years for construction; >6 years bamboo gradually loses strength up to 12 years old. The fabrication of bamboo requires very little energy (30MJ/M3 per N/MM2), especially in comparison to other frequently used building materials: Concrete – 240; Steel -1500; Timber – 80

Bamboo is now a proven alternative to Timber: Bamboo as an alternative to traditional timber is fast gaining acceptance in India and a number of companies have started manufacturing doors, windows, flooring, decking, wall panels from Bamboo engineered wood which can replace traditional timber, engineered Bamboo wood is three times stronger than timber. The demand for timber is growing rapidly in India and it's expected to exceed 150 million cubic meters by 2020, which shall put great pressure on the forests and since we don't have such forest reserves, we shall have to spend dollars to import timber. The timber deficit in our country has been growing. The same trend was seen in China and they have bridged the gap by diversifying into Bamboo timber in such a large way that now they are exporting Bamboo processed products to the world market and have captured 50% market already worth about 7 billion dollars.

Bamboo plants produce a high yield: In a single harvest, one can get 20 times more building material from bamboo than one can with hardwood trees. The yield (weight per acreage) for bamboo is 25% greater than that of timber. A harvest of a single bamboo stand can yield over 200 poles in 5 years, so there's no scarcity. Bamboo's abundance keeps prices low, making it much more affordable.

Bamboo is stronger than hardwood: Bamboo is one of the strongest building materials, tensile strength is 28,000 pounds per square inch versus 23,000 pounds per square inch for steel; withstands up to 52,000 psi. Bamboo is stronger than steel and heartier than most hardwoods, a high-quality material with high durability. Has twice the compressive strength of concrete. Bamboo is resistant to earthquake damage and practical on steep slopes. It is comparable if not stronger than oak in terms of hardness (Janka Ball Test – 1320 PSI). Bamboo exhibits little dimensional change compared to other commonly used woods (2.5x more stable).

Special Advantages of Bamboo in Building: Bamboo structures can be built very quickly, are low cost, durable, and eco-friendly. The energy required in processing bamboo is less than for concrete, wood, and steel. The plethora of uses of Bamboo and its unique properties make bamboo a miracle grass. Not only is it more affordable, but bamboo produces a higher quality of wood than hardwood trees do — making it a valuable building material. Bamboo is also water-resistant, reducing the risk of warping, and both flexible and lightweight to work with. The following attributes brand bamboo better for building - Affordability: Foundations are minimized, wall panels are non-load bearing and can be reduced in thickness, and the basic components (bamboo, wire, bolts, chicken mesh) are inexpensive; Sustainability And Environmental Impact: Can be grown on degraded land; it is treated using environment-friendly preservatives; the use of high energy embodied materials (cement, steel) is minimized; Cultural Acceptability: The system offers traditional materials in a modern engineering context; Durability And Safety: All bamboo components are treated with safe preservatives to give extended life, the structure is engineered to resist wind and seismic forces, and other imposed loads; Improved Jointing Techniques: Nailing is eliminated; wiring, - bolting and strapping provide positive connections; Modular Construction: Bamboo is suited to both prefabrication and fabrication in situ; all components are designed to be prefabricated (ex-infill grids, roof trusses) or prepared on site; Ease Of Assembly: Only basic carpentry, masonry tools and skills are required to undertake construction.

Bamboo Engineering Attributes

Bamboo has good engineering properties and it is a feasible substitute for other materials for housing and construction sector. Bamboo has high tensile strength, very good strength to weight ratio. It can be easily worked upon by simple tools. It can resist forces created by high velocity wind and earthquake. Bamboo and components made of bamboo are environment friendly, energy efficient and cost effective. Bamboo sizes are generally specified by minimum diameter, wall thickness, and length: Column – 80-100mm dia; Wall thickness – 10-12mm dia; Bamboo strips for infill panels – 18-20mm wide, 8-10mm thick.

Bamboo, in a building system, comprises various elements and fulfils the main structural role. Round bamboo columns and trussed rafters act as the main load bearing element. Composite bamboo grid/cement mortar infill panels act as shear walls to resist wind and seismic forces. The system consists of –Foundation: individual column footings; Columns: bamboo culms set in/on concrete footing; Wall Infill: a grid of split bamboo covered in wire mesh and cement mortar; Floor: raised by 2-3 brick courses, filled with rubble and screeded; Roof Structure: bamboo rafters or trusses supporting bamboo purlins; corrugated bamboo mat board for roof covering; Doors And Windows: bamboo mat board shutters.

The potential structural flexibility of bamboo affords protection to bamboo constructions: Protection By Design - Large roof overhangs prevent direct wetting of walls in heavy rains; Drainage channels/gutters to discharge water at a safe distance from the building; The risk of flooring can be reduced by building on a slightly sloping site and using raised masonry or concrete footings; Raising bamboo columns or wall panels clear of the ground reduces risk of termite infestation; Termite shield formed out of galvanized steel or aluminum sheet between footing and walls; Hollow culms should be plugged; Cavity walls should be avoided *Protection By Preservation* - DIP Diffusion Method: Bamboo culms are prepared to size and submerged in Borax/Boric Acid solution which is a water-soluble preservative for several days; The preservative enters the culm through ends and holes drilled in internodes; This process is suitable for both green and dry bamboo.- Hot Andcold Method: The bamboo to be treated is submerged in a tank of preservative that is directly heated by fire after being maintained at a constant temperature for a period, the tank is allowed to cool; During the cooling process, the preservative is drawn into the bamboo. The hot and cold method can be used for green or dry bamboo culms with either Boron or Creosote.

Bamboo wood as the Economic Change Agent

The current estimate of the market for bamboo products is ~ INR 50,000 crore (approximately US $10 Billion). Bamboo is seen as an agent crucial to economic growth in developing economies like India, Vietnam, Indonesia, etc. Bamboo and Bamboo based industries have a tremendous employment generation and poverty alleviation potential. The diversity of bamboo-based applications allows it to be the basis of micro enterprises such as *Agarbatti* (incense) Sticks making as well as big corporates such as paper and textile industries. Based on the estimates of the then Planning Commission, National Mission on Bamboo Applications, and Building Materials and Technology Promotion Council, Govt. of India, the annual market potential of Bamboo based products in India in various utilisation categories are as follows: Bamboo Furniture - 3625 crore (483 m USD);

Bamboo Shoots - 300 crore (40 m USD); Bamboo Flooring - 1950 crore (260 m USD); Bamboo Pulp – 2088 crore (278 m USD); Bamboo Housing – 1163 crore (155 m USD); Bamboo Scaffolding – 863 crore (115 m USD); Bamboo Mat boards – 3908 crore (521 m USD); Miscellaneous Industry - 600 crore (80 m USD); Cottage Industry & Incense Sticks – 1000 crore (133 m USD); Bamboo Ply-board for use in Trucks & Railways – 3408 crore (454 m USD); Bamboo for Roads – 274 crore (36 m USD); Bamboo as Wood Substitute – 284 Crore (37 m USD).

The requirement of "bamboo wood" for multiple uses by the industries and the common man will definitely increase in far greater dimensions. In India, the total demand of various bamboo consuming sectors is estimated at 26.9 million tonnes. The estimated supply is only 13.47 million tonnes i.e. only half of the total demand. The pulp and paper industry, construction, cottage industry and handloom, food, fuel, fodder and medicine annually consume about 13.4 million tonnes of bamboo amounting to Rs. 2042 crores. Demand of bamboo for industrial use is met from state owned forests, while for non-industrial purpose it comes from private as well as state owned resources. Keeping abreast of versatility of bamboo uses and its potential to build up the rural economy, Government of India launched massive programme, viz, National Bamboo Mission for overall development of bamboo sector in the country and also to improve the Indian representation in global bamboo market. The employment potential of bamboo is very high and the major work force constitutes of the rural poor, especially women. 432 million work days per annum are provided by the bamboo sector in India. Bamboo related industries provide food, income, and housing to over 2.2 billion people.

Bamboo Housing and Sustainable Development Goals of UN

Bamboo has been hailed as the change agent and a prominent tool to strive for sustainable development. It is well placed to address five major global challenges of Shelter security - through the provision of safe, secure, durable and affordable housing and community buildings. Livelihood security - through the generation of employment in planting, primary and secondary processing, construction, craft and manufacturing of value-added products. Ecological security - by conservation of forests through timber substitution, as an efficient carbon sink, and as an alternative to non-biodegradable and high-embodied energy materials such as plastics and metals. Food security - through bamboo-based agro-forestry systems, by maintaining the fertility of adjoining agricultural lands, and as a direct food source – example, edible bamboo shoots. Energy Security – as an alternative clean fuel; ethanol and bamboo pellets.

All these global challenges have been recognised in UN resolution for transforming world by 2030, through concerted efforts for achieving Sustainable Development Goals, specifically SDG no. 1 (No Poverty), 2 (Zero Hunger), 7 (Affordable & Clean Energy), 8 (Decent Work & Economic Growth), 9 (Industry, Innovation & Infrastructure), 11 (Sustainable Cities & Communities), 12 (Responsible Consumption & Production), 13 (Climate Action), 15 (Life on Land). In a world of increasing urban densification, construction needs to become safer and more resilient. This is particularly true in the context of a changing climate, with its more extreme weather patterns. In earthquakes, an estimated three quarters of deaths are due to building collapse, and slow rebuilding programmes can leave people without fixed homes for years.

Building codes, earthquake-resilient materials and engineering expertise are all needed to contribute to the UN's Sustainable Development Goal 11: safe, resilient cities. Bamboo construction could be one solution. Lightweight, flexible and resilient in earthquakes, bamboo has been a traditional choice of housing material for millennia. SDG Goal 11(Sustainable Cities and Communities) targets to ensure adequate, safe and affordable housing for all, and aims to significantly reduce the number of people affected by calamities. Bamboo is emerging as the preferred construction material for affordable housing and abodes that can be rapidly erected to retort to earthquakes, floods, and other disasters. More recently, companies and countries are experimenting with even more ambitious materials and structures. Bamboo housing is also used as a material for disaster relief shelters.

Challenges and Remediations in Bamboo Construction

One of the main challenges of bamboo construction is its distribution, with bamboo thriving in tropical regions (where it grows into larger diameter) and needing to be transported long distances for those living in cooler climates. It is possible for bamboo to be grown in other climates, but to maintain a successful and viable bamboo source that can thrive throughout the year, it needs to be grown in conditions that replicate its natural distribution.

The strength of bamboo largely comes from its integral structure, which means that it cannot be joined using many of the techniques we have traditionally come to know in building with wood. Because of this, the traditional methods of building with bamboo are particularly useful in ensuring that its strength is retained. It's important that these are shared across the world to help guide bamboo construction in regions where it has not historically been used. Over time, these ancient techniques can be combined with new methods of joinery that take into account how bamboo materials hold up in non-tropical climates.

Drawbacks of Bamboo in Building: *Bamboo lacks natural durability which contributes to the view of bamboo as a temporary material;*Untreated Bamboo is susceptible to attack by insects and fungi, and its life could be as low as one year when it is in ground contact; *Bamboo cannot span very large structures and high-rise buildings cannot be made from it; *Bamboo Mat Corrugated Sheets absorbs moisture more as compared with asbestos and plastic corrugated sheets. This may influence its durability in external utilization; *May or may not be harvested, manufactured, and shipped in an environmentally friendly manner; *Exclusion from building codes and lack of standards.

Myths about use of Bamboo in Construction: There are a number of common myths and misconceptions surrounding the use of bamboo for construction. One school of thought considers these myths as a challenge, that require scientific validation. Myth 1: *Bamboo is stronger than steel:* This is a very common statement, and is derived from two sources: [1]Since bamboo has a strength-to-weight ratio similar to mild steel, some people conflate this with actual strength.[2]A few laboratory tests have shown some parts of some species of some culms to have ultimate strengths in tension approaching mild steel (250N/mm^2). In reality though, even if some fibres of some species show relatively high strengths, following international practice, the design strength that can be safely used is closer to 5–10% of this value, to account for the variability of the strengths. Myth 2: *Bamboo only needs to be treated to protect it from decay:* As described above, bamboo also needs to be kept dry in order to protect it from rot, and many existing bamboo structures are showing signs of rot because they did not follow the principles of durability by design. Myth 3: *Bamboo performs well in earthquakes because it sways and absorbs energy*: Bamboo is a brittle material and therefore by itself unable to absorb energy in earthquakes. There is also no advantage of its low stiffness in terms of the performance of bamboo buildings in earthquakes; Instead, bamboo structures are primarily good in earthquakes because they tend to be light, and Joints in bamboo buildings are able to absorb some energy. Myth 4: *Bolted connections cannot be used in bamboo structures*: Plain bolted connections can show brittle behaviour due to longitudinal splitting of bamboo culms. Providing confinement to bamboo culms at the connection zones increases resistance to this failure mode and brings significant improvement to strength and ductility. More importantly, bolted connections display predictable yielding. This is vital for performing a rational engineered design. The bolts are also widely available, easy-to-use and versatile. Myth 5: *Bamboo can be used as a replacement for steel in reinforcement:* This misconception stems from the original idea that bamboo is stronger than steel, and hence could simply replace steel in reinforced concrete. In reality, bamboo does not function well as a replacement for steel in concrete for the following reasons - *Bamboo has $\approx {}^{1}/_{30\text{th}}$ of the capacity of high yield steel which is most commonly now used in construction, so one would need 30× extra material. There is no space for this in reinforced concrete; *To ensure a proper connection between the bamboo and the concrete, one needs to use expensive chemicals to form the bond, which are bad for the environment; *Concrete is unable to protect the bamboo from fungal and termite attack; *Bamboo is a brittle material and therefore cannot itself absorb energy in an earthquake, unlike steel; *Once all of the above are considered, concrete reinforced with bamboo has a higher environmental impact than concrete reinforced with steel. More research and scientific case studies are needed to resolve these myths to standardise and institutionalise the use of bamboo in construction.

Remediations: It is important to treat bamboo against rot and insects. One method is to cure the bamboo by standing cut culms on a stone for a month amongst the living culms. The leaves are left on as they continue to remove starch from culm. Cashew nut oil may be applied over exposed bamboo regularly, to improve the life and service of bamboo members and aesthetic also. To make proper joints, bamboo should be screwed and not nailed to avoid splitting of bamboo. After fabrication, culms should be closed from both sides with proper infill material, to avoid insects and termites enter it.

Indian Bamboo Construction Excellence

Bamboo was used for the structural members of the India pavilion at Expo 2010 in Shanghai. The pavilion was the world's largest bamboo dome, about 34 m (112 ft) in diameter, with bamboo beams/members overlaid with a ferro-concrete slab, waterproofing, copper plate, solar PV panels, a small windmill, and live plants. A total of 30 km was used. The dome was supported on 18 m long steel piles and a series of steel beams. The bamboo was treated with borax and boric acid as a fire retardant and insecticide and bent in required shape. The bamboo sections were joined with reinforcement bars and concrete mortar to achieve the necessary lengths.

Experts' perception on "Bamboo as Building Material"[1-21]

In an attempt to promote and institutionalise the use of bamboo in construction, an initiative was made to communicate and share with the people associated with the use of bamboo for construction, which included - builders; Housing Development Authority; Housing Board; architects; expert institutes like IIT (Delhi); CGBMT, Bangalore; NID, Ahmadabad & Bengaluru; SPA, Bhopal; KONBAC, Sindhudurg etc; practitioners and representatives from various bamboo based construction industry; NGOs; along with the other research institutes primarily contributing in exploring the Bamboo based green development. The overarching aim of the consultations was to showcase the Platform and bring together several people or institutes associated with bamboo construction under one roof with a view to exchange experience on encouraging the use of bamboo for construction. Further, collaboration and cooperation from all stakeholders would be needed to ensure the development of this renewable locked green gold in the form of green buildings. The opinions of a range of experts expressed through stakeholders' consultations, personal communication and collated through secondary sources are presented to capture a road map for the bamboo construction in various developmental sectors.

[1]"There is dire need of design interventions in the bamboo sector to bring holistic sustainability. The versatile traditional and contemporary uses of bamboo touch our lives in one way or another. There is a gap between industry and handicraft products usability and quality. There is a need to bring bamboo sector closer to mainstream market for ensuring sustainability in Bamboo sector. Design interventions in bamboo products could also help in increasing the brand visibility of Bamboo product. The importance of multi stakeholder linkages in this sector and its traditional linkages should be appreciated and the focus should shift from handicraft products to products with much more usability in the daily life of common man. There is a need for branding and sustainability in bamboo sector. The ecological, social, economic and cultural aspects of bamboo should be marketed and good design, quality, research and extension work will make bamboo sector sustainable." - *Rebecca Reubens, NID, leading bamboo designer and entrepreneur.*

[2]"Traditional to modernity" is a paradigm shift in bamboo building. The journey of traditional bamboo uses to synergetic structures of the modern world is continued. The characteristics of Bamboo make it one of the most preferred construction materials. Bamboo has different and definite uses in various kinds of civil structures. There is a need of transforming traditional technology of bamboo applications into modernized structure. A 1200 feet long bridge has been constructed by CGBMT with the help of bamboo. With proper treatment, the bamboo assures long term durability. CGBMT has accomplished bamboo construction works at several places like Energy park, Bangalore, Yamuna Biodiversity Park, New Delhi and Bamboo Museum, Palanpur. Presently we should not aim for having full fledge bamboo buildings but can proceed by having a small fraction of bamboo in construction." - *Neelam Manjunath, Leading Bamboo Architect; Founder, Centre for Green Building Materials and Technology, Bengaluru.*

[3]"There is a necessity to bridge the gap between different stakeholders concerning bamboo construction like architects, engineers, builders, etc. Bamboo can play a great role for Wall panel, furniture, ornaments, etc. There is a need to ensure supply of continuous production of bamboo and its quality assurance for making the sector sustainable. IIT Delhi has done research on Compressive Strength of Bamboo. Bamboo is one material if used can change the world, but production of bamboo and assurance of price is important in this regard. It is required to create a system where all these concerns are heard and addressed and also to create a forum that looks at the technical research necessary for this field**." –** *Prof Dr Supratic Gupta, Faculty, IIT – Delhi.*

[4]"Comparing the designs and structures from Bali, Hawai and Vietnam with that of India, there is tremendous gap and potential of bamboo construction in India. Scientific intervention into a traditional craft can bring a great change. Treated Bamboo structure is costlier than conventional cement concrete structure due to various factors such as existing technology, joinery, available skills in the market. Bamboo structures are still less durable as compared to cement concrete structures, hence composite structures may need to be created requiring R&D and involvement of stakeholders. Market acceptability is low for bamboo construction due to age old perception about bamboo confining it to poor-man's timber. This wrong perception needs to be corrected and selling should be in style as rich man's privilege. Bamboo has great potential; it doesn't lack durability but awareness." - *Sanjeev Karpe, Leading Bamboo Entrepreneur; Founder, Konkan Bamboo and Cane Development Center, Sindhudurg.*

[5]**"**Wonder Grass is an entrepreneurial initiative with a vision to bring bamboo-based building systems into the mainstream of the construction industry. Wonder Grass strives to make living in Bamboo houses an easy and enjoyable experience. Wonder Grass has introduced enterprise and vision in form of creations like bamboo Gazebo, Pergola, Transit housing unit, Modular panels, Intermediate housing for post disaster rehabilitation, etc. Bamboo Construction Projects of Wonder Grass include Bamboo bridge at pyramid valley, Bangalore, staff housing for Eklavya school, Vankua, Gujarat. Future projects envisage promoting bamboo construction like bamboo B-Hive for rural housing, community infrastructure, cottages, etc. We have to appreciate the importance of treated and seasoned bamboo for bamboo panels." - *Vaibhav Kaley, CEO, Wonder Grass, Nagpur.*

[6]"With the increasing acceptability of bamboo, its high time to reinforce the use of bamboo in construction. IPIRTI, Bengaluru has been undertaking various experiments and tests on potential of bamboo as a construction material. IPRITI is treating bamboo by many methods and also imparting five days training to the persons related to bamboo construction. Bamboo has been included in national building code in 2005. IPRITI has improvised the bamboo-based construction techniques, and implemented the construction work of Demonstration School Building using Bamboo based Technologies in Tripura and Mizoram. Various performance, energy, seismic studies have also been undertaken like shock resistance and impact tests, Joint Testing, Racking resistance tests, etc by IPIRTI. Development of bamboo structures depends upon availability of graded & standardised raw materials and eco-friendly preservatives and preservative facilities; access to design information like standards & codes, design procedures to engineers/ architects; trained man power; participation of NGO's and Government in encouraging wider use of bamboo building and standard designs and Do-it-yourself kits." - *Dr Jagdish Vengela, Indian Plywood Industries Research and Training Institute (IPIRTI), Bengaluru.*

[7]"Bamboo is arrogant in nature but very easy to use. CEPT Experts under the guidance of renowned professor A S Anand has made around ten thousand houses with the help of bamboo in flood affected areas of Bihar. People should be made aware of a complete pallet of construction materials available; they should not be forced to choose bamboo. The understanding of the fundamentals of bamboo construction highlights the multi-functional nature of bamboo and the ways to use it in constructing simple as well as complex forms. The innovative practices can be coupled with traditional methods. Bamboo has many advantages with respect to timber and steel construction." – *Prof Dr Sankalpa Patel, Faculty, CEPT University (Centre for Environmental Planning and Technology).*

[8]"USA demonstrated few materials like floor tiles, wall tiles, bamboo-based particle board and OSB board for partition wall. China is much ahead but India can be a leader. MP State Bamboo Mission is leading in a way that it can show the way to India. In California, Government is giving 7% discount on green building products. Artison company is making products at Portugal, Greece and Mexico, and plans to setup an industry in MP for manufacturing bamboo-based particle board for which company needs 18,000-20,000 acres of dedicated bamboo plantation for sustainability of industry." - *Dave Mukherji, CEO, Artison Agro-Tech*

[9]"There is a need to develop few models of bamboo construction in Bhopal for demonstration for which the land is also offered which is owned by Van Vikas Nigam and located centrally at 2nd number stop, Bhopal. Treatment of bamboo is must, high pressure impregnation should be used."- *Dr RN Saxena, IFS, Former PCCF & MD, Madhya Pradesh Forest Development Corporation.*

[10]"Builders are ready to use bamboo in construction, but there should be a model or demo of bamboo constructed building. CREDAI is ready to offer support to Bamboo Construction. Every year CREDAI organizes a Property Fair with stalls for property dealers/ builders, this year these stalls can be made of bamboo. There should be skill up-gradation workshops to promote bamboo constructions." - *Vipin Goyal, President, CREDAI, Bhopal.*

[11]"Presently bamboo is not readily available, if the Bamboo Mission makes the bamboo available it will be profitable for, both farmers and builders- *Manoj Singh, Vice Chairman, CREDAI, Bhopal.*

[12]"Traditionally bamboo has been used for construction of houses in various ways by communities all around the world. There are many species of bamboo having being used for these constructions. The techniques of construction are also varying from place to place and available raw materials along with bamboo in various regions. In today's context where the world is looking for sustainable and green living concepts, bamboo is one of the

best suitable material that can fit in. Many Architects and bamboo experts are investing their skills in adapting various building techniques using bamboo for modern applications. Here we can look at bamboo in various forms for creating a living space and a structure. Along with natural forms of bamboo we can also bring various engineered bamboo composites and prefabricated structures and units to make a space in very limited time which could be affordable too. We also need to keep it in mind that apart from structural design, one should also focus on aesthetic appeal which can be suitable for modern living and lifestyle. We should think about a complete systematic approach for bamboo-based construction in the country which can create a new lifestyle in modern India." **–** *C S Susanth, Head Centre for bamboo Initiatives, NID – Bengaluru.*

[13]"Bamboo**,** as a local material, was being used for construction since ages, however couldn't keep pace with the more modern engineering materials like concrete and steel or in other way round the modern engineering materials were marketed so well that the locally available material lost its relevance. The primary drawback was into the thought that timber will not be available in this country for the generations to come and since bamboo qualified as a timber in forest norms, it was not explored. The present state in which bamboo is, can mostly be regarded to the lack of futuristic policies as well as lack of research in the area. The material has come to light, in the present era, due to the concepts of sustainable development goals which are getting more prominence in the national strategic policies. It will be required to pitch bamboo into the ring where the other construction materials are competing to gain space. For this, the strengths of bamboo like mechanical properties, structural properties, low embodied energy, carbon sequestration benefits, ecological benefits, social inclusiveness, etc need to be highlighted. Along with this, its weakness with potential viable means to address them within satisfactory building standards, needs to be brought out. Thus, if bamboo is pitched in a right bracket, it will take-up in future as a green construction material unlocking a potential of creating more than 10 laccrore circular economy in urban, rural and agricultural landscape." - *Dr Korde Chaaruchandra, Founder & Technical Director, GBIT; PhD (Bamboo Structures, IIT Delhi); Post Doc Fellow (TCD, Ireland*).

[14]"Bamboo has contributed to housing and other structural applications the world over since times immemorial. In rural areas, it is used preferentially to other materials for housing because of its intrinsic properties that have been traditionally utilized. Bamboo houses dot the rural landscape in many developing countries of Asia, Latin America and Africa. The properties of bamboo combined with its availability and ease of use make it an ideal material for housing the rural and urban poor. The usage of bamboo housing not only meets safety-related needs essential in seismically active zones but also offers highly viable solutions using renewable resources. The demand for housing products can help develop various forward product linkages for other structures, furniture industry and other infrastructural applications to name a few, and backward linkages into raw material production and processing. The development and adoption of a bamboo-based housing program that deploys local resources in terms of labour and material can enable addressing the need for employment generation and economic growth while simultaneously meeting environmental protection goals. The Bamboo Construction Task Force, facilitated by INBAR, coordinates the activities of international research institutes and commercial companies interested in the structural uses of bamboo." – *Dr T.P. Subramony, Director, South Asia Regional Office, International Bamboo and Rattan Organisation, China.*

[15]"Bamboo is rightly called the green gold as it qualifies under many of the categories listed for green building materials. Bamboo is being currently looked upon as an alternate low-cost material for the enormous housing problem faced by several developing countries. Bamboo has always been popular as a building material, especially in house-building and is now widely regarded as the super material of the 21st century. Bamboo indeed has tremendous potential not only to transform India's rural economy, but also to contribute to the sustainable development efforts. The Building Materials & Technology Promotion Council, Delhi has supported IPIRTI, Bangalore in developing technologies for manufacture of several bamboo composites such as bamboo mat board, bamboo mat corrugated roofing sheets, bamboo mat ridge caps, bamboo floor tiles and laminates. Engineering and material properties were studied exhaustively to utilize the full potential of bamboo as an engineering material in housing. Bamboo housing technology clearly demonstrates the engineering application of bamboo in housing. All load bearing and semi load bearing elements have been made either of round or split bamboo in the form of slivers in combination with bamboo-based composites like BMB and BMCS for roofing with minimal use of timber and high energy consuming materials like iron, steel and cement. Having successfully developed the technology for construction of bamboo-based housing system, the challenge was to develop the technology which is equally viable for other structures, community centres and utility products like toilets. Supported by BMPTC and IPRITI, the South Asia Bamboo Foundation has conducted International and Regional training programs on Building with Bamboo and construction of Bamboo Toilets for community and public in Kochi, Kerala, Haflong and Dimapur in Assam and Nagaland to enhance local capacity and skills. This is where bamboo can play a lending itself as a cost effective and eco-friendly material to build toilets and thereby play a very important role in 'Clean India' mission. The SDGGoal 11 (Sustainable Cities and Communities)includes a target to ensure access for all to adequate, safe and affordable housing, and aims to significantly reduce the number of people affected by disasters. For affordable housing and dwellings that can be rapidly erected to respond to earthquakes or floods and other disasters, bamboo is emerging as the construction material of choice. A number of documented cases in Latin America testify how bamboo structures better withstand the impact of earthquakes than concrete housing, and this understanding is now being applied in other countries, like Nepal. Local bamboo is also being used as the primary construction material for nearly all structures in the Rohingya Refugee Camps and Sites, Cox's Bazar Region, Bangladesh. On the other hand, in the world of modern urban construction, more top architects and designers are specifying bamboo for their creations, due to its durability, look and sustainability aspects. For example, Bamboo flooring was installed on platforms and stairs at Gare-du-Nord in Paris, one of the busiest railway stations in Europe with almost 200 million passengers a year. Bamboo is the only parquet that is suitable for these kinds of covered outdoor areas with high humidity and temperature fluctuations, and intense daily use. SABF with support of BMPTC has developed BAMTECH, an app to make Bamboo Construction technology available in digital platform - *Kamesh Salam, Founder and Executive Director, South Asia Bamboo Foundation (SABF); Former President, World Bamboo Organisation.*

[16]"Bamboo can help provide developing countries with low-carbon infrastructure. Sometimes, the best technology isn't a technology at all. Bamboo, the fast-growing grass plant, common to Africa, Asia and South America, is a natural, renewable and low-carbon material with the tensile strength of steel, and a huge amount of potential for greening infrastructure. The role of bamboo construction has never been more important. Approximately 70 per cent of global greenhouse gas emissions come from infrastructure construction and operations such as power plants, buildings, and transport. Future development risks locking the world into a high-carbon pathway for hundreds of years. As bamboos grow throughout the tropics in Africa, Asia and the Americas, it could provide a natural, renewable material for infrastructure in developing countries. Strong government support is needed to incentivise the take-up bamboo. The Philippines' presidential Executive Order, signed in 2010, makes a good start, by direct[ing] the use of bamboo for at least 25 per cent of public-school desk and other furniture requirements." - *Hans Friederich, Former Director General, International Bamboo and Rattan Organisation, China – Eco-Business.*

[17]"Construction, one of the largest sectors, is a chain process starting from sourcing and preparation of raw materials, transportation and assembling on site. It contributes around 40% of the global carbon emission. The key solution to overcome the issue is through the usage of renewable, high performing and low energy consuming material like bamboo which is fast growing and available abundant (11.4 million hectares) in India. Bamboo as scaffoldings will reduce the need of conventional steels, thereby lot of energy saved. Finally, when bamboo scaffoldings expire after use, can be transformed into charcoal which will reduce coal mining. The good variety bamboo, used in construction has more tensile strength than steel. Reinforced concreting should be effectively encouraged with the use of bamboo saving energy. Bamboo is a best alternate to extensively used steel in state of art construction. More research and innovations on bamboo as building material, encouragement by Real estate authorities by providing subsidies in solar panels etc, to mandate energy efficient construction will boost the use of bamboo." – *Prithvi Jeya Narayan, La Terre Design Studio, Madurai; Leading Bamboo architect and entrepreneur in design and construction.*

[18]"We have been using bamboo as a sustainable and viable option to build bespoke structures across India and the world. Since many years, bamboo is used as a construction material in our country either for temporary construction or structure for poor. Through the initiative of "*VenuKutir*" bamboo cottage exhibit, we are demonstrating that the bamboo can be used to build a durable, aesthetically beautiful and contemporary structure suitable for the likes of today's millennial population. This has been achieved by training farmers to get into bamboo farming, adopting scientific farming and harvesting practices, age-grading bamboo and treating it using state of the art treatment facility created by KONBAC.By building this structure, we are not only demonstrating one of the most sustainable and environmental-friendly structure, but also highlighting the salient features of using a carbon negative material and how bamboo is an icon of sustainability amongst all the floral species in the world. Bamboo structures have both — aesthetic beauty and durability — and are suitable for use in different building applications such as resorts, institutions, banquets, pavilions, clubhouse, beach-front structures, farm houses, landscape elements, schools, community centres, exhibit areas, etc." - *Krunal Negandhi, Director, JANS Bamboo Products.*

[19]"Bamboo has tremendous potential for construction purposes in the days to come. The use of steel, concrete, aluminum and glass in construction ends up negatively impacting the atmosphere through the release of GHGs during its production as well as construction. In contrast, bamboo emits oxygen during its production and selected species of Indian bamboo sequesters up to 200 MT of carbon dioxide per hectare per year. Hence, bamboo is one of the most sustainable and environment friendly materials to build a structure with a negative carbon impact, and it can become the go-to material for sustainability." - *Sanjay Seth, Chief Executive Officer, GRIHA Council.*

[20]**"**Venu Kutir Cottage Exhibit shows that bamboo has caught the imagination of one and all. Bamboo is a miracle crop — it regenerates itself, its shoots are edible, and now it is being used to build high-end houses. What more could we ask for? Imagine if bamboo is used to build low-cost, affordable houses as a part of the housing for all, it would be a game-changer. It can help everybody, not just farmers. We can work through the National Bamboo Mission with a missionary zeal to transform our economy, stop deforestation, and create a new culture of living in harmony with nature because that is the way to live."- *Suresh Prabhu, Member of Parliament.*

[21]**"**The policies of forest and environment ministry are totally outdated and should be thrown away. Sitting in buildings, they don't allow for touching bamboos for cutting for 25 years. If now, through the Indian Forest Act Amendment 2017, bamboo is grass, then as to why the same cannot be cut. The attitude and approach of the forest and environment ministry is wrong. We are not able to protect the environment, nor are we able to develop the economy because of it. He said there is no attention paid if the land is kept barren next to the highway, but the moment bamboo or some tree is planted, it is declared as a forest which makes road widening difficult. India's northern neighbour has been able to create a success story out of bamboo and we have not been able to do the same despite having the Rs 1,300-crore bamboo mission. The efforts to popularise bamboo have not been met with the desired success, and added that the grass holds great potential for upliftment of farmers who can switch to it from a commercial perspective. The grass can also be helpful from a socio-economic upliftment perspective in the 115 aspirational districts of the country**."** – *Nitin Gadkari, Hon Minister of Road Transport & Highways and MSME*

Way Forward

The recent heave in popularity of bamboo construction is a promising sign for sustainable building and the experimentation with the growth of bamboo outside its traditional distribution could only boost the bamboo construction sector. It's not only a green solution for the developed world, but a low-cost, readily-available resource in many regions of the developing world where modern building materials are scarce and expensive. As global wood resources continue to decline, bamboo housing construction is one practical option to look towards drawing on ancient building traditions to create a modern housing solution with aesthetically appealing results. There should be strict policies in place to control the harvesting of only the matured culms forests and plantations. Also, research findings indicate that this renewable resource is under a high threat of depletion, and hence high yielding species should be introduced across tropical and subtropical countries where bamboo growth is sustainable. Bamboo is a resource of the people. Bamboo is commonly processed by the people. Wherever possible, programmes for the people should include bamboo as a building material - that would provide a market and kickstart the bamboo economy, leading to investment, growing, processing, and higher levels of value addition. The approach: of the people, by the people, for the people needs to be taken. The key issues that need to be addressed to institutionalise the bamboo construction-based development in the country include an effective federal bamboo policy enabling legislative changes, a robust institutional framework, transfer of advanced technology, appropriate business development, an initial niche market facilitated by govt adopting maximum use of bamboo structures, and incentives in taxes and subsidies, etc.