STRATEGISING AN ECO-FRIENDLY RURAL HOUSING ALTERNATIVE USING BAMBOO PARABOLIC INFILL ARCHES AS LOAD BEARING ELEMENTS

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by

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Dedicated to

CERTIFICATE

This is to certify that the thesis titled **"Strategising an Eco-friendly Rural Housing Alternative using Bamboo Parabolic Infill Arches as Load Bearing Elements"** being submitted by **Mrs. Smita Chugh (nee Gupta)** to the Indian Institute of Technology, Delhi for the award of **Doctor of Philosophy** is a record of original bonafide research work carried out by her under our guidance and supervision.

In our opinion, the thesis has reached the standard of fulfilling the requirements of all the regulations related to the Degree. The research report and results presented in this thesis have not been submitted, in part or in full, to any other university or institute for the award of any degree or diploma.

We certify that she has pursued the prescribed course of research.

21/10/10

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□Oh life is sweet □ .., When thy song flows through me, My Lord □ . □

- Paramahansa Yogananda. Cosmic Chants. Yogoda Satsanga Society of India

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Smita 21/10/2010
(Smita Chugh)

ABSTRACT

Global warming concerns have prompted researchers to have a relook at alternatives to existing materials and technologies for housing. Finding alternatives to timber as a measure to check deforestation, has triggered research on replacing timber with bamboo as a □green□option for housing. Short gestation period species like bamboo could be used as a mitigation option through carbon sequestration. Moreover, unlike the long gestation trees, bamboo culms require regular harvesting from the time the culms become 3-4 years old, to keep the bush healthy. Thus continuous availability of bamboo for housing purposes is an eco-friendly option.

Reviewing the various constructional materials across the world, brings the fact to light, that bamboo has been used in building construction since time immemorial, but its use has mainly been restricted to being a semi load bearing element/ load distributor in roofs. Addressing the various research gaps, the present experimental study suggests innovation in the design and development of using bamboo in the form of □parabolic vertically separated half-split twin bamboo concrete infill bamboo tied arches□. The structure has been referred to as SBICA (Split Bamboo Infill Concrete Arch), a term coined to refer to such structures in general and in particular to the structure presented in the thesis. It discusses the operational methodology of evolving a parabolic shape for the bamboo concrete composite arches. In the presented design of the arches, bamboo is not embedded inside the concrete; rather two half split bamboos have been used for encasing the concrete from two opposite sides. The requirement of concrete is so optimised as to be kept minimal. The present design, while using the half-split bamboo as formwork for the concrete infill, addresses the age old limitation of the poor bonding between concrete and bamboo, which results due to the swelling-shrinkage in the bamboo concrete composite. A scientific basis for specifications of the SBICA specimen has been worked out. This paves

the way for mass scale replication of SBICA as structural load bearing element for housing. SBICA being minimally processed, are easy to fabricate in decentralised locations, with minimum energy consumption in the process of fabrication, and thus is an eco friendly option for building construction.

Limitations like the variability in the properties of bamboo with topography and environment have been a deterrent to standardisation of bamboo based technologies for housing. Moreover, the absence of the cost effective test set-up for ascertaining the structural safety aspects of bamboo structures, at decentralised locations, have prohibited the massive use of bamboo in building construction. Addressing these limitations, the present experimental study evaluates the load carrying capacity of SBICA, which were tested to actual scale in full sizes in a specifically designed test set-up.

The structural performance evaluation using the load deflection criteria suggests that the SBICA specimen so fabricated is able to satisfactorily function as a main load bearing element. It thus puts across that bamboo could be effectively used as a structural load bearing element for building construction and SBICA is a □green□and □economical□ solution for housing, especially in the rural areas of India. Though the properties of bamboo vary with location and climate, yet the □cost effective□and □easy to install□test set-up enables the evaluation of the structural performance of the SBICA specimens at decentralised field locations where mass scale replication of the SBICA specimen is required. Moreover it enables the evaluation of the structural performance of the SBICA specimens to actual scale in full sizes giving further assurance of their safety.

In view of the facts of the continuous and assured supply of bamboo and the encouraging load deflection analysis results of the SBICA specimen along with the simple and economical test facility, the present research puts the foundation of a new era of green building construction. To a great extent bamboo can satisfy the material requirement for

housing in general and thus bamboo construction and bamboo plantation address the global environmental concerns of reducing the green house gas emissions and mitigating the climate change at large, leading to a sustainable model of growth and prosperity.

When subjected to stress, as in the above structure, failure in bamboo initiates at a sub-surface level before being visible at the surface. Thus there is a need to investigate non-destructively, defects and damage at the sub-surface. Bamboo based applications, also employ resin wherever gluing action is required. Hence, there is an added requirement of using non-destructive techniques for detecting glue deficiencies at the bamboo-glue interface.

The present work explores the possibility of using Non Destructive Testing (NDT) technique, of thermal wave imaging, using infrared radiations, also known as thermography, to study defects and damages in bamboo. Thermal Imaging of bamboo is as yet an unexplored area though thermal imaging of wood has been reported. Active Thermography technique, employing irradiating the specimen and thus infusing energy into it has been used. Frequency Modulated Thermal Wave Imaging (FMTWI) enabled identifying frequencies which would give good images of subsurface defects and glue deficiencies. Lock-in Thermography was then carried out at the identified frequencies.

Blind hole defects of varying diameters at depths from 2mm to 6mm were thus mapped. Defects of 10mm diameter at 2mm depth, have been imaged at 0.001 Hz. The images showed anisotropy in heating with temperature being higher along the fibre length. The bamboo culm node regions are also distinctly visible in the thermal image. These findings point to the possibility of using thermal NDT for structural applications of bamboo and its composites/laminates.

The present work also explores the possibility of employing thermal NDT, to study the interface between bamboo and glue, and gaps in glue application therein. This is a

relatively unexplored area as regards bamboo, and thus a novelty, though thermal imaging of detecting glue deficiency in laminated wood has been reported. Glue bands and gaps upto5mm, could be imaged using FMTWI and Lock-in Thermography through slivers of 2mm thickness. The inspection time ranged from 65sec to 350 sec depending on the glue type. These findings point to the possibility of using thermal NDT for applications of bamboo and its composites/laminates.

Health monitoring of the structures using non-destructive thermography techniques could thus be selectively applied. The novel application of this non-destructive technique on bamboo, which has been a hitherto relatively unexplored area, opens vast possibilities for further bamboo applications, beyond the structures reported here.

Using bamboo as a structural load bearing element could have far reaching consequences for rural housing and the environment. However, introduction of innovations is more than just a technology issue. While identifying the right technology as per the need is an area requiring research, an equally important issue is the methodology of introduction of innovations relating to technology interventions in the rural areas. When implemented with the involvement of house owners themselves, the innovations are sustainable and replicable.

The study brings out that substituting timber with bamboo based load bearing structural elements in roofs of rural houses addresses a felt need in areas where supply of timber is a constraint. But, introduction of innovation in rural housing would be acceptable when change is minimal, and only on those aspects where limitations are felt. Demonstration through State funded building constructions may not always be viewed with a sense of ownership by the community. Skill up gradation of construction workers and related stake holders like bamboo artisans is also an essential requirement.

A methodology for dissemination was worked out in a training-cum-reflection workshop of key stake holders. The methodology includes community mobilisation exercise for awareness building as well as training of all stake holders. Training and community mobilisation modules were prepared in the workshop by participants in a participatory mode. The consensus emerged in the workshop that for sustainability it is best to depend on organisations with good grass root presence of sustained interaction with the community. This supplemented with owner driven construction of demo houses is essential for confidence building in the householder.

Adopting the strategy proposed, the consequent increase in demand for bamboo for such constructions could have far reaching positive consequences for rural economy and ecology through proper supply chain management, avoiding the long distance transportation of bamboo. The introduction of innovation will also encourage rural entrepreneurship leading to prosperity of the area.

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