# ASSESSING THE PERFORMANCE AND SUSTAINABILITY OF BAMBOO PANELS FOR AFFORDABLE HOUSING: A COMPARATIVE STUDY

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**Abstract -** This study evaluates bamboo panels as a Jugaad solution for addressing architectural challenges in resource-constrained environments. With over 700 million people in extreme poverty, particularly in developing countries like India, affordable and effective building materials are crucial. We assess bamboo panels' performance against conventional materials, including thermocol gypsum, focusing on waterproofing, insulation, sound absorption, and fire resistance. Functional assessments reveal bamboo's superior waterproofing and fire resistance, though with modest sound absorption. Life cycle analysis indicates bamboo's lower manufacturing and operational costs and reduced $CO_2$ emissions compared to gypsum, despite higher disposal emissions. The findings highlight bamboo panels as a cost-effective, sustainable alternative that aligns with the principles of frugal innovation and Jugaad, offering a practical solution for low-income communities. This research provides valuable insights for policymakers, architects, and innovators in developing affordable, environmentally responsible building materials.

**Keywords -** Bamboo Panels, Jugaad, Resource-Constrained Environments, Cost-Effective Building Materials Sustainable Solutions, Functional Assessment, Life Cycle Analysis,

## I. INTRODUCTION

A substantial segment of the world's population resides in areas with resource constraints, confronting architectural challenges like limited funds, insufficient access to essential amenities, and underdeveloped infrastructure. As per the World Bank, over 700 million individuals inhabit regions characterized by extreme poverty, predominantly in region with limited resources and economic prospects. The majority of technological advancements within the field of architecture remain underutilized by these marginalized segments of society as these communities are not aware about it or don't have skills to employ it or cannot afford it. Furthermore, India's hot summers pose significant challenges for air cooling, especially during heat waves from May to June (Van Oldenborgh et al., 2018).However, in developing countries like India, conventional false celling for insulation, is an issue for a majority of the population due to financial constraints.

Consequently, individuals in resource constraints resolve their problems on their own through ingenuity and creativity. Moreover, in India, there is a concept known as *Jugaad*, which is related to ability of Indians to innovate cost-effectively in response to pressing needs in critical areas like health, education, agriculture, energy, and housing (Radjou et al., 2012).There are many terms like grassroots innovations, inclusive innovations, and *Jugaad* are synonymous under resource constraints (Dzimba & Poll, 2022).Unfortunately, the terms '*Jugaad*' and 'grassroot innovations' (GI) are often used interchangeably(Kumar, 2020), leading to confusion. Furthermore, there has been an emphasis for developing quality solutions in a resource-constrained environment that are affordable to low-income consumers(Chandni et al., 2021). There are three main domains to focus: (1) substantial cost reduction, (2) concentration on core functionalities and (3) optimised performance level (Weyrauch & Herstatt, 2017). Moreover, frugal innovation follows phases of conceptualization, experimentation, and implementation (Kaur, 2016), indicating a systematic approach. GIs can act as the source of inspiration for Frugal Innovation. Therefore, an analytical framework for assessing effectiveness of GI is important for frugal innovators, policy makers, and architects so that they apply a Jugaad or GI in their projects.The analytical framework is used to analyse two cases which are as follow:

Jugaad using bamboo sheet panel below galvanized steel sheets (identified by author as primary case and no studies are available for assessing its effectiveness).



**Figure 2: Bamboo false ceiling. Image by: Author**

## II. METHODOLOGY AND DATA COLLECTION

To evaluate a *Jugaad* as an appropriate solution proving an acceptable level of quality with low cost, we conducted a literature review to identify relevant parameters of evaluation. The proposed evaluation framework includes: (i) Functional effectiveness, which must be analysed to confirm the *Jugaad* meets

its purpose with performance-based metrics (Zeschky et al., 2011;Bhatti, 2012;Santos et al., 2020; Gomera et al., 2020),and (ii) Cost-effectiveness, which ensures resource efficiency and accessibility for various economic backgrounds (Niroumand et al., 2021;López-Sánchez & Santos-Vijande, 2022;Singh & Awasthy, 2023).This framework integrates functionality and performance, and cost offering a way to assess *Jugaad* and identify a quality design solution in a particular context.

**2.1 Metrics for analysis and data collection**

This section elaborates upon two major aspects of analysis: functional and life cycle cost. The functional assessment evaluates key performance metrics such as waterproofing capabilities, insulation properties, sound absorption, and fire resistance of the materials used.

**2.1.1 Data for Functional assessment**

Thedata for functional assessment are retrieved from various secondary scholarly works which are mentioned alongside the metric:

i. **Waterproofing**: Vapour permeability (Zhang & Yoshino, 2010) [bamboo panel - 29.6 wvp mg/cm2h (Ławińska et al., 2018), convert WVP from mg/cm²h to g/ft²h: 29.6 mg/cm²h × 0.002108 g/ft²h/mg≈0.0624688 g/ft²h; Now, convert g/ft²h to perms:0.0624688 g/ft²h × 57.27 perms per inch of mercury (inHg) ≈ 3.5772 perms per inch]
ii. **Insulation**: Solar heat gain: SHGC (Solar Heat Gain Coefficient) (Shahin, 2019) R-value or U-value of used materials (Al-Homoud, 2004) (among these variable applicable to false ceiling is r-value or u-value)
iii. **Sound Absorption**: Sound absorption (Arjunan, 2019)(Alonso et al., 2020)0.05 to 0.25 NRC for Thermocol (polystyrene) and 0.10 NRC for bamboo panel
iv. **Fire Resistance**: ASTM E119: Standard Test Methods for Fire Tests of Building Construction and Materials for Thermocol (polystyrene) it is 1minute 2.5 cm×2.5cm×2.5cm, and for Bamboo panel it is 3 minutes for 2.5 cm×2.5cm×2.5cm

**2.1.2 Life cycle assessment**

The data on $CO_2$ emissions, and costs for a five-year lifespan. The end-of-life stage included estimates for emissions, and disposal costs, considering waste management and recycling. The LCA is conducted using the International Organization for Standardization (ISO) framework established in the ISO 14040 standards (ISO 2006).

## III. ANALYSIS OF JUGAAD

This section elaborates upon the functional assessment and life cycle assessment of both the panels

**3.1 Functional assessment**

The bamboo panel exhibits superior waterproofing and fire resistance compared to Thermocol (polystyrene), with 3.5772 perms versus lower thermal resistance and longer fire resistance time. Thermocol, however, shows a broader range in sound absorption (0.05 to 0.25 NRC) compared to bamboo's 0.10 NRC, indicating varied acoustic performance.

**3.2 Life cycle assessment**

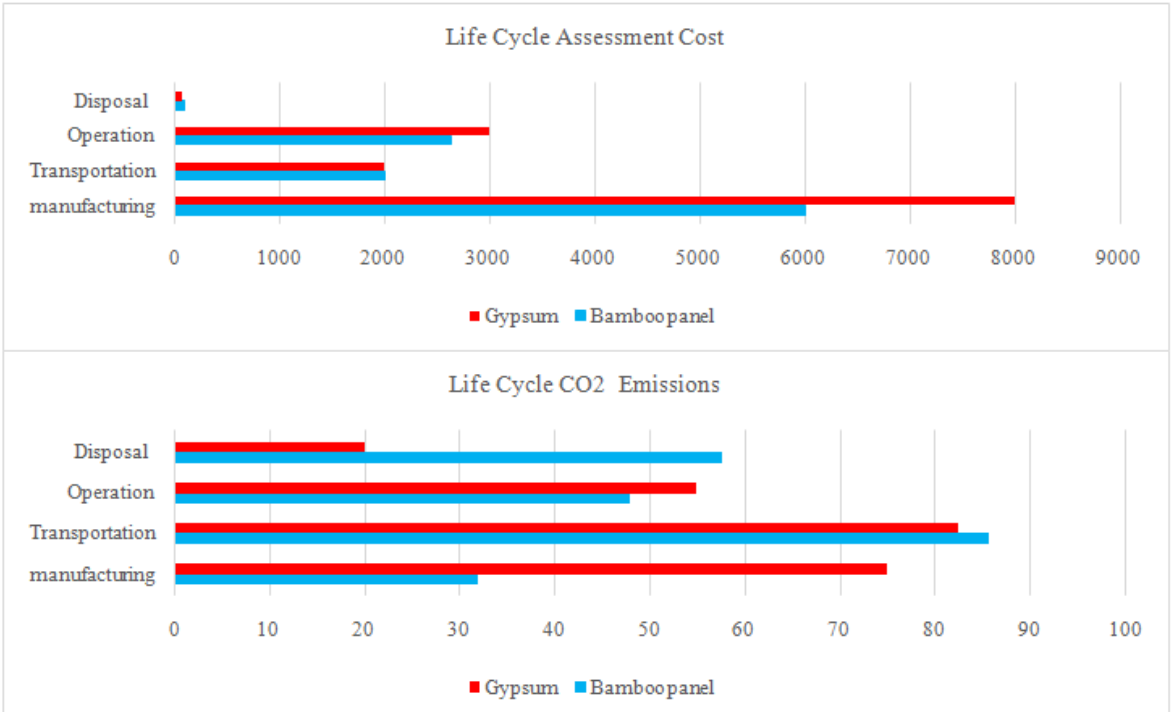
The following sections outline the assessment of functionality and the LCA for the GI and gypsum board ceiling.The various stages of the LCA may be outlined as follows:

**Goal and Scope Definition:**"Gate to grave", thus the following life cycle steps have been analysed: (i)Acquisition, (ii)Use phase, (iii)End-of-life. The impact categories considered in the study include $CO_2$emissions, and cost. Data for the impact categories is collected from USLCI (U.S. Life Cycle Inventory Database) and few secondary sources and specification is taken from manufactures' report declaration.

**Life Cycle Inventory (LCI)**: An extensive inventory has been compiled for the costs and $CO_2$ emissions related to bamboo and gypsum panels. It includes unit cost, total cost, transportation, cleaning, repairing, disposal costs, and $CO_2$ emissions per stage—manufacturing, transportation, recoating, replacement, recycling, and landfill—for both materials.The critical unit data for estimating the overall life cycle cost includes the unit weight (bamboo: 0.32 kg, gypsum: 0.25 kg). The $CO_2$ emissions for bamboo panel manufacturing are 1 kg $CO_2$ per kg, with 2.68 kg from transportation, 0.5 kg from recoating, 1 kg from replacement, 0.1 kg from recycling, and 0.1 kg from landfill. For gypsum, manufacturing emits 3 kg $CO_2$ per kg, with higher emissions from transportation (3.3 kg), recoating (1.8 kg), replacement (1.8 kg), recycling (0.4 kg), and landfill (0.8 kg).

**Life Cycle Analysis (LCI):** The life cycle cost analysis shows that bamboo panels have lower manufacturing (₹6,000 vs. ₹8,000) and operation costs (₹2,625 vs. ₹3,000) compared to gypsum. However, gypsum has slightly lower disposal costs (₹80 vs. ₹93.75). Both materials share equal transportation costs (₹2,000). Bamboo is generally more cost-effective.The life cycle $CO_2$ emission analysis shows that bamboo panels have lower manufacturing emissions (32 kg vs. 75 kg) but higher disposal emissions (57.6 kg vs. 20 kg) compared to gypsum. Transportation emissions are slightly higher for bamboo (85.76 kg vs. 82.5 kg), while operation emissions are lower (48 kg vs. 55 kg).

**Life Cycle Impact Assessment:** This analysis provides a comprehensive comparison of the life cycle costs, and $CO_2$ emissions among the panels.




**Life Cycle Interpretation:**
The critical interpretation reveals that bamboo panels are more cost-effective, with lower manufacturing and operation costs than gypsum. Bamboo also has lower manufacturing $CO_2$ emissions but higher disposal emissions. While transportation emissions are slightly higher for bamboo, its overall environmental impact and cost are generally lower compared to gypsum.

## IV. RESULTS AND DISCUSSION

The study reveals that bamboo panels outperform gypsum in cost-effectiveness, with lower manufacturing and operational expenses. Bamboo also has reduced $CO_2$ emissions during production but faces higher disposal emissions. Thermocol offers broader sound absorption range but lower performance in waterproofing and fire resistance compared to bamboo. The life cycle analysis confirms bamboo's overall lower cost and environmental impact despite higher disposal emissions, making it a more sustainable and affordable option in resource-constrained settings.

## V. CONCLUSION

This study highlights the effectiveness of bamboo panels as a viable Jugaad solution for resource-constrained environments, addressing the architectural challenges of affordability and performance. The functional assessment demonstrates bamboo's superior waterproofing and fire resistance compared to Thermocol, while its sound absorption is modest but acceptable. The life cycle assessment shows bamboo's cost-effectiveness, with lower manufacturing and operational costs despite higher disposal emissions. This research aids in bridging the gap between advanced technology and under-resourced communities by providing an affordable, functional alternative to conventional materials. Stakeholders, including policymakers, architects, and frugal innovators, can leverage this analysis to implement cost-effective and sustainable solutions in low-income settings, enhancing living conditions while promoting environmental responsibility.

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